Geothermal Capacity Building Program Indonesia - Netherlands

Date: 25-09-2017

Course 1.07 notes
'Company investment decision-analysis for geothermal projects'

Author: Christian Bos

Company/ institute: TNO

Document number: Restricted [GEOCAP-2017-REP-TNO-1.07-5]

COOPERATING COMPANIES & UNIVERSITIES

Geothermal Capacity Building Program Indonesia - Netherlands

IF technology

Gadjah Mada University

DNV GL

University of Indonesia

Well Engineering Partners

University of Twente, Faculty ITC

Technical University Bandung

Utrecht University, Faculty of Geosciences, Department of Earth Sciences

Delft University of Technology, Department of

Netherlands Organisation for Applied Scientific Research

SUMMARY

This report provides the pre-reading and part of the post-course reference material for participants to the WP1.07 course on '*Company investment decision-analysis for geothermal projects*'. The contents are based on the course's *Study Guide* (ref. document GEOCAP-2016-REP-TNO-1.07-3), where it is indicated that participants to the course are supposed to have read this report prior to taking part in the classroom course.

The objective of the GEOCAP WP1.07 course on '*Company investment decision-analysis for geothermal projects*' is to equip geoscientists, engineers, economists and other disciplines involved in geothermal project maturation, with a number of analytical techniques and general knowledge so as to support the corporate investment decision-making process. Estimating the uncertainties of future, projected cashflows is essential to understanding the investment risk, mitigating these risks and maturing a project up to Final Investment Decision. Moreover, as uncertainty has two sides, i.e. risk and opportunity, course participants will also be exposed to the opportunity-side of uncertain cashflows and understand how to steer an evolving project such to grasp the upside where possible. Geothermal asset management can be characterized by the fact that only gradually, during the geothermal project execution and asset life-cycle, more information will be revealed on the productive system and on the contextual conditions (socio-economic, political etc.). How to anticipate on possible future information being revealed in time and how to condition current decision-making on these eventualities, is a key concept in this course.

Uncertainty in future cashflow projections has many repercussions on decision-making. Because of their large 'technical' and 'systemic' uncertainties, this is especially true for geothermal projects in Indonesia. The objective of the WP1.07 course is to strengthen the geothermal Decision Analysis (DA) capability in Indonesia, thereby enabling decision-support staff to analyse these uncertainties and understand how to resolve the various investment risks that prevent undeveloped geothermal resources from being developed.

TABLE OF CONTENTS

TABLE OF FIGURES

COURSE NOTES

'*Company investment decision-analysis for geothermal projects*'

GEOCAP program Indonesia – Netherlands, Work Package 1.07

Course dates: 30 October – 3 November 2017

Venue: PPSDM, Jakarta

by

Ir. C.F.M. Bos

TNO (dept. of Applied Geosciences)

Email : christian.bos@tno.nl

v. 1 (25 September, 2017)

Course participants :
(names to follow)

1 INTRODUCTION TO COURSE

GEOCAP 1.07 course on ‘Company investment decision-analysis for geothermal projects’

This course on *‘Company investment decision-analysis for geothermal projects’* is part of the GEOCAP program aimed at exchanging, between Indonesia and the Netherlands, know-how and skills for defining and assessing the feasibility of geothermal projects. In this 1.07 course, the focus is on Decision Analysis (DA) pertaining to investment decisions and, hence, this course is targeted at assessing the added value of new geothermal projects to enable investment decision-making. As a consequence, a number of economic indicators are introduced, which can be derived from the analysis of an investment opportunity. In different situations, different methods and indicators will be appropriate, and their use is discussed.

As will be mentioned, however, economics is not always the primary deciding factor in a decision; other interests may influence an investment decision, such as establishing an early presence in a new geographical market to create a portfolio of new opportunities. Also, non-quantifiable motives may influence an investment decision, such as investing in local jobs and community projects, as this could enhance the company’s reputation and improve its competitive position for possible future investment opportunities as a result of the government’s licensing process. In this course, the various decision criteria will be discussed and presented in a way that allows Decision Analysts to present a project’s required information to their corporate decision-makers. Ultimately, however, the decision-makers will weigh the different aspects, quantifiable and non-quantifiable, and decide. Hence, the project with the best quantifiable Key Performance Indicator is not necessarily selected as the best.

Central to course 1.07 is the concept of *uncertainty*, expressed mainly as uncertainty in the projected discounted cashflows. Technical uncertainties, mainly from the poorly known productive geothermal system, and non-technical uncertainties, such as political, economic, financial uncertainties, have to be combined to compute the *total* uncertainty of a project’s future cashflows. This is not trivial, since these uncertainties should also be related to possible future *decisions*, as these will influence the data acquisition and, hence, the remaining uncertainty. Uncertainties and decisions are therefore combined into so called *decision-trees*. Other sophisticated methods of combining uncertainties with (possible) decisions exist, but unfortunately can be quite complex.

The GEOCAP 1.07 course programme is given in Appendix 1. Appendix 2 provides some key learning points, grouped by subject. A glossary is also included. Apart from this hand-out, the course contents also consist of the PowerPoint sheets from the various lectures, (computer / spreadsheet) exercises, computer demonstrations and some recommended literature. Students are also urged to take notes during oral discussions.

Caveat

A word of caution on the contents of the course is perhaps opportune. The reason is that similar courses have proven rather difficult for the students to comprehend. Possibly, this is due to the rather abstract concepts discussed in this course: concepts such as '*added value*', '*uncertainty*', '*opportunity*' and '*risk*' etc. are perhaps less easy to master than courses on hardware or physics. Teaching uncertainty requires students to shed their deterministic mindset and, rather than presenting their certainties (as they have been mostly trained), discuss future projections in terms of their uncertainties. Students participating in the '*Company investment decision-analysis for geothermal projects*' course are therefore requested to pay particular attention to general academic / master skills such as:

- How do I know whether I adequately understand some topic?
- When can I stop questioning?
- What does it mean to have a critical attitude?
- What does it mean to be curious?
- What does it mean to think autonomously?
- What does it mean to nimbly switch between abstraction levels?
- What is relevant detail?
- When and how should I verify whether some theory is applicable to the problem in question?
- How do I formulate a question in such a way that it can be solved with the available methods?
- How do I show mastery of a subject? How do I influence the thinking process in a group?

- What should my attitude be towards class and lecturer during classes?
- How do I take responsibility for my own professional know-how development?
- How should I engage in a group discussion? What does it mean to master a subject?
- And, when working on a thesis: what are the dos and don'ts? Why? What should my attitude be toward my coach?

It is hoped that the '*Company investment decision-analysis for geothermal projects*' course will also contribute to these more general, but crucial requirements to demonstrate that you master the difficult skills of defining, assessing and comparing decision alternatives.

2 INVESTMENT THEORY

In this chapter, the theory on capital budgeting within companies is discussed. Capital budgeting is the planning process used to determine a firm's investments, which are expected to contribute positively to the firm's long-term financial performance. Part of the capital budgeting process consist of applying analytical methods, which are used to determine whether to accept or reject possible investments. Within these methods, a division can be made between methods targeted at analysing *endogenous risk* (or technical risk), and methods analysing *exogenous risks* (or *non-technical risk*, or *systemic risk*). Danielsson & Song Shin (2002) define endogenous risk as 'the risk from shocks generated and amplified within the productive system', i.e. project risk. They define exogenous risk as 'risk from shocks that originate from outside the productive system', i.e. market risk, political risk etc. This division will be used to describe the methods. This chapter will end by describing the analysis of a project for its effect at the portfolio level so as to sketch a more complete picture of methods used to analyse investment opportunities.

2.1 CAPITAL BUDGETING

One of the tasks of a board of directors is to select investments that add value to the firm. The concept behind investing is that one must spend money in order to create money. For example, a company invests in machinery in order to produce and sell its products. Such companies usually have a certain long-term production target, and new investments will be needed to achieve this target as old investments will gradually lose their productivity, or stop producing altogether. Therefore, it is up to the decision-maker to select investments, which are 'worth' undertaking. To do so, a sound procedure to evaluate, compare and select projects is required. This procedure is called *capital budgeting*. In case of more project opportunities than the applicable capital (or other) constraints, the decision-makers must identify the projects, which will contribute the most to the profit and thus create the most value for the company. The basic method for assessing the project's future performance is described below.

2.2 DISCOUNTED CASH FLOW (DCF)

The first method to be discussed is the DCF method. This method describes how to value a project, company, or financial asset using the concepts of the time-value of money and the risk that 'something may happen'[1]. To allow the summation of future cashflows, all yearly flows must first be made 'equivalent' and be expressed in 'present value' terms, i.e. be referenced to the same year (normally the year of first capital expenditure). If these flows from different years would not be expressed in equivalent terms, that would be tantamount to summing 'apples and pears'. Revenues and expenditures in the different projected years are estimated and discounted to obtain the present value. Only then can they be summed to obtain total project profit. The discount rate used is the appropriate cost of capital, which incorporates the time-value (i.e. the risk-free interest rate) and a market risk premium. From this DCF method several Key Performance Indicators (KPIs) are derived. These help to identify profitable projects and will now be discussed.

2.2.1 Net Present Value (NPV)

The NPV method is used by companies in assessing the validity of undertaking a project. The simplified investment rule for NPV can be generalized in the following way:

- Accept a project if the expected NPV is greater than zero.
- Reject a project if the expected NPV is less than zero.

However, in reality certain constraints will apply to this rule, and higher-level considerations (portfolio-level, corporate-level) will also apply. Moreover, as will be explained later, all projections should in principle be done probabilistically, and in such probabilistic analysis certain statistical concepts would also apply for rejecting / accepting a project.

The NPV is calculated by taking the sum of net future cashflows discounted using the company's WACC as discount rate (the Weighted Average Cost of Capital, or the WACC, will be explained later). Applying the above NPV rule, the project should be accepted if the sum of discounted cash-in flows is larger than the sum of discounted cash-out flows. What does a positive NPV imply? In principle, a positive NPV is the added value to the firm's value if the project is undertaken. The project generates more cash than is needed

[1] http://en.wikipedia.org/wiki/Discounted_cash_flow

to service its costs of capital. When ignoring various company constraints and other key considerations, a project with a positive NPV should be undertaken.

In analysing the NPV method, one should be aware that projecting net cash flows has a risk of failing to materialize. Therefore, the decision-makers have to take into account the applicable risk constraints. Moreover, as already mentioned above, higher level criteria may apply, i.e. at the portfolio or corporate level, and other constraints or criteria will apply. This is why the project with the highest NPV is not necessarily the 'optimal' project. But optimizing the NPV of a project is a good first-pass optimization principle.

2.2.2 Internal Rate of Return (IRR)

Another KPI which is widely used to evaluate projects is the internal rate of return (IRR). IRR is defined as the discount rate at which the NPV of a project equals zero. Many companies use an 'IRR hurdle rate' equal to WACC+, i.e. the WACC plus a profit margin and a risk margin to take into account that in the portfolio of projects some of them will make a loss. For individual project capital budgeting decisions, the bar can thus be raised to include risk and hopefully obtain, at the portfolio level, a good *average* project performance. For example, suppose that the WACC is 8%, then a company may decide to use an IRR hurdle rate of 15% as a screening, or acceptance/rejection, criterion, and subsequently rank all projects meeting this criterion according to the magnitude of the NPV. Other criteria will typically also apply, for example early cashflow (see pay-back period method below). An IRR hurdle rate is a so called 'screening criterion': projects not meeting this condition are rejected. Other screening criteria may also apply.

The IRR is sometimes confused with the 'opportunity cost of capital'. The opportunity cost of capital is another standard indicator for deciding whether to accept a project, and expresses the minimum required rate of return. It is equal to the return offered by equivalent-risk investments in the capital market[2], or in the company's portfolio if the company is capital-constrained. The IRR-rule implies that the NPV is positive for discount rates below the IRR and negative for discount rates above the IRR. Unfortunately, this is not the case in more complicated situations where more than one sign change occurs in the net cash flow and therefore may cause some problems. For this discussion reference is made to Brealey et al (2001) and Jaffe et al (2005).

[2] Brealey, Myers & Marcus (2001): 'Fundamentals of Corporate Finance'. Page 174

2.2.3 Payback Period method

A third KPI widely used is the Payback Period method, defined as the number of years needed to recover the (discounted) costs and start making a profit. In this method, the company sets a particular cut-off date: all investment projects that have a payback period of less than the cut-off date are accepted (i.e. after discounting the cash flows), and all investment projects with a payback period later than the cut-off date are rejected. This method gives a quick insight when the generated cashflows recover the initial investment of the project. For a detailed discussion reference is made to Brealey et al (2001) and Jaffe et al (2005).

2.2.4 Constrained optimization

Before continuing to discuss the appropriate discount rate, a remark about how to use the various KPIs in decision-making is appropriate. The NPV is generally used as optimization (maximization) criterion, under the constraint of a certain payback period and IRR hurdle rate and, sometimes, also under the constraint of a value for the Maximum Exposure (i.e. the deepest negative cumulative cashflow of the project) so as to reduce the risk of jeopardising the company's consolidated cashflow. Decision-makers typically aim at maximizing profits and do so, i.e. as a first approximation, by maximizing the NPV of individual projects[3]. The applicable payback period, IRR and Maximum Exposure constraints are derived from portfolio and corporate considerations.

[3] Because projects influence each other, the approach to optimize individual projects can only be a first approximation.

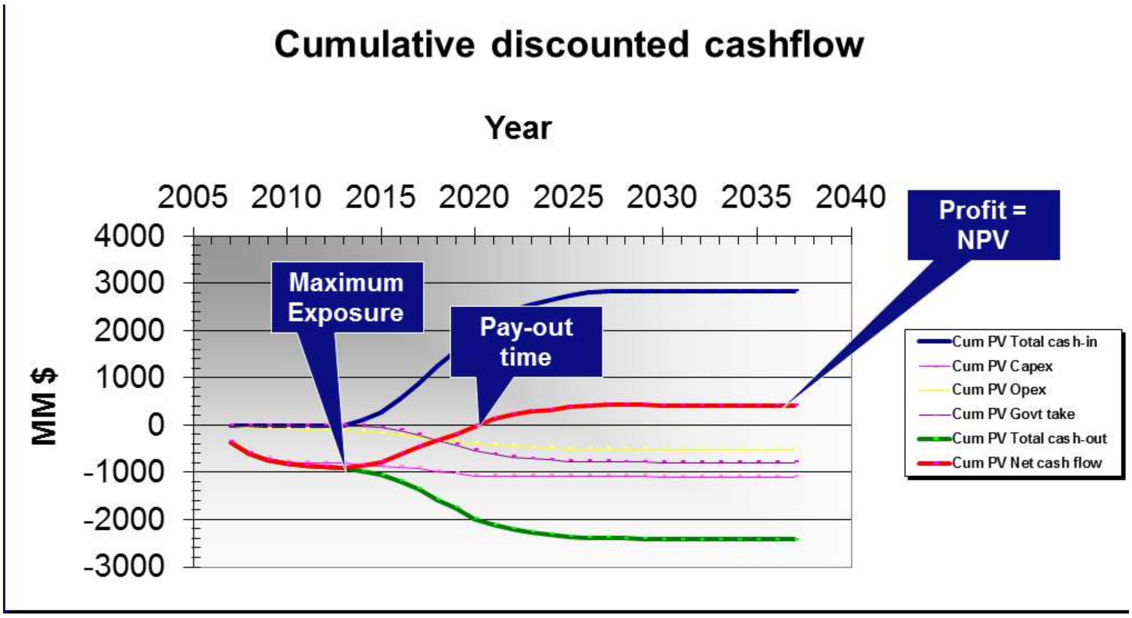


Figure 1 - Cumulative discounted cashflow

In this respect it can be helpful to think in terms of a decision-maker's '*objective function*' and write it down mathematically. For example, when comparing alternative projects deterministically (i.e. not probabilistically), the decision-maker's '*objective function*' could be:

- **MAX (NPV | IRR>15%; POT< 6yrs; MaxExp > -$10M)**, *with*
    - MAX = the maximize function, i.e. select the project with the highest value
    - The sign '|' meaning: '*conditional on*' or '*subject to*'
    - POT = pay-out time (yrs)
    - MaxExp = Maximum Exposure (million $), note that prior to pay-out the cumulative cashflow is negative, hence the sign '>' means that the maximum negative cumulative cashflow must be greater than -10$M, or less negative than -10$M.

This means that from the different projects that meet the conditions of IRR>15%, POT<6 yrs and a MaxExp>-$10M, the project with the highest NPV is selected. But again, in practice more constraints and /or higher-level considerations will apply, and when the projects are assessed probabilistically other statistical concepts will apply.

2.3 DISCOUNT RATE

In adopting the DCF method, one has to forecast future cashflows. Future cashflows are based on projections of future returns, but whether these cashflows will actually materialize is uncertain when making the investment decision. There are ways to cope with this uncertainty. One way is to incorporate *market risk* into the discount rate. The Capital Asset Pricing Model (CAPM) and the Weighted Average Cost of Capital (WACC) will briefly be discussed. To include project-specific risks, other methods exist, which will be discussed afterwards.

2.3.1 CAPM

Investors need to be compensated for investing in a project. This compensation can be divided into two parts. Investors need to be compensated for placing money in any investment for a period of time which represents the time-value of money. The second part is that investors need to be compensated for taking the market risk to invest in the project. This is represented by the 'risk premium'. This *relationship between risk and return is fundamental in capital budgeting* and is expressed by the *Capital Asset Pricing Model* (CAPM) in the following formula:

$$r = Rf + \beta \times (Rm - Rf)$$, with

r	=	Expected return
Rf	=	Risk free rate
β	=	Beta, uncertainty of a stock's return relative to the uncertainty of the return of the overall market, often expressed as the ratio of their standard deviations over an assumed time interval.
Rm	=	Expected return on market

The relationship between expected return and beta can best be illustrated by deriving from the CAPM formula the security market line[4] (SML, see Figure 2). A security market line is defined as a straight line that shows the equilibrium relationship between systemic risk, i.e. the market risk that cannot be diversified away by the portfolio of projects, versus the expected rates of return for individual securities. Non-systemic risk, i.e. project-specific risk, can in principle be diversified away by the portfolio.

[4] Source: http://www.duke.edu/~charvey/Classes/ba350/riskman/rm15.gif

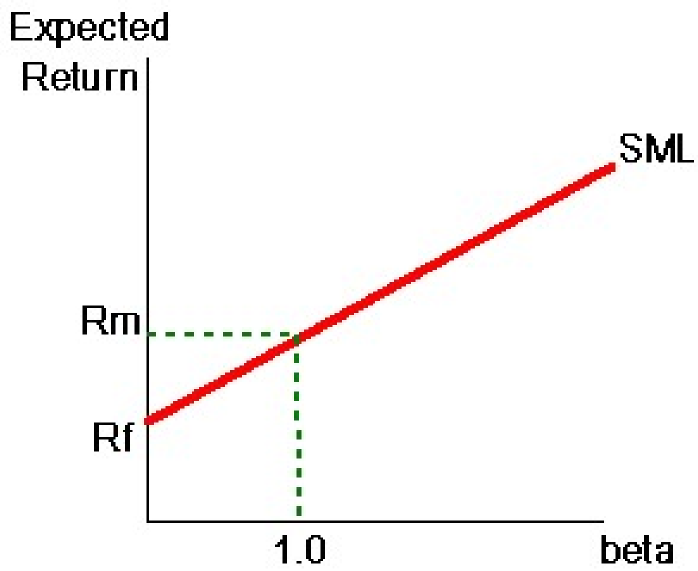


Figure 2 - Security market line

According to the CAPM, the *expected rates of return* on all *project-portfolios* lie on this line. The security market line also sets a standard for other investments. Investors will be willing to hold other investments only if they offer equally good prospects. There are some critical views on the CAPM. The CAPM assumes that investors have homogeneous expectations about the expected returns and risks of available investment projects. However, investors don't have the same risk profile, i.e. some investors are more risk averse than other investors. In addition, it is likely that investors don't have access to the same information and thus have divergent expectations concerning the expected return of an investment. A second critical remark is that the assumption that all investors can borrow money at the risk-free rate is not true for smaller, non-institutional investors. A third remark is that CAPM uses the beta as full measure for market risk. This is measured by the volatility of an asset's systemic risk, relative to the volatility of the market as a whole. However, the beta does not include other risks that investors face, such as inflation and liquidity risks.

Despite these limitations, the CAPM offers the financial manager and investors a very insightful methodology for recognizing and making explicit the relationship between risk and return inherent in financial decisions. This method provides a fair representation of an acceptable discount rate to be used by the company in assessing projects.

2.3.2 WACC

The previous paragraph discussed the CAPM as an appropriate method to establish the discount rate used in the DCF analysis. Before choosing CAPM as the method for establishing the discount rate, one has to take an additional factor into account. It is important for the discount rate whether it is an all-equity project or whether it is financed partly with debt. In the former case, the CAPM is appropriate. In the latter case it is better to use the Weighted Average Cost of Capital (WACC). This approach takes the costs of using debt and equity into account when deciding on the appropriate discount rate.

$$rWacc = \frac{D}{D+E} \times rD \times (1 - Tc) + \frac{E}{D+E} \times rE$$

D = Debt

E = Equity

rD = Return on debt

rE = Return on equity

Tc = Taxes

The WACC takes into account the return demanded by debt holders and the return demanded by shareholders in estimating a discount rate. In case the project is financed both with debt and equity, the WACC is an appropriate method to settle on the discount rate used for assessing projects.

2.4 OTHER METHODS FOR ANALYSING UNCERTAINTY

The previous paragraphs together form the basic method of analysing the investment decision in a deterministic manner, i.e. the decision analyst determines single values for the input variables. The next paragraphs describe additional methods that can be used to deal with uncertainty.

2.4.1 Sensitivity and scenario analysis

After the whole process of computing future cashflows and obtaining a value for NPV, IRR, and the payback period as KPIs, the question arises which variables have a large effect on the value of these KPIs. A technique commonly used to investigate this issue is a sensitivity analysis, where variations to a deterministically established 'base case' are tested. This technique examines how sensitive a particular NPV calculation is to changes in the underlying assumptions. To illustrate this, one could ask the question: "what is the effect, *ceteris paribus*[5], on the NPV of the base-case project if investment costs are 20% higher than expected?" The sensitivity analysis gives insight in which key variables materially affect the profitability of the project and for which variables more information would be needed. Identifying these variables and taking into account the feasibility and uncertainty of obtaining a better, more correct, value for these variables are crucial considerations in the decision making process.

This deterministic, univariate sensitivity analysis is widely used in practice. Graham and Harvey (1999) reported that 51.54% of the companies in their survey use this method. Unfortunately, the method also suffers from some drawbacks. The most important drawback is that the analysis treats each variable in isolation when, in reality, the different variables are likely to be related: deviations from the base-case values of the different variables are highly likely to coincide. In order to minimize this problem, a variant of the univariate sensitivity analysis, the scenario analysis, is employed. This approach examines a number of different possible deterministic scenarios, where each scenario involves a confluence of factors. A common practice is to develop a low-medium-high scenario for a project. In this way, one can combine different values for several variables likely to have influence on each other.

Performing a scenario and sensitivity analysis gives the investor a better feeling about the attractiveness of a project. A better insight in the importance of key variables and in the possible upside and downside of the project is thus obtained.

2.4.2 Multivariate analysis

The multivariate analysis consists of a set of techniques designed to analyse data sets with more than one uncertain variable, where these variables are permutated

[5] Ceteris paribus = all other factors remaining unchanged. This is also called a univariate sensitivity analysis.

simultaneously. Abdi (2003) has indicated which technique is appropriate given a data set. With these techniques, a distinction can be made between dependent and independent variables. Dependent variables are those that are observed to change in response to the independent variables. Independent variables are those that can be controlled by the user to trigger a change in the dependent variables[6]. In this way, the relationship between variables can be identified. This can give more insight into how one variable affects other variables in the process, which is valuable information. Note that multivariate analysis is an automatic output of the Monte Carlo simulation process, described below.

2.4.3 Monte Carlo simulation

It would have been ideal if all uncertainty analysis were possible using *analytical* functions that compute, from the probability density functions of the model's input variables, the error ranges and probability density functions of all uncertain model output. Unfortunately, analytical error functions only exist for idealized conditions, and in many cases one will have to resort to *sampling* or *simulation* methods.

Univariate sensitivity analysis, scenario analysis and multivariate analysis compensate to a large extent the analytical limitation of having to put a large number of possibilities into single numbers. Moreover, these tests are static and rather arbitrary in their nature. The Monte Carlo simulation method adds the dimension of dynamic analysis to investment evaluation by making it possible to build up random scenarios that are consistent with the analyst's key assumptions about risk (Savvides 1994). The principal of a Monte Carlo simulation is to define the uncertain variables that determine the outcome of a project in terms of probability distributions. Repeated sampling from these model input variable distributions and computing, per *set* of sampled input variables, the resulting Key Performance Indicators, yield probability distributions for the various types of outcomes (i.e. vectors: a population of full time-series per time-dependent variable, and scalars such as Key Performance Indicators). The value must cover all of the possible outcomes of the event with the sum of the probabilities equal to 100%.

Monte Carlo sampling uses a Random Number Generator (RNG), which samples a random value between 0 and 1. An RNG is no more than a mathematical function, which we will not describe here. When using the RNG many times, a uniform distribution must

[6] http://en.wikipedia.org/wiki/Dependent_variable

result for all values between 0 and 1: all values are equiprobable. When applying the Monte Carlo sampling process to a probability density function (pdf) of an input variable (with on the x-axis = value of variable; y-axis = probability density; area under curve is 100%), then first the pdf is converted to a reverse cdf (cumulative probability density function, i.e. starting at 100%). Now the y-axis has the range 0 to 1, and the RNG samples on the y-axis a random value in this range. Next, the associated value on the x-axis is looked up, and this value is then the sampled value for the uncertain input variable (see e.g. Figure 16 on page 68, although this is a model-output KPI rather than an input parameter of the model).

When modelling the uncertainties of the uncertain input variables, a distinction must be made between *discrete* and *continuous* distributions. Some variables will have discrete values (e.g. only integers), while other variables will be continuous (i.e. they can take any real number within the specified range). For example, flipping a coin (2 possible outcomes) or rolling a die (6 possible outcomes) will have discrete distributions (there are no intermediate values), whereas the porosity of the geothermal reservoir will have a continuous distribution. A continuous distribution for a variable describes the probability of that variable taking any real value within the range of that distribution. Although the probability of a specific outcome is infinitesimally small, the outcomes can be 'binned' (in classes, or categories, i.e. sub-ranges) and per bin the probability can be computed. The Monte Carlo method is widely used in combination with the previously described methods in dealing with uncertainty.

2.4.4 Decision tree analysis

A decision tree is a graphical representation of alternative sequential decisions and possible outcomes of those decisions (see Figure 3)[7].

[7] http://home.comcast.net/~dshartley3/PSYCHALG/DECTREE.jpg

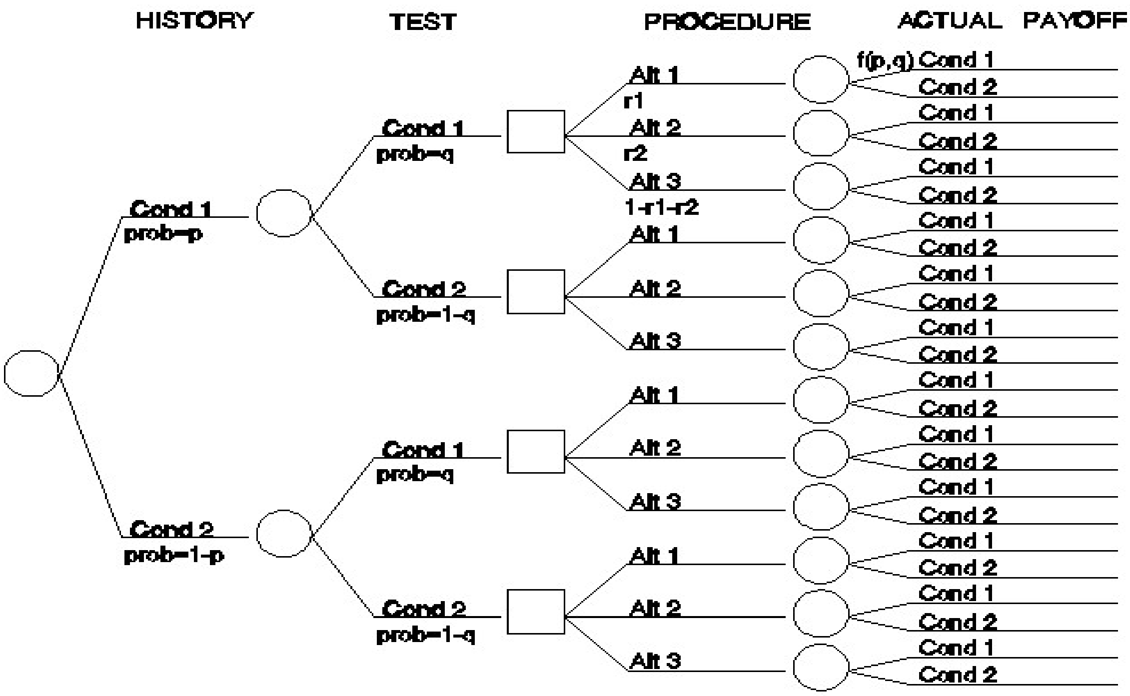


Figure 3 - A decision tree

It can be used to design the strategy that is most likely to be successful in reaching a goal. This method can be performed throughout the entire investment process. Using it in combination with the sensitivity analysis, it allows the investor to test the impact of a variable on the decision. There is a downside to this approach. It is difficult to establish reliable probabilities for certain events. A sound statistical base is needed to derive representative probabilities per event, which is hard to obtain in many cases. A pragmatic approach is to vary the values of these probabilities and study the impact on the decision-making. This may give confidence on the probability values chosen (see also Figure 24 on page 78).

Decision trees can also be used in combination with Monte Carlo processing of the uncertain model input variables: at the end of each decision tree branch (with scenario / decision combinations), i.e. in the so called '*leaves*', values must be filled in for all KPIs. In these leaves, an integrated technical-cashflow model can be computed using Monte Carlo sampling to obtain histograms for all KPIs per leaf. 'Rolling back' the tree to include all statistics from the leaves up to all decisions in the tree, including the top decision, and to establish the 'optimal' decision given the criteria specified, is a complex exercise, but there are software tools capable of doing this.

2.4.5 *Multi-criteria analysis (MCA)*

When investors face a complex problem, they can adopt a multi-criteria analysis (MCA), a decision-making method developed for complex problems[8]. It is a method that can help evaluate the relative importance of all criteria involved in the decision making process. There are two MCA methodologies, which can help evaluate the relative importance of factors. The first methodology is *ranking*. This involves assigning each DCF-KPI a weight that reflects its perceived degree of importance relative to the decision made. The second methodology is *rating*. This is similar to ranking with the difference that values between 0 and 100 are assigned to the various KPIs. This line of reasoning implies that there may exist other (qualitative) factors affecting the investment opportunity that have to be taken into account. These factors can form a part of the MCA. Their relative importance can be determined by applying the methodologies of ranking or rating. The portfolio determines the weights/ranks of these factors in the MCA.

In case of *ranking*, the (simplified) 'objective function' of the decision-maker, i.e. to select the best option from the framed decision alternatives, changes from the one on page 15 to

- **$\mathbf{MAX}\ (w_1 \times NPV + w_2 \times IRR_{>15\%} + w_3 \times POT_{<6yrs} + w_4 \times MaxExp_{>\$10M})$**, *with*
    - w_n being the relative weight factors, and
    - $\Sigma\, w_n = 1$

In case of *rating*, the above formulation does not have the second condition, i.e. $\Sigma\, w_n = 1$. In practice, however, most companies use the formulation of a *single* optimization criterion (normally NPV), subject to a number of constraints. Moreover, they will test the solution found to other criteria (portfolio and corporate effects, non-quantifiable effects, other effects such as robustness and flexibility to steer the project midway as a function of the truth being revealed in time, etc. In case of probabilistic (Monte Carlo) processing, additional criteria may apply.

2.4.6 *Real Option Valuation (ROV)*

The previous paragraphs have described important methods used to analyse investment opportunities. Still, the analysis is incomplete. Important in the whole process of investments is the instalments of capital. As recognized in the NPV analysis, delaying as

---

[8] http://www.cifor.cgiar.org/acm/methods/mca.html

much as possible expenditure creates value. However, NPV implicitly assumes a now-or-never / all-or-nothing investment, and fails to recognize that capital investments made today give the investor the choice of pursuing future investments if the conditions are favourable, to delay the project if market uncertainties increase, or to abandon the project if the environment has deteriorated. It provides the investor with the flexibility to address systemic (i.e. non-technical, or market-) uncertainty being revealed in time, and therefore understand the impact of a changing environmental (i.e., contextual) risk on the future course of the project. Real Option Valuation (ROV) can be used to value this flexibility[9]. ROV is based on the Black & Scholes model (1973) to value financial options (i.e. put-options, call-options, etc.). ROV is only applicable if the value of the real asset fluctuates with the market and if this value fluctuation due to market volatility can be modelled. For a detailed description of the theory of real options, and their application, reference is made to the literature.

In general, with projects subject to market uncertainty (systemic uncertainty), an investor creates value by *staging* the total investment such to obtain stepwise information that can reduce the uncertainty and, hence, the project risk. Larger investments can thus be postponed to a time when more information is available and, hence, when the environment is more predictable. The option to make further investments or to abandon the project has to be added to the investment process to create a more representative picture of the investment decision.

2.5 INVESTMENT ENVIRONMENT

The previous paragraphs highlighted the relationship between *risk* and *return* and how to cope with systemic risk in uncertain cash flows. It was discussed that the WACC provides in general the best measure for the discount rate. However, there is an additional factor playing a part in the process. Systemic risk is incorporated into the WACC. However, the β may be unknown due to integration of companies along various markets. The environment in which the investor plans to invest influences the projected future cash flows. A stable investment environment is important for companies when forecasting future cash flows. Several institutes, such as the Business Environment Risk Intelligence[10] (BERI) and the Economist Information Unit[11] (EIU), publish reports in which

---

[9] An option is the right, but not the obligation, to do something in the future against previously agreed conditions.

[10] www.beri.com

the investment environment of several countries is analysed. A good investment environment would contain stable and clear economic and political forecasts. This would imply a predictable future in which companies have a fair idea about the level of risk and the expected return (and thus the expected cash flows) of the project. When assessing the investment environment of, for example, a gas market, this may not be the case. For example, the liberalization of the gas and power markets in the EU has triggered major changes, which have created new uncertainty about the future rules in the gas market. These changes have reduced the amount of information available to investors, deteriorating their capability to evaluate the investment decision. This has increased the risk of investment and reduced investments in the gas market.

Analogous considerations may apply to the geothermal industry in Indonesia: the recent change in the Geothermal Law has in principle improved some aspects of the geothermal investment environment, but at the same time it has created many new questions. Apart from licensing / permitting uncertainties, a dominant risk factor of the geothermal investment environment in Indonesia remains the MWh-tariff to be negotiated with the state monopolist PLN, the national power company responsible for generation, transport, and pricing. And, since the government pays part of the initial, high-risk exploration and appraisal costs, the tariff negotiated by the Operator for recovering the cost of the surface installations + a few production wells may not be sufficient to recover the costs of the field's incremental development. That may be a reason why Indonesia has such a high proportion of proved/undeveloped geothermal resources[12].The lacking *investment climate*[13] for geothermal companies is perhaps the main stumbling block in Indonesia, rather than the level of technological know-how (as suggested by the GEOCAP program).

Having discussed the importance of the investment risk resulting from the context (the 'environment-risk'), the next section will look at portfolio effects and what influence it has on the investment decision making process.

---

[11] www.eiu.com

[12] This hypothesis would require further research and corroboration.

[13] The 'investment climate' can be characterized by, *inter alia*, the tax regime, the predictability and transparency of the licensing process, the market power of dominant players, the availability and quality of data, the education level and availability of local manpower, wages, import tariffs, the competition (also from other sectors) in the industry, the political stability, public acceptance, institutional checks and balances, etc. etc.

2.6 Modern Portfolio Theory (MPT)

The previous analysis has described methods how to evaluate an investment opportunity assuming that the project is independent of other projects. Individual projects are however seldom 'stand-alone'. What is still missing in the analysis is the effect of having a portfolio of projects. A portfolio is an appropriate mix of or collection of investments held by an institution or by a private investor[14]. The Modern Portfolio Theory (MPT) developed by Markowitz (1952) proposes how rational investors use '*diversification*' to optimize their portfolio. The theory assumes that the investors are risk averse, i.e. when there are two projects offering the same return, the investor will prefer the less risky one. An investor can reduce the portfolio risk by having assets that are *negatively correlated,* i.e. as the truth is being revealed in time and the initial assumptions are updated, the value of the assets have the tendency to move in opposite directions: one asset increases in value, the other one decreases in value[15]. The total uncertainty, and hence also the risk, of the portfolio is therefore lower than if the projects were uncorrelated.

The value of the portfolio can be expressed as the portfolio's expected return (e.g. the sum of the NPV of all projects), and can be related to the uncertainty (or risk) of the portfolio's NPV (e.g. the standard deviation). This represents one point on a graph of risk (x-axis) vs. expected return (y-axis). Now, suppose that all possible portfolios, i.e. all possible combinations of projects, are computed in terms of total portfolio risk, and total expected return of the portfolio, then one can derive a line called the '*efficient frontier*' (Figure 4 below).

This line represents all possible portfolios for which there is the *lowest possible portfolio risk at a given level of portfolio return*, or the *highest possible portfolio return at a given level of portfolio risk.* Therefore, when considering an investment opportunity, the decision analyst has also to take into account, i.e. next to the project stand-alone NPV evaluation, how the new investment would affect the XY location of the updated portfolio vis-à-vis the efficient frontier. To do so, the decision analyst has to quantify the dependencies between the projects, e.g. one project requires something from another project in order to get started/function optimally/ finish. Sometimes, a project needs to

[14] http://en.wikipedia.org/wiki/Portfolio_(finance)

[15] A lighthearted, but illustrative example of negatively correlated projects is a company producing both umbrellas and ice-cream: if it rains, the sales of umbrellas goes up and the sales of ice-cream goes down. But if the sun shines, the sales of ice-cream goes up and the sales of umbrellas goes down.

be terminated first before the investor can start a new project (e.g. due to cash constraints).

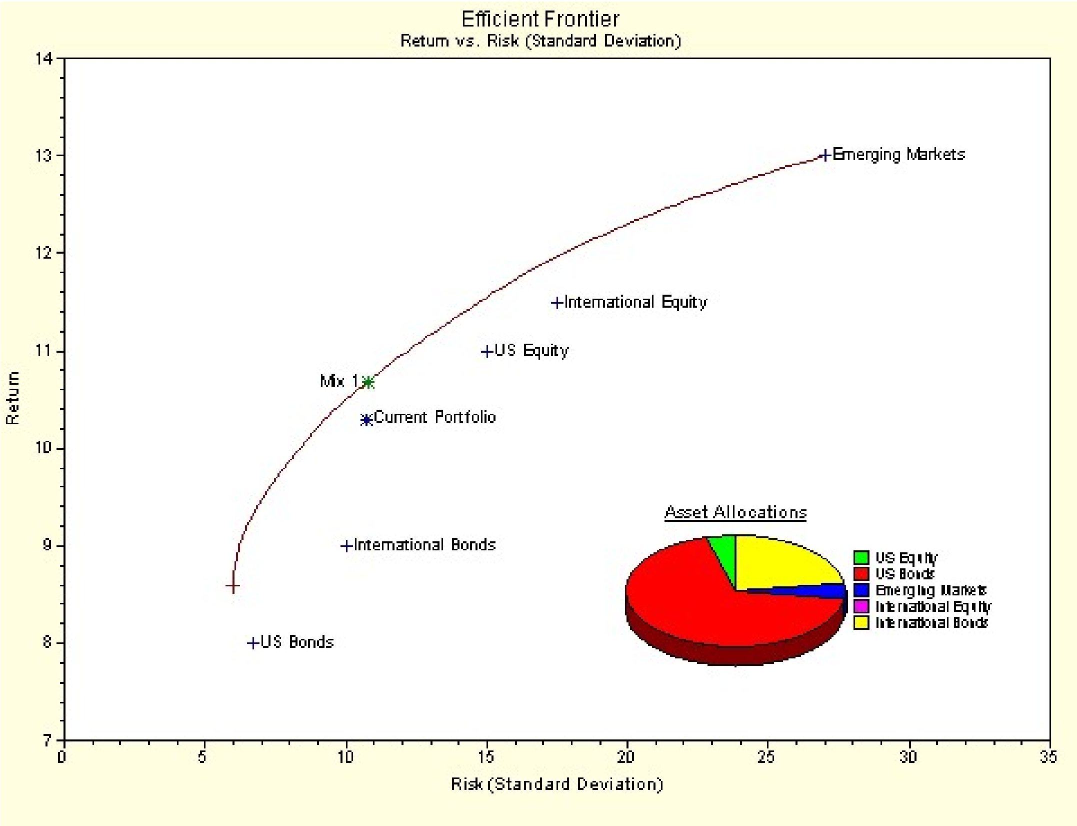


Figure 4 - Modern Portfolio Theory: efficient frontier

A decision analyst should understand thoroughly these project interrelations. In addition, the decision analyst should be aware of potential spill-over effects: when assessing an investment opportunity, the decision analyst has to take into account what the effect of the project will be on the performance of the portfolio's other projects. The possible positive or negative effect of undertaking a project on other projects has to be taken into account when evaluating the investment opportunity.

A visual representation of the investment decision analysis / decision making process, as discussed in this chapter, is provided in Figure 5 below. Every investment decision has upfront requirements, which have to be met before the actual analysis can take place. The decision analyst can opt for either a deterministic or a probabilistic approach when designing his/her analysis. Through the whole process, KPI hurdle rates have to be met to validate the whether the investment meets the applicable constraints. Possible qualitative effects can be incorporated in the Multi-Criteria Analysis (MCA) before deciding whether to invest or not, taking into account the investment environment in which the investment takes place.

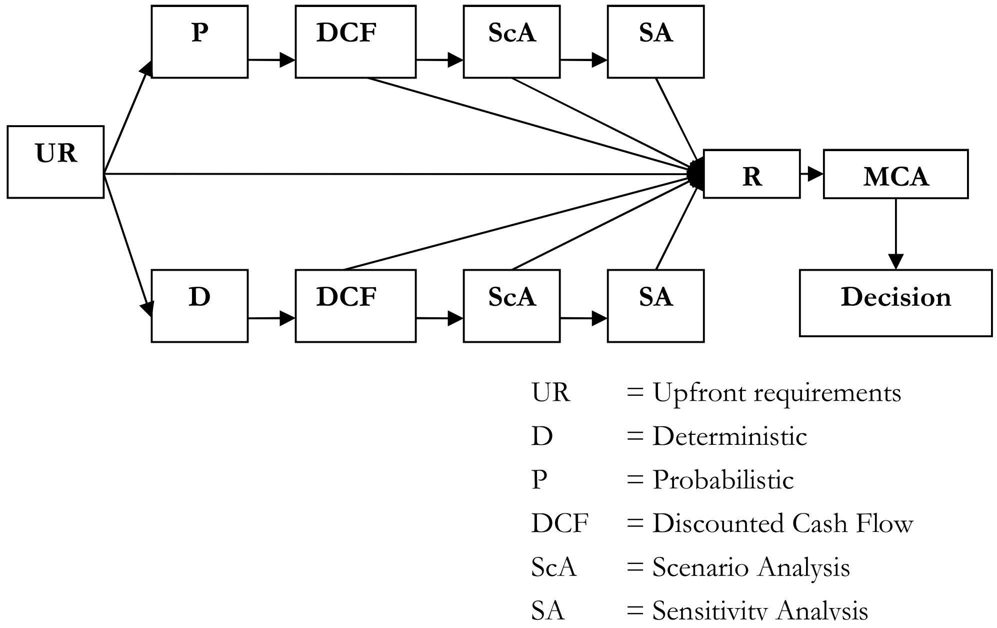


Figure 5 - The investment decision making process

3 THE ROLE OF ECONOMICS IN THE DA-PROCESS

3.1 ECONOMICS

The scientific discipline of micro-economics plays its role in the decision analysis / decision making process by establishing a consistent set of methods by which to evaluate the attractiveness of an investment opportunity. These opportunities may range from exploring for geothermal prospects in a new area, to carrying out appraisal activity on a discovery, planning a new field ('greenfield') development or incremental development of a producing field ('brownfield'), farming-in to an activity run by some other company, farming-out acreage or any other asset.

A way of achieving consistency between all quantities determining the attractiveness of an investment opportunity is to translate all these quantities into monetary terms. The advantage of having all these quantities converted into monetary terms is obviously that all disciplines have one common language that in principle is a good proxy for the company's core business, i.e. competing in a playing field where financial strength is the key to success. There are however also dangers: many corporate values cannot be simply expressed in monetary terms. Senior management must therefore always be vigilant and balance the different corporate values and constraints in an operationally and strategically coherent way.

In general, economic valuation techniques are applied to advise management on the attractiveness of such investment opportunities, to assist in selecting the best options, to determine how to maximise the value of existing assets, and to support negotiation of contracts or equity determinations (e.g. in the oil and gas upstream industry).

Note that the decision analysis staff responsible for evaluating (geothermal) investment opportunities do not necessarily need to be a university graduate with a bachelor or master degree in economics. Often, technical staff (engineers etc.) execute the economic evaluation discipline of a (geothermal) company. *Pros* are typically that technical staff understand the underlying physical and technical processes and are able to judge how these may impact on the bottom line. *Cons* of having technical staff executing economic assessments are that they may not be eager enough to fully understand the non-technical risks, that they may get bogged down in technical detail and have difficulty in identifying which detail is (ir)relevant for the decision-making process. Generally, a combination of decision analysts with a technical and economics background may be preferred.

3.2 The skill and position of the economist

The skill of the economist in a geothermal company is to express the value of geothermal assets and geothermal projects in monetary units. Therefore the economist commonly acts as the link between the technical disciplines and the decision-making managers.

The economist is consulted in major decisions in all phases of the life cycle of a geothermal venture. He advises on the commercial attractiveness of an exploration license or an exploration well, on the commercial necessity of acquiring additional geophysical surveys or drilling a well for appraisal purposes, on the commercial ranking of a number of development options of a geothermal field, on the commercial viability of the selected development option, on the timing of mid-life development options and eventually abandonment. He also makes important contributions to decisions on acquisitions and divestments of (geothermal) assets or companies.

In acquiring the data for his calculations he will have daily contact with all technical disciplines: explorers (geophysicists, geologists), reservoir engineers, field engineers, drillers and operators. He will also have regular contacts with non-technical staff such as concession lawyers (on contractual terms and conditions), fiscal specialists, financial specialists, planners (e.g. on electricity prices, corporate hurdle rates, portfolio constraints) and management (on screening criteria).

The economic analysis of opportunities requires the gathering of much information, such as capital costs, operating costs, anticipated revenues, fiscal (tax) structures, forecast oil/gas prices, the timing of the project, and the expectations of the stakeholders in the investment. These data must be collected from a number of different departments and bodies (e.g. reservoir engineering, engineering, taxation and legal, host government) and each data set carries with it a range of uncertainty. The data gathering and establishment of realistic ranges of uncertainty can be very time consuming.

The economic model for evaluation of investment (or divestment) opportunities is normally constructed on a computer, using the techniques discusses in this course syllabus. When adopting the *deterministic* analytical process, the uncertainties in the input data and assumptions are handled by establishing a base case (often using the 'best guess' values for the poorly known variables), and then performing sensitivities on a limited number of key variables. This not only indicates which of the parameters have the highest impact on the attractiveness of the proposal (and which can then be addressed), but also provides a method for setting threshold values (e.g. a minimum oil price for which a project is attractive) and for optimizing the project. Sensitivity analysis is an essential part of an economic evaluation. Consider the evaluation of a project in June 2008 which only assumed one oil price (around $146/bbl at the time, and actually dropping to less than $38/bbl in August, 2015).

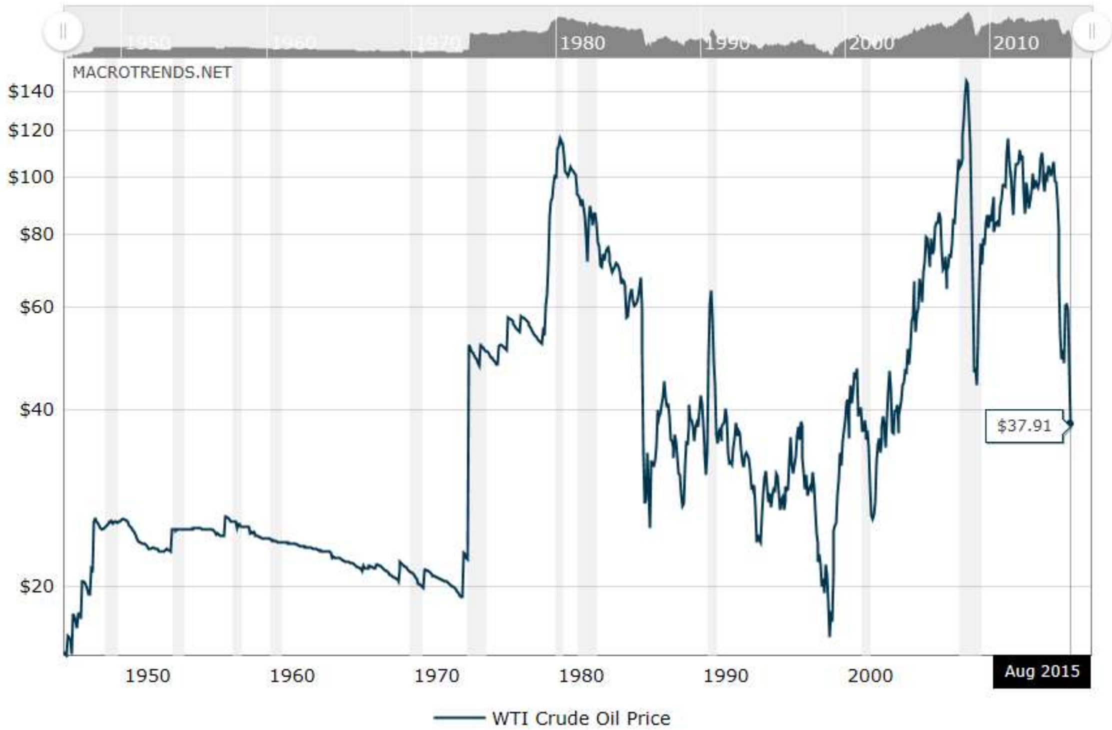


Figure 6 - Oil price history

The largest uncertainties in data usually occur at the earliest stage of a field's life-cycle, i.e. during the exploration activity. A typical proposal to bid for an exploration licence in a new province may have to be based on limited geophysical surveys only, although in more mature areas additional information will be available (e.g. on well productivities). The methods applied to exploration economics are largely based on gambling theory (statistical theory), with the analogy being that the cost of exploration (e.g. geophysical surveys) is compared to the price of a ticket to enter a lottery with the outcome (dry well, non-commercial discovery, or commercial discovery) being regarded as the prize.

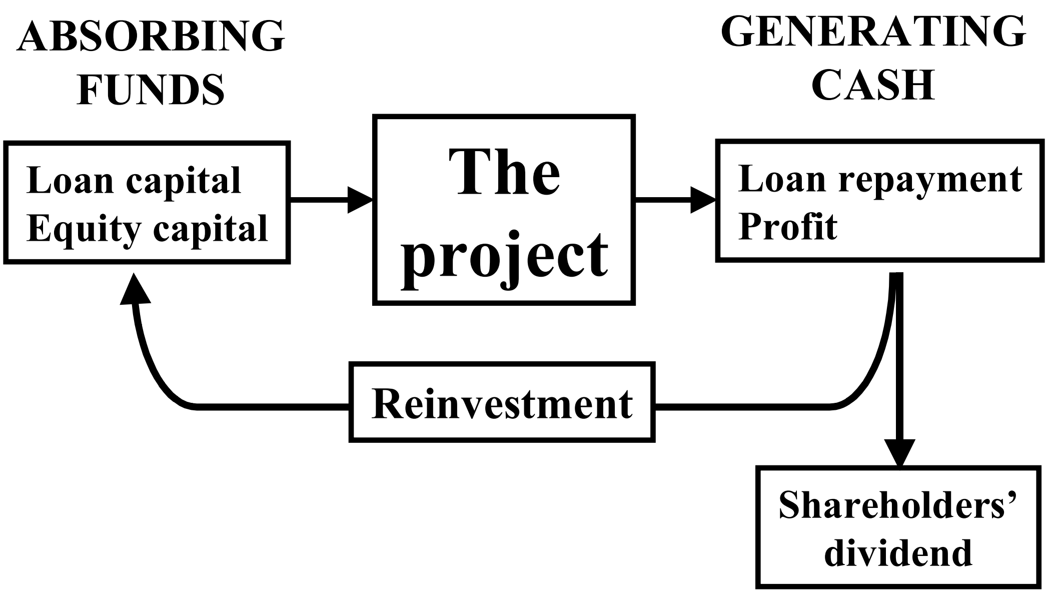
The quantification of the range of possible volumetric outcomes is the task of the exploration geoscientist, and the costs of developing potential discoveries would be prepared by engineering departments, but exploration economics methods are applied to determine the price which a company would be prepared to pay to enter the lottery (i.e. proposing a work program, including all costs, as part of the bid for the exploration license)! Traditionally, exploration economics are distinguished from development economics for which geological uncertainty ranges are narrower. In this course, we will stress however the generic benefit of probabilistic methods both for exploration and for development economics.

In the production period of the field's life-cycle, the typical decisions to be made relate to *incremental* projects rather than to the economics of full field development. In this situation, it is important to determine the baseline case (normally the 'do nothing case', or the 'no further activity case'), and to evaluate the proposal for an incremental project on the basis of the difference in cashflow (expenditure and revenue) compared to the baseline case. This approach is named 'incremental economics', and that is typically how the investment problems is seen: historical costs ('sunk costs') and revenues from past projects are left out of the equation.

4 DEVELOPMENT ECONOMICS

4.1 THE ROLE OF THE PROJECT IN CORPORATE ECONOMICS

From an overall economic viewpoint, any investment proposal may be considered as an activity that initially absorbs funds and later generates money. The funds may be raised from loan capital or from shareholders' capital, and the net (after tax and costs) money generated may be used to repay interest on loans and loan capital, with the balance being due to the shareholders. The profit can partly be paid out as dividends to shareholders, and partly be reinvested in the company to fund the existing venture or new ventures. The following diagram indicates the overall flow of funds for a proposed project. The detailed cash movements are contained within the box labelled "the project".



From this overview it is apparent that the project must generate **sufficient** return on the funds absorbed to at least pay the interest on loans and satisfy the expectations of the dividend payable to shareholders. Any remaining cash generated can be reinvested in the same or alternative projects. The minimum return expected from the investment in a project will be discussed later.

Within the geothermal project, the funds provided are used in designing and constructing the facilities (e.g. design costs, pipelines, power plant etc.) and the subsequent sales of electricity (or heat) provide the cash, which pay for the operation of the project (e.g.

maintenance, manpower) and obligations to the host government (e.g. tax and royalty). The remaining, money generated is then available for repayment of interest on loans, distribution to the shareholders as dividends, or reinvestment on behalf of the shareholders in the same or in other projects.

Still within the project box, the cashflow of the project (or other investment opportunity) is the estimate or forecast of the funds absorbed (the costs) and the money generated (revenue) during the project lifetime. Take, for example, the development of a geothermal field as the investment opportunity. Initially the cashflow will be dominated by the capital expenditure (capex) required to design, construct and commission the hardware for the project (e.g. pipeline, wells, power plant).

Only when production commences (in Indonesia: ‘Commercial Operation Date’, possibly 3-8 years after the first capex), revenues are received from the sale of the power. These revenues are used to pay for the operating expenditure (opex) of the project (e.g. manpower, maintenance, equipment running costs, support costs) plus the host government take which may (in the simplest case) be in the form of taxes and royalty.

The opex and host government take are costs which occur throughout the project life, with the host government take usually representing a significant fraction of the costs. One exception to this would be at the stage of abandonment of the wells and facilities, when the single largest cost is the operating expenditure required to pay for securing wells and removing the hardware associated with the project. However, the cost of decommissioning the plant normally attracts large tax reliefs.

The balance of the money absorbed by the project (capex, opex, host government take) and the money generated (revenue from sales) yields the project’s net cashflow.

The project’s forecast cashflow forms the basis of the economic evaluation methods, which will be described below. From the cashflow, a number of economic indicators can be derived and used to judge the attractiveness of the project. Some of the techniques to be introduced allow for the economic performance of proposed projects to be tested against the company’s investment criteria, and also to be compared with alternative investments.

4.2 INPUT / OUTPUT DATA

4.2.1 Technical input data

The basic technical data required to calculate the value of a geothermal asset are the production profile and the costs associated with its development, operations, maintenance and abandonment. In earlier phases of the life cycle such as exploration and appraisal, one uses more generic data such as reserves estimates, well productivities, and rough cost data (on wells, facilities, pipelines, etc.) of similar developments in the area of interest.

4.2.2 Commercial input data

The most important commercial parameters are the price of the produced commodity, i.e. the MWh-price, over the production lifetime of the asset and the commercial and fiscal terms that apply to the license of interest, i.e. the royalty, the tax(es) and the conditions underlying the association with partners. Of lesser importance are the development of exchange rates and inflation in the countries associated with the venture, either by delivering goods or services or by receiving the product. Most companies apply screening (investment) criteria on which the commerciality of projects is ranked and judged. The MWh-price forecast[16] is an important element of these screening criteria. Ideally one would like to know the annual MWh-prices over the production lifetime of the venture. As this is obviously impossible to forecast, many companies use a single price forecast, either in nominal or in real terms (e.g. 2001 money). In Indonesia, the proposed MWh-price, i.e. as part of the company's bid package to obtain an exploration license, would be established by doing a sensitivity study on IRR vs. price. The geothermal company will set a hurdle rate for the IRR (including risk and profit margin), and base its offered price on this hurdle rate. It makes sense to keep such sensitivity analyses confidential. Most companies regard screening criteria as "MOST CONFIDENTAL".

4.2.3 Output data

Most economic results are expressed in money terms. For well-defined developments this can be done deterministically as Net Present Value (NPV), and for less well defined ventures in the exploration or appraisal phase as Expected Monetary Value (EMV = the mean of the statistical NPV-distribution). Other Profitability Indicators such as internal

[16] In Indonesia, as there is no market price for electricity, the MWh-price is less a forecast than an assumption of a negotiated result: in the bid documents, the geothermal operator has to offer a sales price. This price offer will be a most important criterion for the government to decide whether or not to grant the license to this operator: the lower the offered price, the more attractive the operator is to the government.

rate of return (IRR), Profit Investment Ratio (PIR[17]), pay-out time (POT) and maximum exposure (ME) are also reported to management.

4.3 CONSTRUCTING A PROJECT CASH-FLOW

The construction of a project cashflow requires information from a number of different sources. The principal inputs are typically:

SOURCES	INFORMATION
Reservoir Engineering	Reserves, resource maturation forecast Production forecasts – steam, temperature, liquids, pressures
Drilling Engineering	Drilling and completion costs
Engineering	Capital costs - pipelines - gathering site - power plant - pumps, etc., lifting costs
Operations & Maintenance Eng	Operating costs (fixed / variable opex) - maintenance - well workover - manpower requirements
Human Resources	Manpower costs - operators - technical staff - support staff - overheads
Host Government	Fiscal system - tax rate - royalty rate - company status (e.g. newcomer) - project status (e.g. ring-fenced) - environmental and abandonment costs
Corporate Planning	Portfolio constraints Forecast oil and gas prices Discount rates Hurdle rates Exchange rates Inflation forecast Market factors Political risk, social

[17] Whereas NPV (or EMV), POT and ME are *absolute* values, the indicators IRR and PIR are *relative* indicators and refer to *capital efficiency*.

		obligations

The data gathering process can be lengthy, and each input will carry with it a range of uncertainty. For example, at an early appraisal stage in the field life the range of uncertainty in the reserves and production forecast from the field may be ± 50%. As further appraisal data is gathered this range will reduce, but at the decision point for proceeding with a project uncertainties of ± 25% are common.

The uncertainty may be addressed by constructing a base case, which represents the most probable outcome, and then performing sensitivities around this case to determine to which of the input variables the project is most sensitive. The most influential parameters may then be studied more carefully. Typical sensitivities are considered in Chapter "Sensitivity Analysis". It is therefore important when collecting the data from the various sources that the *range of uncertainty is also requested*. In particular, when estimating operating costs it is desirable for the operations and maintenance engineers to estimate the cost of these activities based on the particular facilities and equipment types being proposed in the engineering design. For example, the cost of operating and maintaining a modular wellhead turbine (to obtain early production) will be significantly different from a conventional centralized power plant.

For any one case, say the base case, the project cashflow is constructed by calculating on an annual basis the revenue items (the payments received by the project) and then subtracting the expenditure items (the payments made by the project; capex, opex and host government take). For each year, the balance is the annual cash surplus (or cash deficit). Hence, on an annual basis

Cash Surplus = Revenue - Expenditure

Cash surplus is also commonly known as **net cash flow**. For a geothermal company, the typical revenue and expenditure items are summarised in the table below:

Revenue items	**Expenditure items**
Gross revenues from MWh sales	Capex (e.g. wells, facilities, assets with lifetime < 1 year)
Tariffs received	Opex: - *fixed (not related to prod)*

	- *variable (related to prod)*
Farming out payments	Government take: royalty, tax, other

5 DISCOUNTED CASHFLOW METHOD

The discounted cashflow (DCF) method is a method to assign a monetary value to a detailed forecast of the money flows related to a project such as a geothermal project. This value is expressed in Present Value terms (to be explained later), allowing cashflows from different years to be summed. Note that the difference between an economist and an accountant is that the accountant describes the financial performance of a company in a *past* period, whereas the economist forecasts and evaluates a project over its *future* performance. By comparing a number of possible future scenarios the economist can therefore assist in selecting the optimum development concept of a project.

5.1 CASHFLOWS

A cashflow is a table, annually forecasting the amounts of money flowing into a venture and out of a venture in the course of time. In a way, the venture can be regarded as a savings account in which money is deposited in the early years (the investments for developing the geothermal resource), but generates money in later years when the field is producing. In the final years, some money may have to be deposited again to pay for the abandonment expenses unless the account is closed at an earlier date by divesting the field.

5.1.1 Cashin: money generated by the venture

The most important cashin item relates to the revenues from the sales of electricity. Its magnitude equals the annual production times the year-average sales price of the commodity.

$$Annual\, revenues = 365 \times \left(daily\, electricity\, production \times electricity\, price\right) / 1.0e-6$$

Here the (annual) revenues are expressed in million US dollars per year, the daily electricity production in MWh per day (MWh/d), and the electricity price in \$/MWh.

Less common cashin items for a project relate to third party payments for acquiring an equity interest in the project, and rebates of the National Electricity Company in case they decide to participate in the development of a discovery after the exploration / appraisal phase has been carried out at sole risk by the Company(ies).

5.1.2 Cashout: money spent by the venture

5.1.2.1 Technical costs

The economists distinguish two types of technical costs, depending on their fiscal treatment. The capex (CAPital EXpenditure) represents long life items (i.e. more than 1 year), which have to be depreciated over a number of years for fiscal purposes (i.e. determining the yearly tax payable to the Government). These are the costs of building the roads, facilities, drilling the production wells, power plant, laying the pipelines etc. Most capex occurs up front, i.e. well before production starts. Later in the field's life mid-life investments may occur to stem production decline or transform the facilities for a new role such as commencing to produce the steam cap once most of the steam contained in the liquid phase underneath has been produced.

The second type of technical costs is the opex (OPerating EXpenses), which can be immediately expensed fiscally, as they recur yearly. These costs relate to:

- ***Production Costs*** (proportional to electricity production)

  lifting, water treatment, workovers, injection
- ***Maintenance Costs*** (proportional to capex)

  inspection, preventative maintenance, remedial maintenance
- ***Other Costs*** (proportional to production)

  office, terminal operations

The relative shares of the different types of opex can vary considerably between different ventures.

5.1.2.2 Government Take

The contracts that govern the relationship between geothermal companies and governments can take several forms. Because of their analogy to and relevance for geothermal energy, we refer in this course to oil and gas upstream contracts such as the Concession Agreement and Production Sharing Agreement versions (PSA). Alternative contracts exist, for example a Technical Service Agreement (TSA). In Indonesia, the contract form is similar to the Concession Agreement, i.e. the geothermal company receives a monopoly on exploration and production for a certain license area and for a certain duration of time. Many other conditions will also apply.

It should be understood that, for the company, Government Take is just a Cashout item as part of its annual cashflow. The company computes all its yearly Cashin and Cashout items to obtain the yearly pre-tax Net Cashflow, and then computes the after-tax yearly Net Cashflow by calculating the yearly Government Take. One should also be aware of the fact that if the project is not ring-fenced (i.e. treated as a separate entity for tax purposes), tax can only be computed by consolidating the project with all other assets (projects) of the company that fall under the same tax regime. In those cases, calculating the Government Take as if it were a stand-alone tax entity can be misleading. As a first approximation of the project's after-tax yearly Net Cashflow it can be a valid approach for prioritizing alternative project definitions, but in principle this should be verified with the company's financial department.

5.1.2.3 Concession Agreement

The revenues that accrue to the government under a *Concession Agreement* take at least three forms: 1) Royalty, 2) Tax, 3) Duties and levies. Other forms may also apply, such as 4) a Carbon tax. These forms are briefly explained below.

- **1. Royalty**: The royalty is a percentage of the revenues from the sales of electricity by the geothermal company. Typically, the royalty is tax deductible.

- **2. Taxation**: The base for the tax is the yearly profit made by the company. The profit in a particular year is defined as revenues minus costs, whereby the costs should be in line with the fiscal conditions. The taxes use the following formula:

$$Tax = taxrate \times (annual\,revenues - opex - depreciation - uplift - royalty)$$

The **depreciation** is derived from the capex following the fiscal conditions. It can take several forms, of which the *straight-line depreciation* method is commonly applied. Under this method the capex of given year is evenly spread over a period of, say, 6 years, commencing in the year that the capex is spent.

Example of Straight Line Depreciation

Year	1	2	3	4	5	6	7	8	Total
Capex	**120**	**240**	**240**						**600**
Depreciation 1st year capex	20	20	20	20	20	20			120
Depreciation 2nd year capex		40	40	40	40	40	40		240
Depreciation 3rd year capex			40	40	40	40	40	40	240
Total depreciation	**20**	**60**	**100**	**100**	**100**	**100**	**80**	**40**	**600**

In Indonesia, depreciation is done using the Declining Balance (DB) method, or Double Declining Balance (DDB) method. The result is faster depreciation in early years, and slower in later years (i.e. less tax payable in early years). This is more beneficial to the company than straight line depreciation. The same example as above is depreciated below using the *Declining Balance Depreciation* method[18]. The result is displayed below:

Same example using Declining Balance Depreciation (salvage = 10%)

Year	1	2	3	4	5	6	7	8	Total
Capex	**120**	**240**	**240**						**600**
Depreciation 1st year capex	38,28	26,07	17,75	12,09	8,23	5,61			108
Depreciation 2nd year capex		76,56	52,14	35,51	24,18	16,47	11,21		216
Depreciation 3rd year capex			76,56	52,14	35,51	24,18	16,47	11,21	216
Total depreciation	**38,3**	**102,6**	**146,5**	**99,7**	**67,9**	**46,3**	**27,7**	**11,2**	**540**

In the DB method, a 'salvage value' needs to be specified, i.e. this salvage value is not depreciated and remains on the company's balance sheet. In the above example, 10% has been used, resulting in a total depreciation of $540M, rather than $600M. One can see that the DB method results in faster depreciation. This gives the company a significant added Present Value of his net after-tax profit, compared to the Straight Line method. The Double Declining Balance (DDB) method can result in even faster depreciation.

Note that in several countries, 'Special Taxes' or conditions may also apply. An example is the **uplift** and could amount to say 5% of the capex during a number of years. It was originally intended to fiscally compensate the companies for the effect of inflation when depreciating capex items: with a capex cost escalator (uplift) a larger capital allowance results, hence a lower taxable income and lower tax.

- **3. Duties and levies** associated with importing equipment or buying equipment or services locally. Import duties and sales tax (Value Added Tax) are examples of this form of Government Take.

[18] See also the XL spreadsheet program, where this function is explained.

- **4. Carbon Tax** can be levied on fossil fuel used in operations, or when lost (e.g. venting or flaring). This tax is imposed in several countries and intends to incentivize companies to reduce CO_2 emissions.

5.1.2.4 Production Sharing Agreement

A *Production Sharing Agreement (PSA)*, as applied in many countries, generally has the following characteristics:

1. Ownership of the resource usually remains with the Host Government who employs the Company as a "contractor" and compensates him out of the revenues of the production (hence, production *sharing*)
2. The Contract between the Host Government and the Company (the contractor) covers an exploration phase of a fixed number of years, during which the contractor guarantees to carry out a minimum work programme (e.g. number of exploration wells drilled, km of seismic, …). This money is entirely at contractor's risk.
3. In addition to the work programme, there may be a number of "premiums" to be paid, e.g. signature bonus, production bonus, road construction, education, etc. These expenses are usually not deductible against any production tax.
4. If a discovery is made within the exploration period and the Host Government agrees it is commercial, then a production licence is awarded. Once production commences (i.e. the Commercial Operation Date in Indonesia), the contractor is paid "in kind" (i.e. in the case of geothermal energy, in electricity). Payments are split into *Cost Recovery* and *Profit Share*.
5. Allowable (i.e. tax deductible) costs include exploration, development and operating costs. The rate of cost recovery is normally constrained by a maximum % of production to be used for cost recovery (e.g. 40 or 50%). Exploration costs and operating costs are usually allowed to be recovered immediately (though subject to above production limit), but development costs generally are only allowed to be recovered over a fixed time period (say, 5 years).
6. After allowing for cost recovery, the remainder of the production, called *profit oil* (in case of an oil production sharing contract), is shared between the Government and the Contractor. The simplest form is a fixed split, e.g. 85:15% for Government : Contractor. Other forms exist (e.g. a sliding scale with *production tranches* for the profit oil, some countries have up to 8 tranches).

Apart from potentially valuable information on the subsurface and services provided to the Government as part of the PSA (training etc.), the monetary revenues that accrue to the government under a PSA normally take two forms:

1. Premiums (signature bonus, production bonus, etc.)
2. Share of *profit oil*

Normally, tax and royalty do not apply in this PSA-system.

Variations on the standard PSA include for example:

- Government participation: the Government can elect to participate at the time of development and from then on be treated as if it were a partner at an agreed share. Past costs may not be repaid.
- Allowable costs: strict rules such as limiting exploration costs, or production wells, can be applied in some countries.
- Other sliding scales
- Profit shares, tranches by bidding
- Taxes may be imposed on the yearly pre-tax revenue. Sometimes even royalty is paid in addition.
- Ring-fencing: this limits the geographical area where costs can be offset against revenue. For the contractor, the worst form is that each discovery is ring-fenced. Then costs and revenues cannot be consolidated over the total concession area, let alone over the total company (i.e. the national subsidiary in case of a multi-national company).

5.2 Discounting

5.2.1 *Time value of money*

Expected cashflows associated with an investment extend well into the future, sometimes over a period of more than 30 years. It is clear that a payment of, say, $100 million over 25 years does not have a value of $100 million today. If the money would be available today, it could accrue a significant amount of interest over the 25-year period and moreover there is the risk that something may happen during the 25-year period that could result in not receiving the money at all. Therefore the economists apply a discount factor smaller than 1 to deferred receipts or payments. It is somewhat analogous to the perspective in the 3rd dimension when drawing:

objects further away have the same size but look smaller. The further in the future, the smaller the discount factor.

5.2.2 *Mechanics of discounting*

Since money today does not have the same value as money tomorrow, all cashflows from different years have to be made equivalent in order to allow summation over different years. Therefore, the basic concept of discounting is to translate all future amounts of money into either receipts or payments of money today, called Present Value (PV). These PVs should grow to the future amount over the given time period when put on a savings account with the desired discount rate as interest:

$$future\ amount = present\ value \times (1 + discount\ rate)^{time\ period}$$

This implies that the PV of a future amount is given by:

$$present\ value = future\ amount\ / (1 + discount\ rate)^{time\ period}$$

If an entire cashflow, i.e. a time-series of successive payments or receipts, is to be discounted, the PV of the cashflow amounts to the sum of the PVs of the individual elements of the cashflow from the reference date, usually the date of first capex to be spent (i = 0) until abandonment (i = n). As this PV normally refers to the cashflow “net of tax”, it is commonly referred to as the Net Present Value, NPV:

$$NPV\left(Cashflow\right)=\sum_{i=0}^{i=n} Cashflow\left(i\right)/\left(1+discount\ rate\right)^{i}$$

This implies that NPV only has a meaning when the Reference Date and the Discount Rate are known. *When reporting an NPV, these two characteristics must always be mentioned!* Spreadsheet programs like Excel are equipped with functions that perform the PV operation adequately.

5.2.3 Setting the discount rate

Setting the corporate discount rate (or the IRR hurdle rate) as an investment criterion is an important management decision. As mentioned earlier, the discounting procedure allows for the compensation of two distinct factors impacting on the Present Value, i.e.:

1) The fact that money received later will not carry interest immediately. This foregone interest is related to the risk-free interest rate, which is part of the ‘Cost of Capital’, and to a premium banks may be prepared to give to the savings account holder.
2) The Risk that the forecasted late cash payment will not be received at all or only partially due to unforeseen events between today and the time of the payment. This risk is related to the risk-premium shareholders and banks demand and is part of the ‘Cost of Capital’.

Most companies set their discount rate at their cost of capital. A big company with a diversified portfolio and a high rating from credit rating agencies has a lower cost of capital than a small company with a few kindred projects and a lower credit rating. The same project would therefore result in a higher NPV for the big company than for the small company. Projects are normally accrued to the company’s portfolio of projects and the company’s consolidated balance sheet is ultimately the project’s collateral. However, if the project is financed using ‘project financing’, for example by a Development Bank, then the cost of capital applicable to this project may be used as discount rate. In this case, the project itself is the collateral, and not the balance sheet of the company executing the project.

Depending on the total risk of the project (i.e. technical and non-technical risks), companies set their project acceptance / rejection criterion at a certain *IRR hurdle rate*:

the higher the risk, the higher the IRR hurdle rate. The IRR hurdle rate is always (significantly) higher than the cost of capital.

Some companies that are cash-constrained, but not opportunity-constrained, may use the *opportunity cost of capital* as their discount rate. Reinvesting the money generated from existing projects should result in at least their portfolio's financial performance (rate of return). If this is much higher than their cost of capital, and the company for whatever reason does not want to or cannot attract new external capital, then applying their portfolio's average return (the *opportunity cost of capital*) as the discount rate is a fair assumption.

5.2.4 Cost of Capital

A company obtains his capital from two sources, from issuing equity shares to stockholders and from the bank as loans, each with different costs of capital. The cost of capital of the company is the weighted sum of the cost of capital (coc) of both sources and is commonly referred to as WACC, the Weighted Average Cost of Capital:

$$WACC = gearing\ ratio \times coc(loans) + (1 - gearing\ ratio) \times coc(equity)$$

where the gearing ratio represents the outstanding long-term loans of the company as a fraction of its total assets. The cost of loans is basically the interest rate of the bank, corrected for any tax rebate on interest payments:

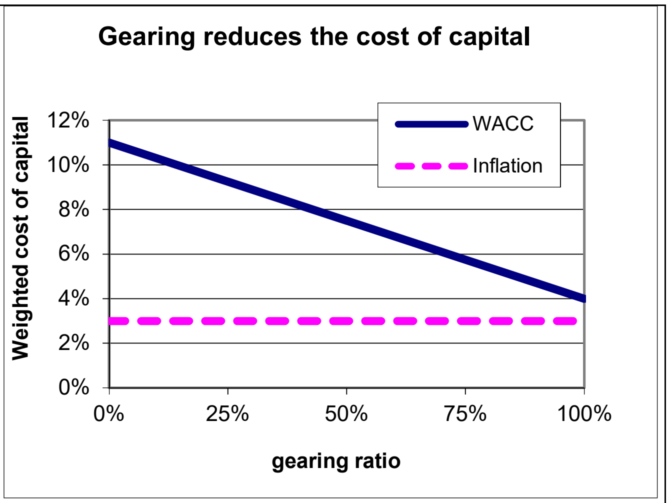
$$coc(loans) = Interest \times (1 - tax\,rate)$$

The cost of equity is more complex. Shareholders can benefit in two ways from owning shares: they can receive dividends and the value of their shares can increase. Dividend payments are, however, at the discretion of the company and share price increases are not certain either. Therefore owning shares carries a risk, for which the shareholder wants to be compensated. The higher the nervousness or volatility of the share price, the higher the risk, and the higher the required cost of equity. The risk averse shareholder has the option to buy risk-free Government Bonds with a guaranteed return of a few percentage points above inflation. This risk-free rate sets a floor to the shareholder expectations. The well-known Capital Asset pricing Model (CAPM) derives the following formula for the cost of equity:

$$coc\,(equity\,) = risk\ \ free\,rate\, + beta\, \times average\ \ equity\ \ risk\ \ premium$$

Here *beta* represents the ratio of the volatilities of the stocks in a certain sector divided by the average volatility of stocks. For the oil sector on the New York Stock Exchange (NYSE) *beta* is about 75%. The "average equity risk premium" is some 8% and the "risk-free rate" is some 2% above inflation. With inflation at 3% this results in a coc(equity) of some 11%, or 8% above inflation.

The interest on loans depends on the financial strength (i.e. credit rating) of the borrower but will for the larger companies be some 3% above inflation, i.e. 6% nominal. Correction for the tax rebate results in a coc(loans) of 4%. Now we can calculate the WACC for companies, which will depend on the gearing ratio of the companies. Note that highly geared companies will have a lower discount rate than companies with little or no long-term loans. This is one of the reasons why companies use different discount rates as investment criteria.



Of course, the amount a company can borrow relative to its equity (share-capital) is not unlimited as banks will ascertain whether the company's financial strength is adequate to pay back the loans or bonds. For stock-listed companies, but also for many other companies, their financial strength is assessed independently by "rating agencies". These look at many variables, with the gearing ratio as perhaps the most significant one, and form an opinion on a company's credit-worthiness. The better the rating, the lower the perceived risk of a default, the lower the interest rate a bank will demand for a loan. Therefore, a high gearing ratio may jeopardise the rating of a company, which could result in higher interest rates. A company has to carefully balance its gearing in order to keep its cost of capital (loans) at an acceptable level.

Examples of credit rating agencies are Standard & Poor's, Moody's or Fitch Ratings and use letter-designations such as A, B, C. The Standard & Poor's rating scale is as follows, from excellent to poor: AAA, AA+, AA, AA-, A+, A, A-, BBB+, BBB, BBB-, BB+, BB, BB-, B+, B, B-, CCC+, CCC, CCC-, CC, C, D. Anything lower than a BBB- rating is considered a speculative or junk bond. The Moody's rating system is similar in concept but the naming is a little different. See also the table below:

Moody's		S&P		Fitch		Remark
Long-term	**Short-term**	**Long-term**	**Short-term**	**Long-term**	**Short-term**	
Aaa	P-1	AAA	A-1+	AAA	F1+	Prime
Aa1		AA+		AA+		High grade
Aa2		AA		AA		
Aa3		AA-		AA-		
A1		A+	A-1	A+	F1	Upper medium grade
A2		A		A		
A3	P-2	A-	A-2	A-	F2	
Baa1		BBB+		BBB+		Lower medium grade
Baa2	P-3	BBB	A-3	BBB	F3	
Baa3		BBB-		BBB-		
Ba1	Not prime	BB+	B	BB+	B	Non-investment grade speculative
Ba2		BB		BB		
Ba3		BB-		BB-		
B1		B+		B+		Highly speculative
B2		B		B		
B3		B-		B-		
Caa1		CCC+	C	CCC	C	Substantial risks
Caa2		CCC				Extremely speculative
Caa3		CCC-				In default with little prospect for recovery
Ca		CC				
		C				

Moody's		S&P		Fitch		Remark
C		D	/	DDD	/	In default
/				DD		
/				D		

6 PROFITABILITY INDICATORS

6.1 PROJECT INDICATORS

Key Performance Indicators (KPIs) pertain to the viewpoint from which someone is assessing an activity. In a company, one would typically distinguish the following organizational levels from which to assess a planned activity: project; asset; portfolio, subsidiary (if applicable), corporate. The different levels have their different KPIs. Moreover, one should understand the relationship of a lower-level KPI to the next-higher-level KPIs. This is unfortunately not straightforward, especially when uncertainty and risk have to be consolidated at the next-higher level.

A project is commonly defined as a (planned) activity with a start date, with a budget, and with clear 'deliverables' that are handed over during or upon termination of the project. When ending the project, the result is 'commissioned', i.e. formally accepted by the client (which may be an internal client) and the final invoice is settled. Such limited-definition projects typically look at *costs* and *time*, and less at *(added) value*. For a project, a typical set of KPIs the project manager would use to monitor progress and success is: '*within time, within budget*'. The project manager's accountability and how his/her superiors will judge him would typically be expressed in these terms. However, for large projects this is often too narrow a view, and additional considerations should also be included, such as: *robustness of the project / design* to adapt to changing conditions (new information / new insights being revealed in time: both project time and asset life-cycle time, resulting in scope changes), or: *does the project allow learning*? Therefore, *uncertainty evaluation* may also have an important place when assessing an individual project. Such additional project evaluation criteria are not easily established nor agreed. But it makes a lot of sense to think about it and try to develop the associated practical indicators.

6.2 ASSET LIFE-CYCLE INDICATORS

Activities that have a perspective beyond a 'project' and cover one or more a life-cycle phases of the asset (i.e. and thereby influence the exploitation / monetization phase) are typically assessed using the Discounted Cash Flow method. As such, a 'project' may also be an activity whose impact stretches beyond the limited definition of the previous section. The key performance indicators of these activities are derived from the cumulative cashflow, such as depicted in Figure 7 below. In the example, the cashflow itself (columns) shows cash deficits (i.e. a negative cash surplus) in the first three years during which the capex is spent and then remains positive afterwards until abandonment. The cumulative cashflow reaches a minimum after three years at –$463 mln. This **Maximum Exposure** is the maximum amount that the company loses when the venture is untimely aborted. After nearly 6 years, the pay-out time, the venture breaks even. At abandonment, the total amount of money generated by the venture has increased to $590 mln, the ultimate cash surplus.

Profitability indicators-1

Maximum exposure: $463 mln.

Pay-out time: 5.8 years

Ultimate cash surplus: $590 mln.

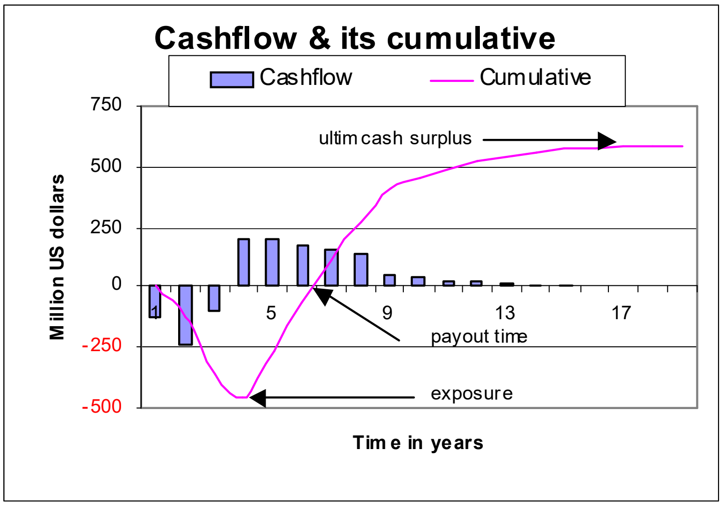


Figure 7 - Yearly and cumulative undiscounted net cashflow curve of a project

A second set of profitability indicators is derived from the Present Value Profile, a graph of the **Net Present Value** (NPV) as a function of the discount rate (Figure 8 below). One distinguishes again the ultimate cash surplus of $590 mln, i.e. the non-discounted NPV (at 0%). The NPV at 5%, 10% and 15% amount to $343 mln, $184 mln and $80 mln, respectively. The discount rate at which the NPV turns negative has a special significance. It is called the '**Internal Rate of Return**', commonly referred to either as IRR or ROR. Before 1990, this was the single most important profitability indicator of many companies with a high IRR indicating robustness to risk.

After 1990, many companies started to realise the shortcomings of the IRR. It is not defined for cashflows with more than one sign change and it does not give proper credit to ventures with a very long lifetime such as geothermal (or oil/gas) ventures. Therefore the Profit Investment Ratio, PIR, was introduced, being the ratio of the NPV to the PV of the capex, both discounted at the corporate WACC. This yardstick is the proper ranking parameter for capital-constrained companies and treats long-term geothermal and oil- and gas ventures more equally. As certain investments (exploration, appraisal, infrastructure, R&D) of a geothermal company will not be cash-generating, the funding of such investments will have to be borne by the cash-generating investments. This renders the PIR an attractive investment-screening tool for such cash-generating ventures.

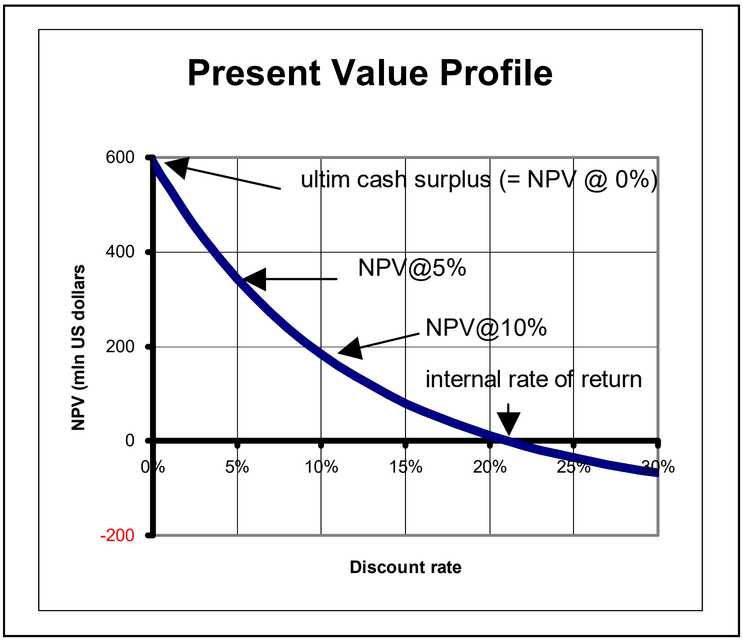


Figure 8 - Present Value Profile

KPI ▼	discount rate 0%	discount rate 5%	discount rate 10%	discount rate 15%	discount rate 20%
PV capex	600	539	488	444	406
NPV	591	343	184	80	11
PIR	98%	64%	38%	18%	3%

Note: IRR = 21.0%

The message is that asset life-cycle profitability is exponentially dependent on the discount rate and, hence, on the project's diversifiable technical risk and on the systemic risk, as expressed in the applicable WACC.

Other asset life-cycle indicators exist, for example on environmental footprint (CO_2 etc. emissions), or **Unit Technical Cost** (UTC in \$/MWh, at a given discount rate and reference year), or **Break-Even Price** (often referred to as the LCOE, or **Levelized Cost Of Electricity**[19]). Some indicators are rather complex as they are related to uncertainty

[19] Note that when reporting a value for the UTC or LCOE it is often unclear whether, apart from the capex and opex, the production (in the denominator) has also been discounted (i.e. at the same discount rate as the costs). This should always be specified.

evaluation (quantification) and 'optionality', i.e. the assessment of how the project is 'robust' for eventualities that are imposed by the truth being revealed in time. Optionality deals with whether and how the project or asset can be steered mid-course to avoid an undesired outcome / to grasp an upside opportunity. The concept of *robustness* or *resilience* will be discussed later (see e.g. section 9.1).

6.3 PORTFOLIO INDICATORS

Portfolio indicators refer to the (change in) (expected) performance of the portfolio of assets. As assets in principle influence each other, the portfolio's performance is not simply the arithmetic sum of the individual assets' performances. Assets (can) influence each other in two ways: 1) because they share one or more constraints; 2) because they are subject to uncertainty. An example of (1) is two geothermal assets (fields) sharing the same powerline: expanding the production in one asset may constrain the production of the other asset. An example of (2) is two geothermal fields with a large uncertainty in their potential upside capacity (ΔMW_e): their combined uncertainty will be normally less than the sum of the individual uncertainties, i.e. when considered relative to the expectation value.

Therefore, when evaluating individual project KPIs (with impact on the asset life-cycle), one should in principle assess the impact of the project on the portfolio's performance. This can be done by quantifying the impact of the project on the position of the updated portfolio vis-à-vis its efficient frontier (see section 2.6 and Figure 4 - Modern Portfolio Theory: efficient frontier), and by studying the portfolio's time-series (cashflow, production, etc.) with and without the new project. Ideally, one should do this probabilistically, i.e. with full Monte Carlo uncertainty propagation. Although an extremely valid approach, which can yield very beneficial insights, this analysis is seldom done as it typically is considered too time-consuming and requires scarce expertise, tools and skills.

Portfolio indicators are therefore mostly limited to simplified arithmetic summations of the base case deterministic definitions of assets (projects), although extended with any applicable constraints (time, manpower, capital, etc.), which may reduce total production or re-phase projects in time as compared to a project stand-alone analysis. The common portfolio performance indicators are therefore consolidated production vs. time, cash vs. time, arithmetically summed except when some constraint applies. Project-KPIs such as

NPVs, IRRs etc. are less meaningful for assessing a portfolio, as these typically are aimed at individual project decision-making / capital budgeting.

6.4 CORPORATE INDICATORS

Ideally, all KPIs of new projects should be consolidated *ex ante* at the corporate level to assess the project-interdependencies and understand why at the corporate level the projects do not necessarily sum to the arithmetic sum of the individual projects. In practice, however, this is seldom done as it is time-consuming, the computing tools are not always available, and perhaps most significantly: the consolidation of uncertainties is complex. Moreover, increasing the sophistication of quantitative tools has its limits: in practice many less quantifiable factors influence a company's course and one should not fall in the trap of believing one's quantitative model too much. Intuition and other 'imponderable' factors also have their place in the analysis. More sophisticated models may give a false illusion of accuracy. Nevertheless, one should always be open to understanding the pros and cons of improved quantitative tools.

At the corporate level, other KPIs will be of relevance. Some of them are taken from an oil & gas Exploration and Production company comparative performance review by Prudential and are given below:

I. Adjusted Production Costs

II. Depreciation, Depletion & Amortization Expenses

III. Production Income

IV. Quality of Earnings

V. Cash Flow

VI. Production Replacement Ratios, excluding acquisitions and divestments

VII. Finding & Development Costs, including acquisitions and divestments

VIII. Discounted Future Net Cash Flow

IX. Upstream Returns

There will be many other corporate indicators, such as environmental footprint, manpower employed, Earnings Per Share (EPS), Return On Capital Employed (the ROCE criterion) or, Return On Average Capital Employed (ROACE). Let it suffice here just to mention some of the corporate indicators without explaining them in detail.

The message from this chapter is that, due to interdependencies, project or asset or portfolio KPIs cannot normally simply be summed to obtain a correct measure for what is likely to happen at the corporate level. However, the regular project / asset / portfolio indicators are usually good approximations of what is likely to occur at the higher level. Awareness of possible errors in these approximations is however important.

7 THE INVESTMENT DECISION-MAKING PROCESS

7.1 INTRODUCTION

Analysing which possible decision, among a series of “framed” alternatives, is optimal is not straightforward. The DA (Decision Analysis) process helps the project team to present robust proposals to their management team (i.e. the decision-makers). In the previous paragraphs, it was already explained that the definition of ‘*optimality*’ depends on one’s perspective: there is the project stand-alone perspective, there is the asset life cycle perspective, there is the portfolio perspective and the corporate perspective. A solution that is optimal at one level is not necessarily ‘optimal’ at the next level. In principle, an ‘optimal’ solution at one level should be propagated to the next-higher levels, while continuity between the levels is assured (i.e. what is optimal at one level should also be optimal at the next higher levels). As discussed, however, this can be cumbersome and often even totally impractical to execute, especially if also all uncertainties should be propagated and merged with the higher levels. In practice, therefore, simplified approaches are adopted, for example only summing the deterministic base cases of the individual projects / assets, and constraining the summation to the applicable boundary conditions of the company.

7.2 OPTIMIZING VALUE AT ONE LEVEL IS NOT NECESSARILY OPTIMAL AT NEXT HIGHER LEVEL

In a simple world, all deterministic project NPVs can be summed arithmetically to establish the portfolio’s NPV. However, due to both deterministic and uncertainty relationships between the projects, this assumption is in general incorrect. Moreover, in an organization the optimization criteria (or utility function) per organizational level (KPI to be optimized under the constraint of other KPI hurdle rates, and perhaps under the constraint of other KPI risk tolerances) have to be set such that they are meaningful (i.e. can be influenced by the staff working at that organizational level). This means that implicitly the assumption is made that the utility function at one level is also valid at the next higher organizational level. Normally most companies make this assumption tacitly and only marginally verify its validity, especially in case uncertainty relationships are to be taken into account.

Below, some examples are given of how different value propositions may prevail at the different organizational levels and which simplifications are being made:

- *Project level*: execute project 'within time, within budget'
    - *Often, there is no explicit method to assign a value to optionality, flexibility in design, nor is there a formal way of taking into account new information that is acquired during project execution.*
- *Asset level*: realize maximum NPV over the life-cycle of the asset, conditional on some IRR hurdle rate.
    - *At the asset level there is no explicit driver to minimize portfolio risk, or come closer to the Efficient Frontier, or to test the asset's optimum to the portfolio's possible Money-of-the-Day constraints*
    - *No direct relation to after-tax portfolio economics: at the portfolio level there may be tax benefits that are not visible at the asset level.*
- *Portfolio level*: maximize EMV under some risk constraint (Efficient Frontier)
    - *No direct driver to optimize corporate economic KPIs such as earnings per share, ROACE, tax, etc.*

7.3 HIERARCHICAL OPTIMIZATION

Organizations typically have a layered, hierarchical structure and have to organize their business drivers such that they are operational (i.e. practical) at the various organizational levels. This means that different value propositions prevail at the different organizational levels: KPIs to be optimized are "rolled up" to the next higher level, KPI hurdle rates (constraints within which to optimize the other KPIs) are cascaded down the hierarchy (see Figure 9 below). The question then emerges whether these different value propositions form a continuum throughout the corporate hierarchy, i.e. whether an optimum found at one level automatically coincides with the optimum at the next higher level. Unfortunately, often this is not the case. Including probabilistic measures, for example to optimize *risk* at some expected *reward*, further exacerbates the complexity of hierarchical optimization.

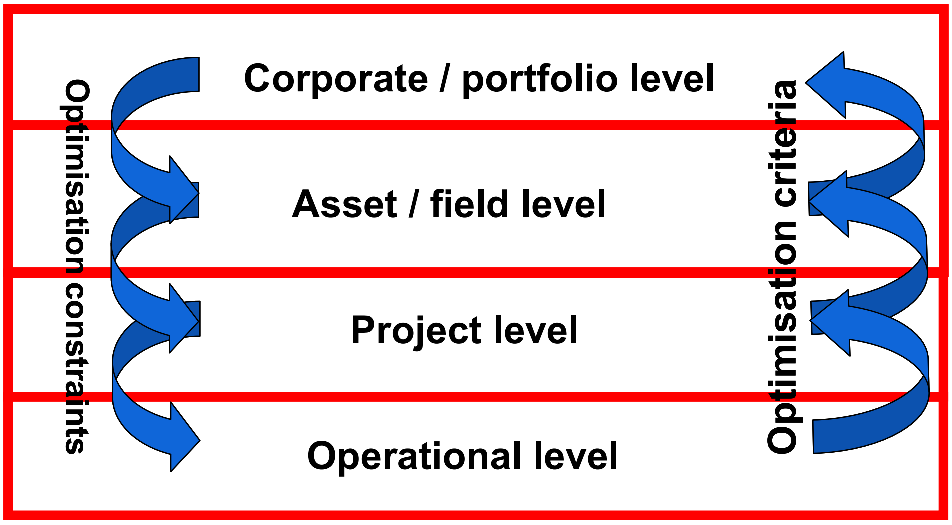


Figure 9 - Hierarchical constrained optimization

Forming such hierarchical continuum is a challenge, especially when uncertainty relationships have to be taken into account. Typically, simplifying assumptions have to be made without understanding clearly how this invites sub-optimality in the whole system.

7.4 PROJECT OPTIMIZATION

Looking at the project and the asset life-cycle perspectives, the Decision Analysis process will help the team to submit a robust investment proposal to their decision-makers. Possible flow charts of the DA process are given in Figure 10 and Figure 11 below. The process is most useful during the concept selection phase of a project (high-level / approximate definition of the project). But also in more detailed analyses the process is highly relevant when combined with detailed engineering.

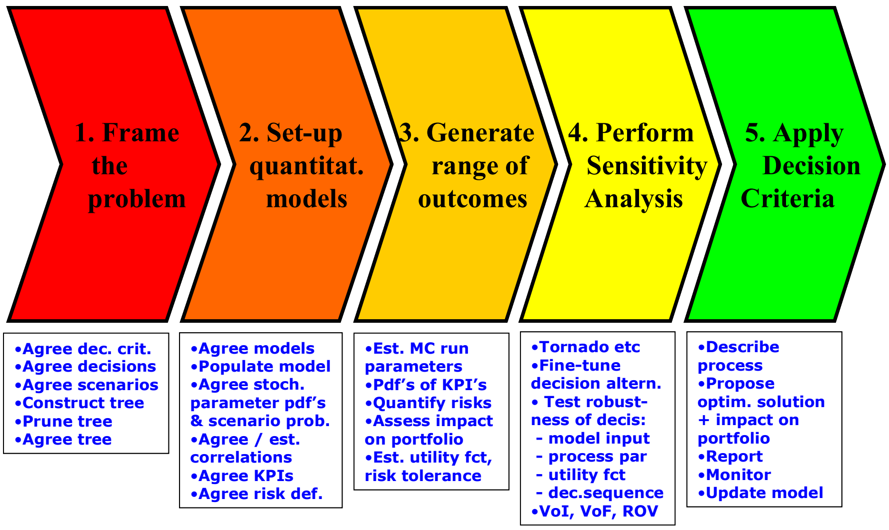


Figure 10 - Decision Analysis (DA) process

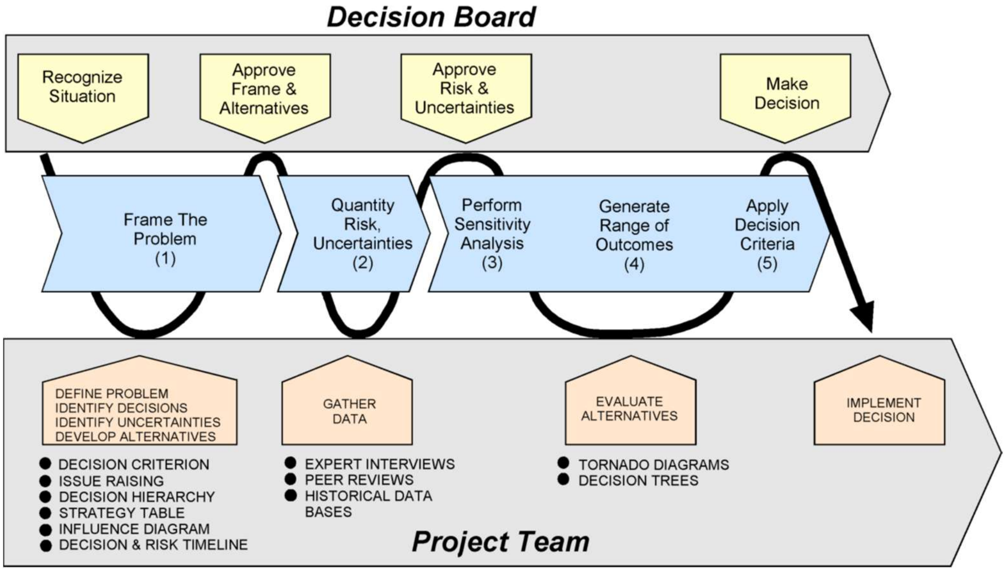


Figure 11 - Decision & Risk Analysis process, according to ConocoPhillips (2000)

7.5 IMPORTANT STEPS DURING THE MODELLING AND DA PROCESS

In geothermal asset evaluation as well as in oil and gas E&P, when designing the project evaluation process, the important steps are given below. Note that these steps are decision-driven and, hence, follow the Decision Analysis (DA) process.

1. Establish the appropriate decision level. Ascertain whether the decision under study could influence the company's higher decision levels significantly (notably, the portfolio of projects). As a function of the decision level (see figure), different modelling steps, functions and input values may be applicable.

2. Given the decision level, frame the problem, i.e. select the main scenarios that define the decision tree.

3. Establish the relations between the scenarios. If possible, establish exclusion rules (e.g. a strong aquifer drive scenario may be mutually exclusive with a water injection development scenario).

4. For each scenario, select the applicable model or models.

5. For each model, select the applicable variables (parameters) and select the constants.

6. For each variable (parameter) determine the valid numerical range or, in probabilistic modelling, determine the a priori probability density function (pdf) of the parameter.

7. In probabilistic modelling, establish the statistical correlations (dependencies) between all input parameters on the one hand, and between all scenarios on the other hand. For the input parameters this will determine how they are jointly sampled from their individual a priori pdf's. Note that the statistical correlations depend on the aggregation level of the parameter (e.g. the correlation between porosity and permeability on a core-plug scale is unequal to the correlation on a simulation model grid-block scale, which again is unequal to the correlation on a region-average scale, etc.).

8. Determine the workflow. In probabilistic modelling one needs to describe how to concatenate the applicable stochastic models to obtain the pdf's of the relevant Key Performance Indicators. As part of the workflow, one must decide whether to use parameter estimation techniques (i.e. inverse modelling). One should be aware that the position and shape of the KPI-pdf may be workflow-dependent.

9. Generate a range of outcomes by processing the applicable model(s); establish the pdf of the KPI(s).

10. Perform a sensitivity analysis, establish the parameters and conditions that have a significant impact on the position and shape of the KPI-pdf.

11. Select the applicable utility function (which again is a function of a corporation's constraints, financial structure, relations with banks and shareholders, etc.)

12. Finally, apply the selected decision criteria and rank the different opportunities.

Subsequent to the implementation of the decisions, the further steps in the Decision & Risk Analysis procedure are:

1. Do business, monitor and report performance
2. Analyse the business performance in terms of KPIs. Analyse / update the factors having a significant impact on the KPIs, and re-calibrate their relations. (In order to be able to act swiftly on changing KPIs, the main factors and their influence on the value of assets and portfolios need to be monitored diligently. In this way it is possible to exercise timely the available options as foreseen).
3. Acquire new data, if opportune. This should allow the company to mitigate the downside.
4. Exercise options, if opportune. This should allow the company to grasp the upside.
5. Re-define / update scenarios, options, actions and strategy for different outcomes. Update decision tree, i.e. both the tree's structure and the probability values at the chance nodes. When opportune, use updated forward models and updated constraints. Close loop and go back to step 1 above.

7.6 IMPORTANT STEPS DURING THE PROJECT MATURATION PROCESS

As discussed earlier, the capital budgeting process will commit capital not earlier than strictly necessary. The reason is that new information can be expected in time, uncertainties will gradually be reduced, and the capital budgeting process can be adapted accordingly. One crucial type of information is the Government information, especially that information that influences the licensing process. At various governmental levels (national, state, provincial, municipal, etc.) licenses will have to be obtained for the different activities planned by the company. In Figure 12 below, a schematic, simplified overview is given on how the company's project maturation process and asset life-cycle depend on decisions to be made by the various authorities.

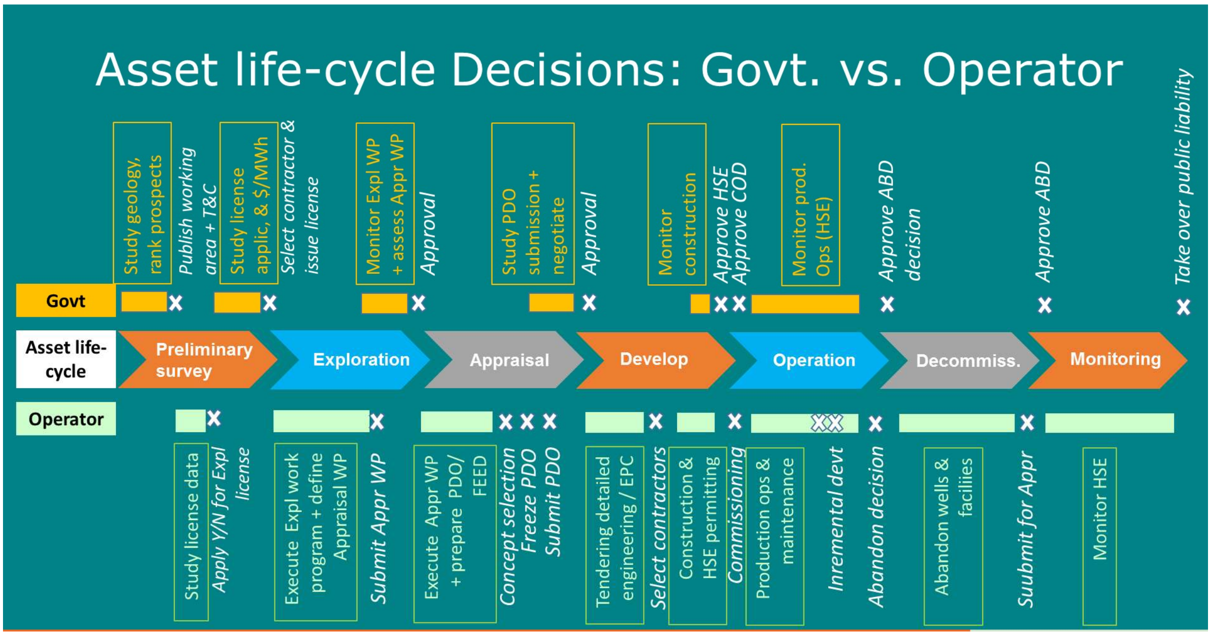


Figure 12 - Company decision-making depends on the country's licensing authorities

8 SENSITIVITY ANALYSIS

8.1 TREATMENT OF UNCERTAINTY

Typically, the economic evaluation process described above is done using a deterministic approach, whereby either the 50/50 percentiles or the mean values of the input parameters are supplied as single numbers to the calculation model. However, as virtually all input parameters, technical and commercial, are uncertain, the only thing one can be certain of is that such deterministically assumed value will be wrong! Therefore techniques have been developed to show the impact of the variation of input parameters so than one can concentrate on those uncertainties that have the biggest impact on the forecasted NPV and the decisions to be made. Once the high impact parameters are known, the parameters of lesser importance can be frozen in order to simplify the multi-parameter statistical process.

8.1.1 Single parameter variations

In a process called "univariate sensitivity analysis" the economist varies the input parameters one by one relative to base case, in order to answer 'what if …' questions of the type "What happens if the reserves are 25% larger?", or "What happens with a capex overrun of 30%?". As the list of potential questions is endless, the results of a sensitivity analysis are often presented as '*spider diagrams*' (see Figure 13), whereby the economic result (NPV, IRR or PIR) is plotted against the percentage change in the input parameter.

The steep 'legs' of the spider relate to those parameters whereby a small change will have a relatively large effect (i.e. the outcome is highly sensitive to that parameter). If moreover the uncertainty range of such a parameter is large, it will be a critical parameter for the success of the project. *It is therefore crucial to obtain a quantitative view for the statistical range of the input parameters*.

Typically the Decision Analyst will ask for a set of percentiles for these parameters, e.g. the 90/10 and the 10/90 percentiles and use these as end-points for the legs in the spider diagram. The centre point of the spider should in principle represent either the 50/50 percentile or the mean of all parameters, but mostly the centre point represents the 'base case' of the project, which has no quantitative probabilistic definition as it has been defined using the deterministic approach, rather than the probabilistic approach.

From the example spider diagram of Figure 13 below (from an oil upstream case), we note that the reserves represent the largest upside, but capex overruns and low prices or reserves present serious downsides. Opex variations do not appear to be a serious threat. The tax sensitivity is a steep line, but the anticipated range is relatively small.

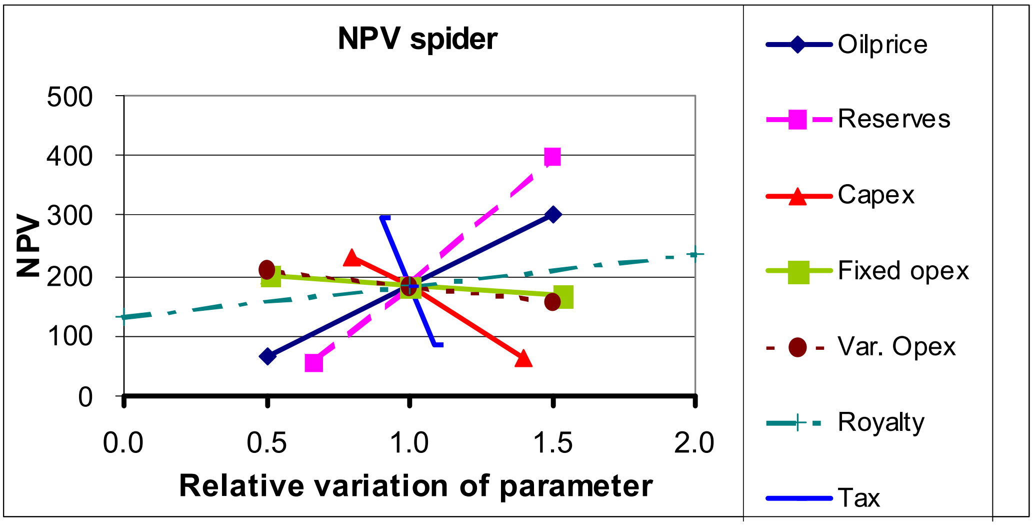


Figure 13 - Spider plot

An alternative way to present this information is the 'Tornado Plot', whereby the sensitivities are presented as (horizontal) bar diagrams, with the parameters ranked according to the magnitude of their effect. The parameter with the largest impact is put on top, which gives the resulting picture the shape of a tornado. This presentation is most effective to select the most important parameters for further study, and to identify which less sensitive parameters can be frozen in the next step of the statistical analysis.

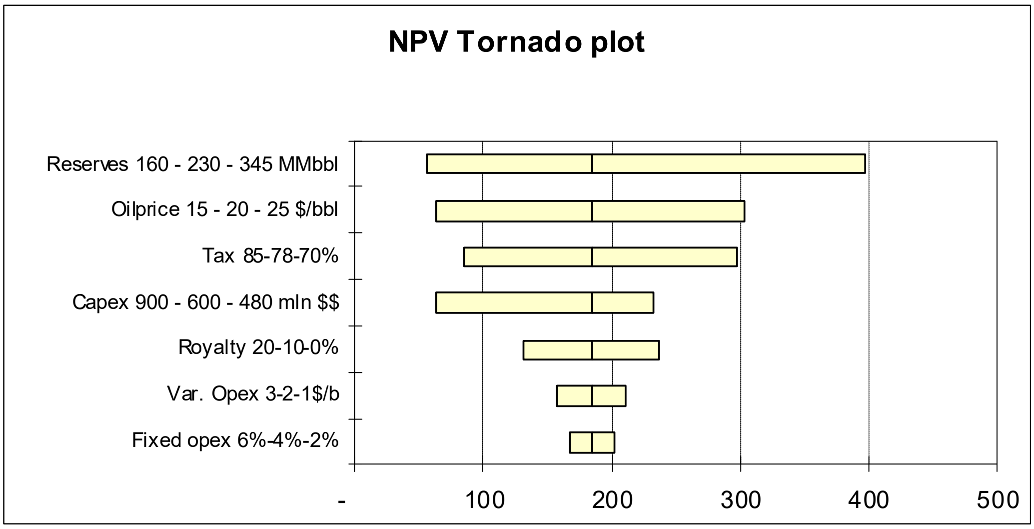


Figure 14 - Tornado plot

8.1.2 Multi-parameter variations

Having identified the critical parameters for the statistical analysis a full scale, multi-parameter statistical analysis can be made. Monte Carlo routines such as Crystal Ball and @RISK are available as 'add-ins' for spreadsheet programmes like Excel, which perform such analysis satisfactorily. In this type of analysis, the cashflow calculation is repeated many times (e.g. 1000 x) with different sets of input parameters, of which the statistical distributions satisfy a user specified input.

Use can be made of different type of distributions, like normal, lognormal, uniform, triangular, Poisson, Beta etc. Also, stochastic correlations can be defined between the various uncertain parameters. Note that through the Monte Carlo sampling process, stochastic correlations can significantly influence the KPI-statistics and that these correlations should therefore be seen as *formal knowledge*, to be diligently updated as more information is gained by the company. An example of a Crystal Ball output is shown in Figure 15 below. In this example, positive stochastic correlations have been assumed between the reserves and the capex and between the tax rate and the oil price. The latter correlation has been observed in previous periods in many fiscal systems around the world. Note however that if a deterministic relationship exists between one or more variables, it would in principle always be better to model this directly in the spreadsheet's equations, rather than correlating these variables through stochastic correlations thereby influencing the Monte Carlo sampling process. Only if deterministic relationships between variables are unknown, or cannot be established, should one resort to stochastic correlations.

8.2 MONTE CARLO EXAMPLE

The assumptions of the following Monte Carlo example are quite typical for E&P economic input distributions. They will probably also hold for geothermal evaluations.

Parameter	Distribution	Correlations
Reserves	Lognormal	
Capex	Skewed triangular	positive with reserves
Fixed opex	Uniform	
Variable opex	Uniform	
Oil price	Normal	
Tax rate	Normal	positive with oil price

The correlations used in the analysis reduce the impact of capex and reserves variations and strengthen the impact of oil prices and the associated tax rate. The resulting distribution curve (Figure 15 below), based on 1000 iterations, shows the typical ‘raggedness’, which disappears when more iterations are done and/or when cumulative distributions are used instead. The ‘*reverse cumulative distribution function*’ (1-cdf), see Figure 16 and Figure 17, is also known as *expectation curve*, which is eminently suited to read the distribution’s ‘*percentiles*’ (i.e. *y* probability to have a KPI of more than *x*). These can also be output directly from the Monte Carlo software.

The NPV distribution shows that there is a 5.2% probability that the 10% NPV will be negative under the assumptions used; on the other hand NPV’s in excess of $300 mln cannot be excluded.

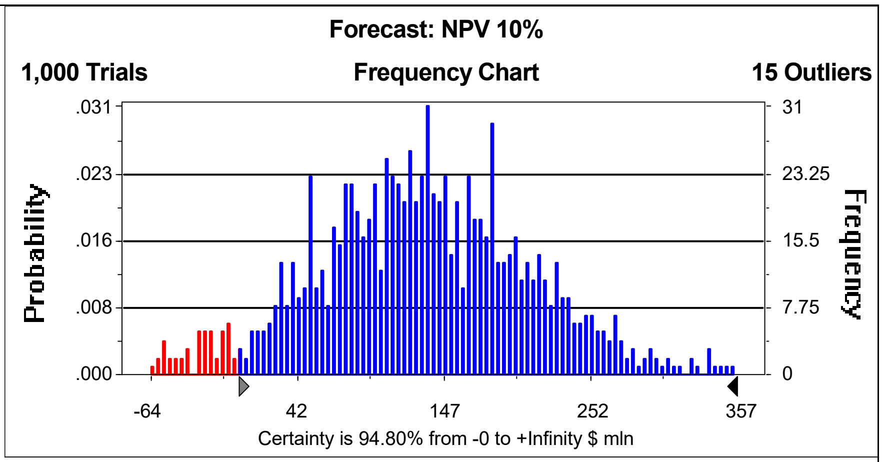


Figure 15 - Output histogram of NPV

Management often use the expectation curve to judge the probabilities that a project fails to meet the expectations. If that is considered to be a serious concern, spiders or tornados can be used to see the causes these failures and remedial action can possibly be taken to limit the downsides or enhance the upsides of the project.

The expectation curve for IRR indicates a range between 6% and 29%. There is a 31% probability that the IRR will be less than 15%, an important message for companies with this IRR yardstick.

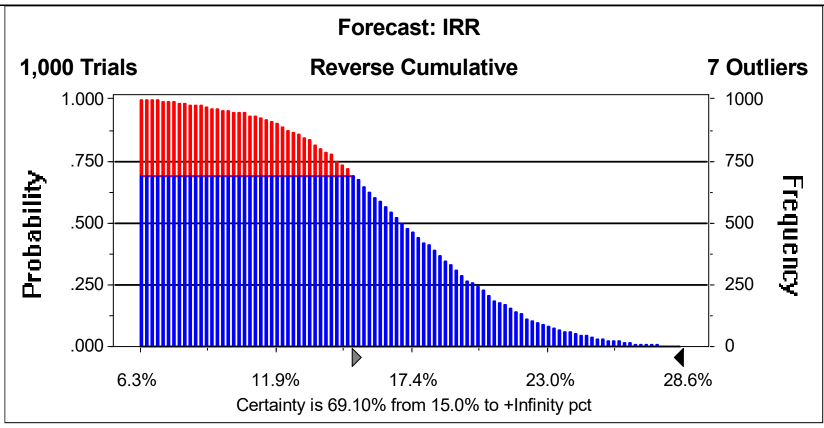


Figure 16 - Output expectation curve of IRR

Note that capex and opex can also be positively correlated with the oil price as evidenced by Figure 18 below: if the oil price goes up (2000-2008), the Upstream Capital Cost Index (UCCI[20]) goes up, although with a time-lag. And if the oil price goes down (2008-2009), the UCCI goes down. A similar observation can be made on the Upstream Operating Cost Index (UOCI). Modelling such information in the spreadsheet models can be highly valuable, since typically various oil price assumptions have to made to understand the sensitivity of the KPIs to the oil price. Using a direct relationship between oil price and capex/opex cost escalators can change one's assessment of an investment opportunity. This knowledge could even be valuable in case of geothermal projects with fixed electricity prices such as in Indonesia, as drilling capex and power plant capex may well be correlated to the international oil price.

The expectation curve for PIR extends between –12% and 65%.

For companies with a 20% PIR yardstick, there is a 42% chance that this would not be met.

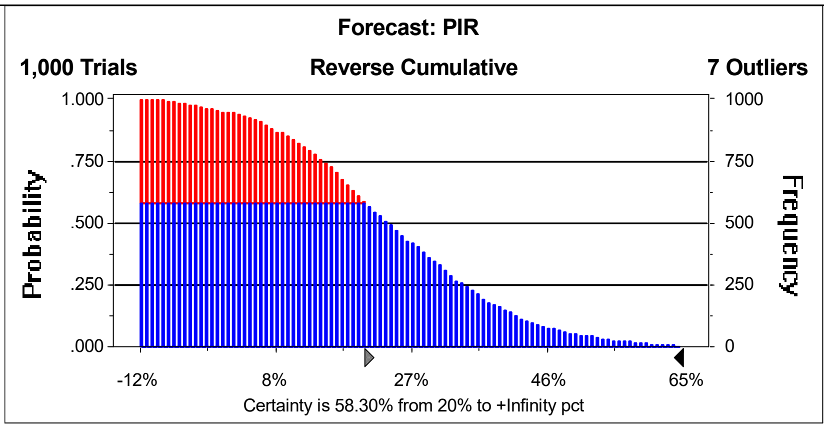


Figure 17 - Output expectation curve of PIR

[20] See IHS / CERA for the details on the various cost indices in the oil and gas and chemical industries. Note that the graph would need to be updated with 2010-2015 data.

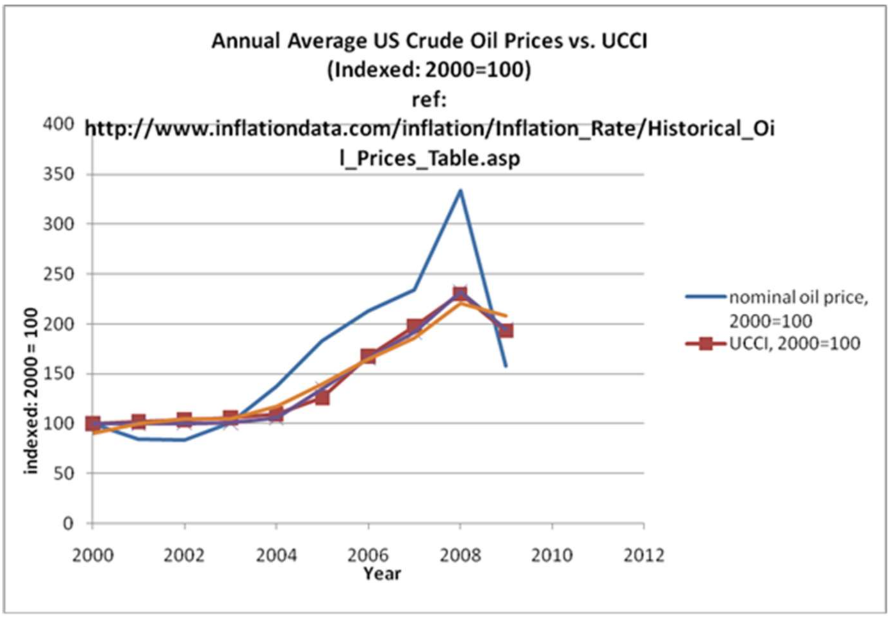


Figure 18 - Positive stochastic correlation between UCCI capex index and oil price

9 PROJECT SCREENING AND RANKING

9.1 COMPARING ALTERNATIVE PROJECTS / PROJECT DEFINITIONS

Project screening means verifying that the predicted (i.e. estimated) economic performance of a project is likely to pass a prescribed threshold or 'hurdle' (acceptance criterion). One common screening tool in project economics is the RROR[21], and the hurdle rate should be set at a level which covers the cost of capital plus an allowance for risk (both in the specific project and in the oil and gas E&P business). For example, if the hurdle rate for the RROR is set at 20%, then a project whose RROR is calculated at 28% clears this screening procedure by a healthy margin. As discussed earlier, this is not the only screening tool used.

With unlimited resources, the investor would take on all projects that meet the screening criteria. Project ranking is necessary to optimize the portfolio of projects when the investor's resources are limited and not all projects can be selected due to one or more corporate constraints (cash, manpower, etc.).

[21] RROR = Real-terms Rate of Return. This is identical to the IRR (Internal Rate of Return) or ROR (Rate of Return) assuming that all cash has been indexed to inflation so as to obtain the same purchasing power in each year.

Once the proposed projects are shown to pass the screening rate, then it is recommended that they be ranked on the basis of the NPV (i.e. in case of a deterministic analysis, in case of a probabilistic analysis this would be the EMV = Expected Monetary Value = the mean of the NPV-distribution), using a discount rate which represents the cost of capital to the investor (since this gives the true value of the project).

It is not necessarily true that the project with the higher earning power (IRR or RROR) has the higher NPV at the appropriate discount rate (i.e. that representing the cost of capital). Once again the PV Profile can be used to show that the decision will depend upon the cost of capital. In Figure 19 below, Proposal 2 has a higher RROR than Proposal 1. However, at a cost of capital of less than 18% Proposal 1 is preferred. At cost of capital greater than 18% proposal 2 is preferred.

The above method is ranking on value only. In making completely informed decisions, other constraints are to be taken into account, for example:

- maximum exposure
- production limitations
- manpower constraints

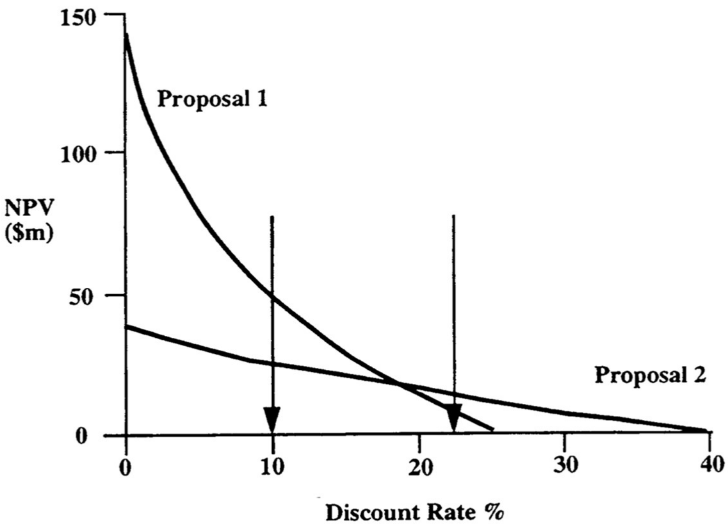


Figure 19 - Comparing two projects at different discount rates

To compare proposals where the maximum exposure is a constraint, the Profit to Investment Ratio (PIR) and its exposure-based equivalent PI_e are useful. When the company is production-constrained or manpower-constrained, ratios such as *profit per MWh* are useful (NPV / PV production) for ranking the alternative investment opportunities.

When performing the sensitivity analysis (SA), the economic indicator which should be considered is the true value of the project, i.e. the NPV at the discount rate which represents the cost of capital, say 10%. The result of the SA may be represented in tabular form or graphically. As already discussed in section 8.1.1, a useful graphical representation is a plot of the change in NPV (@10%, ref. yr) against the % change in the parameter being varied (see Figure 20 below). The plot immediately shows which of the parameters the 10% NPV is most sensitive to: the one with the steepest slope. Consequently the variables can be ranked in order of their relative impact.

This form of presentation also provides some insight into trade-offs in parameters. For example, it can be seen that compared to the base case (giving an NPV at the point where all the lines cross the variation axis at 0%) the equivalent reduction of NPV is brought about by either a 20% increase in capex or a 60% increase in the fixed opex.

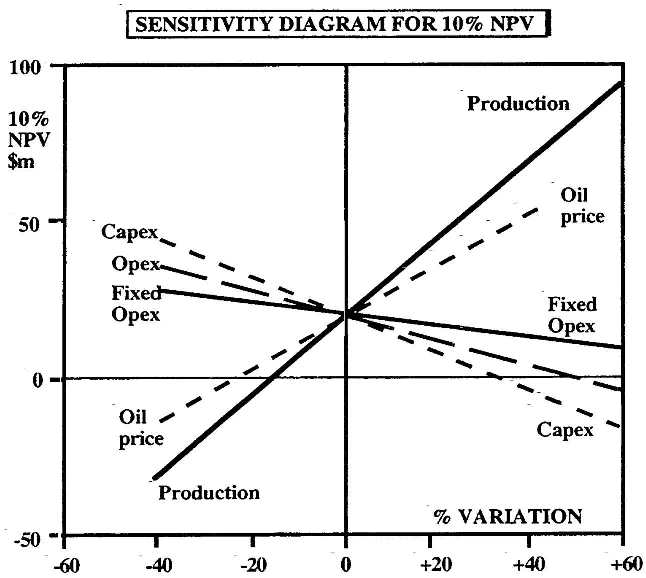


Figure 20 - Deterministic spider diagram for NPV

In other words, this indicates that the project capex could be increased by 20% if it leads to a 60% reduction in fixed opex. Alternatively, also reading from the plot, one could afford to spend 20% more capex if it provided an increase in production by 8%. Geothermal investments may well have such trade-offs, for example mobile wellhead steam turbines vs. centralized scaled-up steam turbines. Capex and opex are significantly different for these alternative solutions. If the company is cash-constrained, then one could also opt for lower capex + higher opex, as this may relieve the cash position of the company.

This type of analysis is called **project optimization**, and is used to establish trade-offs between the cost and benefit of say increasing capex to reduce opex or increase production.

Sensitivity analysis is not restricted only to the technical and economic parameters mentioned, but also to the potential impact of a changing business environment, which is usually outside the control of the company. **Scenario planning** involves forecasting a set of different future political, social and economic situations, and using these to test the robustness of a project or even of a company strategy (i.e. a set of targets and constraints for the company's portfolio performance). It is not the intention of scenario planning to predict the probability with which any of the scenarios may occur, but rather to provide a selection of 'backdrops' against which proposals may be set. Such backdrops can be translated into a *consistent set* of macro-economic time-series, such as inflation, $/€ exchange rate, oil price, gas price, CO_2 emission price, electricity price, coal price, steel price, labour cost index, etc. These time-series are then input into the economic evaluations of the project.

Given these sets of exogenous, non-controllable variables, the project's *resilience* or *robustness* against such scenarios can be tested (**resilience testing**). For a company managing a portfolio of assets, it is important that it arranges these assets such that in the least favourable scenario the company survives, and that in the most favourable scenario it is positioned to take advantage of the situation.

9.2 PORTFOLIO EFFECTS

As discussed earlier in section 2.6 (Modern Portfolio Theory (MPT)) and section 6.3 (Portfolio indicators), a project is in principle never (or seldom) to be assessed as a stand-alone activity. The project is generally executed within the context of the company's activities, consisting of a variety of other projects (assets). Therefore, the optimization problem of project / asset selection should be reformulated for the portfolio level. Consider the following: at the project stand-alone level, the time-domain is implicit, hence not explicit, as all KPIs are expressed in terms of Present Value. Project selection can therefore be formulated as a scalar[22], constrained-optimization problem. When

[22] Wikipedia: A *scalar* is an element of a field which is used to define a *vector* space. Scalars in physics are usually real numbers, or any quantity that can be measured using a single real number, such as temperature,

evaluating a project at the portfolio level, however, time should be modelled explicitly to assess the projects' *interactions in time* and obtain insight in the company's portfolio performance in time. Therefore, the time-domain should be brought back into the evaluation. The project selection process is therefore improved if it is formulated as a vector[23], constrained-optimization problem. From a set of projects / assets, the challenge is to select those assets that offer 'best' performance in terms of NPV, cashflow, reserves maturation, production constraints, development constraints, etc. The solution is then to perform an 'optimization in the time-domain', although this is an oxymoron since a vector, by principle, cannot be optimized.

Nevertheless, for all pertinent variables at the portfolio level, one can in principle compute the portfolio's performance with and without the project considered. And when done probabilistically, and when assuming a target level for 'optimization'-KPIs and a constraint level for 'hurdle'-KPIs, this can even be done by computing the probability vs. time of meeting some target / not-meeting some constraint. An example is shown above in Figure 21 below[24], where the probabilities vs. time of meeting / not-meeting various targets and constraints, with the new project (green line) and without the new project (blue line), is computed for the total portfolio.

length, and mass, and is usually said to have magnitude but no direction. A quantity described by multiple scalars, such as having both direction and magnitude, is called a *vector*.

[23] A *time-series* can be regarded as a *vector*, where the direction-domain has been substituted by the time-domain.

[24] Ref. SPE 68576 (Howell, Tyler): Using Portfolio Analysis to Develop Corporate Strategy

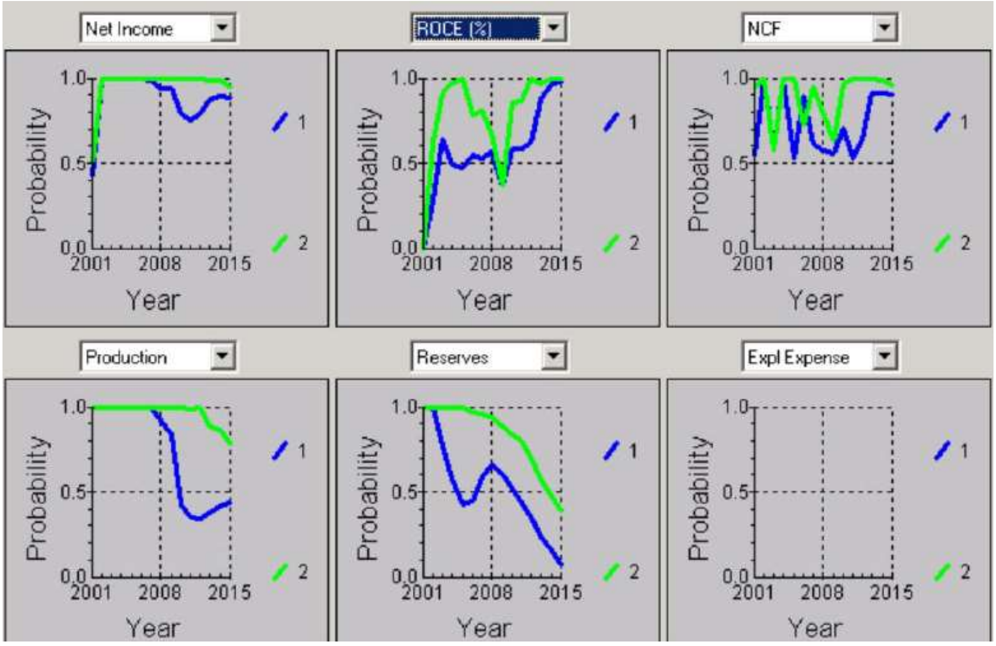


Figure 21 - Probabilistic portfolio performance vs. time (ref. Howell & Tyler, SPE68576)

Having such methodology can be extremely valuable for portfolio analysts / decision analysts, as it allows them to plan and tune new projects in a comprehensive, deeply insightful way. By tuning certain controllable variables, for example when to phase in & phase out new projects, the analysts can ascertain that the probability of meeting some portfolio targets / not-meeting some portfolio constraints is 'acceptable' at all times, especially in the near-future. Also, if targets or constraints seem unrealistic, the corporate strategy may have to be adjusted to obtain a more balanced set of projected portfolio performance indicators.

When combined with the Efficient Frontier method (see section 2.6 and Figure 4 - Modern Portfolio Theory: efficient frontier), a powerful combination of methods can be applied to study the impact of a new project on the company's future performance.

10 DECISION-MAKING UNDER RISK

The decision making process uses both the DCF method and statistical techniques. Very few decisions are straightforward in the sense that the decision-maker knows intuitively, and with sufficient confidence, which option will yield the highest NPV and will add the most value to the portfolio. In most cases there will be prior uncertainties on how subtle changes in expected reserves, well productivities, costs, electricity prices, partnerships etc., including their interrelationships, will affect the value of the project. As those uncertainties are resolved in future time, there will be many instances where, based on prior decisions, new decisions will have to be made in the future, often by different people.

10.1 Decision trees

Today's decisions can only be made based on the currently available data, information, knowledge and methods/tools. When there are uncertainties, statistical methods are generally superior to deterministic methods and are to be preferred. These methods assume that the decisions by future managers will also use a rational process, similar to our own. This assumption is incorporated in the decision tree methodology. The structure of a decision tree is a diagram that progresses in time, usually from left to right or from to bottom, and that depicts decisions and the outcome of uncertain events in a structured way. Each decision leads to a set of possible scenarios and each uncertain event leads to a complete set of possible outcomes. Consider the case where a decision has to be made whether or not to install water injection (WI) facilities in a producing field. With WI-facilities one will be certain of pressure maintenance, thus ensuring a high recovery factor. Without WI-facilities one is dependent on the strength / replenishment of the aquifer for pressure maintenance in the reservoir: with a weak aquifer the reservoir pressure will decline and a significant amount of hot water / steam will be left behind in the reservoir as being non-recoverable.

10.2 Decision nodes

This simple decision tree (Figure 22 below) has only one decision node, i.e. a junction of lines where a decision has to be made. At the trunk of the tree one sees the decision of whether or not to install water injection facilities. In decision trees the decision nodes are often depicted as rectangles and the decision-analyst is supposed to propose the scenario with the highest commercial value.

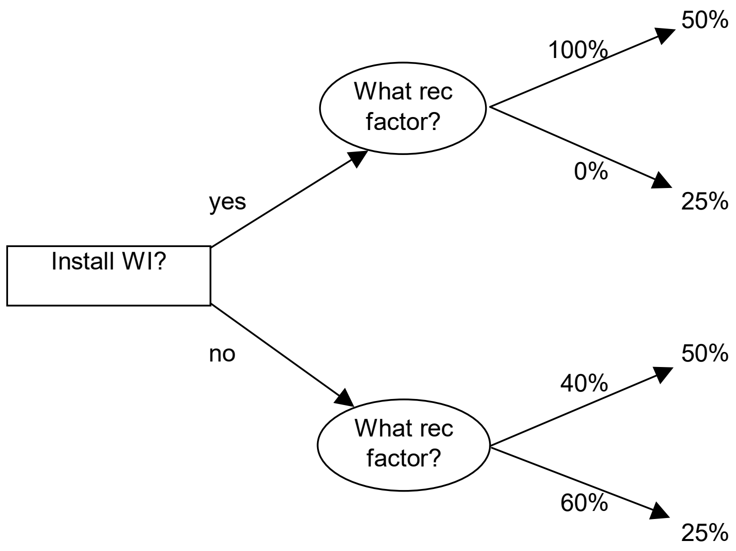


Figure 22 - Simple decision tree

10.3 Chance nodes

The example tree shows two chance nodes, one for each of the branches related to development scenarios. At a chance node, one has no possibility to influence the outcomes: one is dependent on nature (reserves, well productivity), or on third parties (government, partners, energy prices). In this example, it is assumed that one is solely dependent on the strength of the aquifer, which influences the recovery factor. In order to solve the decision tree one has to assign probabilities to all possible outcomes of chance nodes. The value of a particular chance node is the weighted average of all possible NPV-outcomes, also named the Expected Monetary Value (EMV).

10.4 Leaves

Our example tree has 4 possible branches and thus 4 possible outcomes: the 'leaves' of the tree. The leaves can be evaluated using the DCF method. In this simplified case, the NPV is the difference between the PV of the revenues and the costs. The PV revenues are higher in case of WI or a strong aquifer, and in case of WI the costs are obviously higher. In more realistic cases the NPV calculation will be more complex.

10.5 Rolling back the tree

In rolling back the tree (Figure 23 below), one starts at the leaves, and moves to the left. At the chance nodes, the weighted average NPV (i.e. the EMV) is taken, and at a decision node one selects the decision alternative with the highest EMV. Suppose that in the example, the WI case has a NPV (in this case = EMV) of \$200 mln, compared to an Expected Monetary Value (EMV) of \$300 mln without WI. Note also that, in case nature provides us with a strong aquifer, the project will have a value of $300 mln, unachievable under the WI scenario.

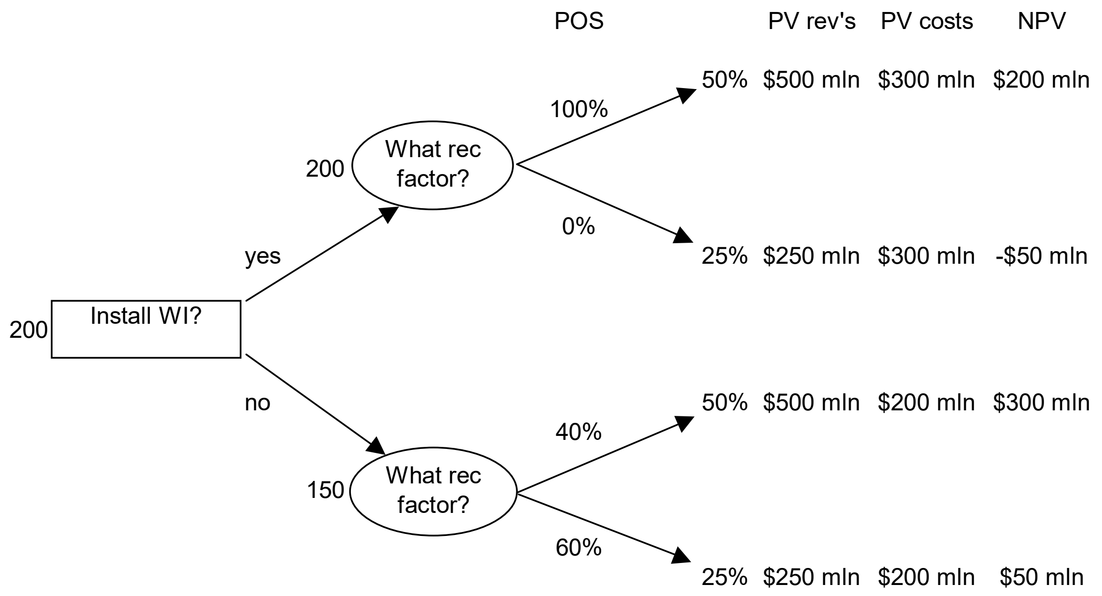


Figure 23 - Rolling back the tree

In practice, decision trees are often much more complex, with dependent ("contingent') decisions, with conditional probabilities (scenario probabilities depend on each other), and with Monte Carlo sampling / probabilistic computation in the leaves. Also, time-aspects (constraints, dependencies) can be complex and may be hard to model in a decision-tree. Moreover, probabilities are often hard to estimate. But then a sensitivity analysis can be made. This can be done as explained below:

Estimating the probabilities is often the difficult part of the decision tree method. For the key probabilities, it often helps to plot the outcome versus this key probability in order to find the probability where the decision changes. Then the important question for the decision-maker is whether the probability is smaller than 60%.

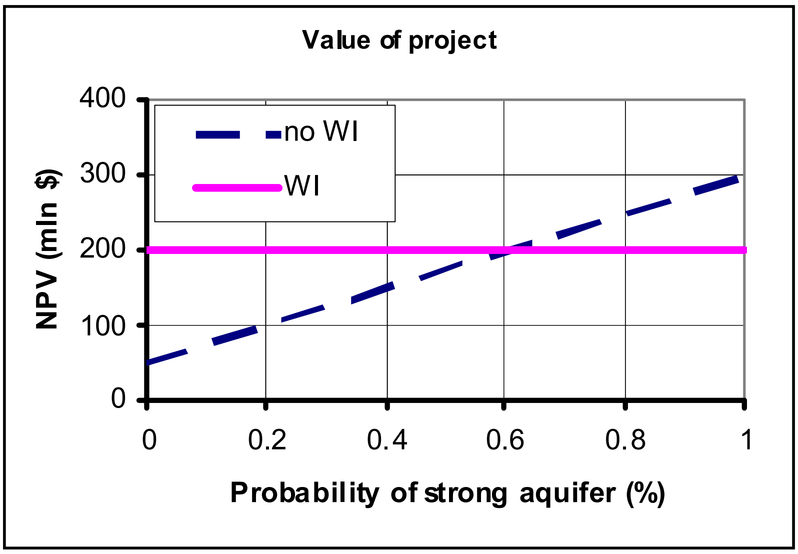


Figure 24 - Sensitivity analysis when a scenario-probability is poorly known

11 FLAWS IN THE TRADITIONAL NPV METHOD

Earlier in this document, we already discussed that the NPV discounted cashflow method is not fully comprehensive and, in principle, no more than a good first-pass approximation for optimizing a company's planning. Indeed, the NPV method is incomplete and simplistic, although in many cases it can be 'fit-for-purpose' (good enough). An often reported pitfall is that the method is flawed and tends to systematically undervalue investment opportunities. It is a static calculation that fails to consider the many options that management has over the life of an investment project. The accepted flaws with traditional NPV methods include:

1. NPV assumes that each investment decision is irreversible i.e. once management has made a decision, no change or response to future business conditions are possible. For example, the owner of a gas field and associated pipeline has the option to add compression and expand pipeline capacity should additional discoveries be made in the surrounding area. Traditional NPV calculations do not take account of this flexibility i.e. the right but not the obligation to expand.

2. NPV implicitly assumes that the risk increases at a constant rate over time. The concept of time diversification illustrates that risk may actually decline over time. For example, a 25-year-old is advised to commit a large proportion of his pension to the stock market. This is because over an extended period the stock market will provide higher returns than a fixed income investment. However, a 55-year-old is significantly nearer retirement and therefore should be more risk averse, conventional wisdom says he should put his pension fund in a fixed income, less risky, investment. For long-term investments there is a significant probability that periods of low returns will be followed by periods of high returns. Therefore in the case of the 25-year-old, due to the extended nature of the investment period, the risk is reduced because of this diversification effect.

3. A single discount rate is not appropriate to account for the changing risk in a project over time. Over the life of an asset the risk profile changes. For example, let's analyse the risks associated with a field that is currently under appraisal. At the start of any investment decision, oil (or electricity) prices are known, but they become more uncertain over time. Additionally, uncertainty surrounding the quantity of recoverable reserves is high at the start of the project, but will be reduced over time by additional drilling and reservoir performance monitoring.

4. Difficulty in determining the appropriate discount rate to be used for a project. The generally accepted convention is that all projects should be evaluated using the company's weighted average cost of capital. Unfortunately, this implies that all projects have the same level of risk as the company, which is clearly not the case (for example, compare a low risk pipeline investment in Western Europe with a high risk exploration opportunity in India).

12 CURRENT PRACTICE IN THE ANALOGOUS OIL&GAS E&P INDUSTRY

To remedy (part of) the flaws inherent in the NPV-method (see chapter 11), various modelling improvements can be made, sometimes implying a totally new paradigm (such as in Real Option Valuation, see also section 2.4.6). With reference to Figure 25 below (Taxonomy of methods for the valuation of uncertain, projected cash flows from individual projects)[25], and with reference to various international conferences, publications, etc., the 'typical' current practice in the E&P and other industries to evaluate uncertain cash flows from projects, as observed by the author, can be characterized as follows. Note that any generalization by definition is incomplete and does not honour the diversity and richness of the actual situation. Hence, any generalization is debatable. Nevertheless, it may provide insight about the current practice.

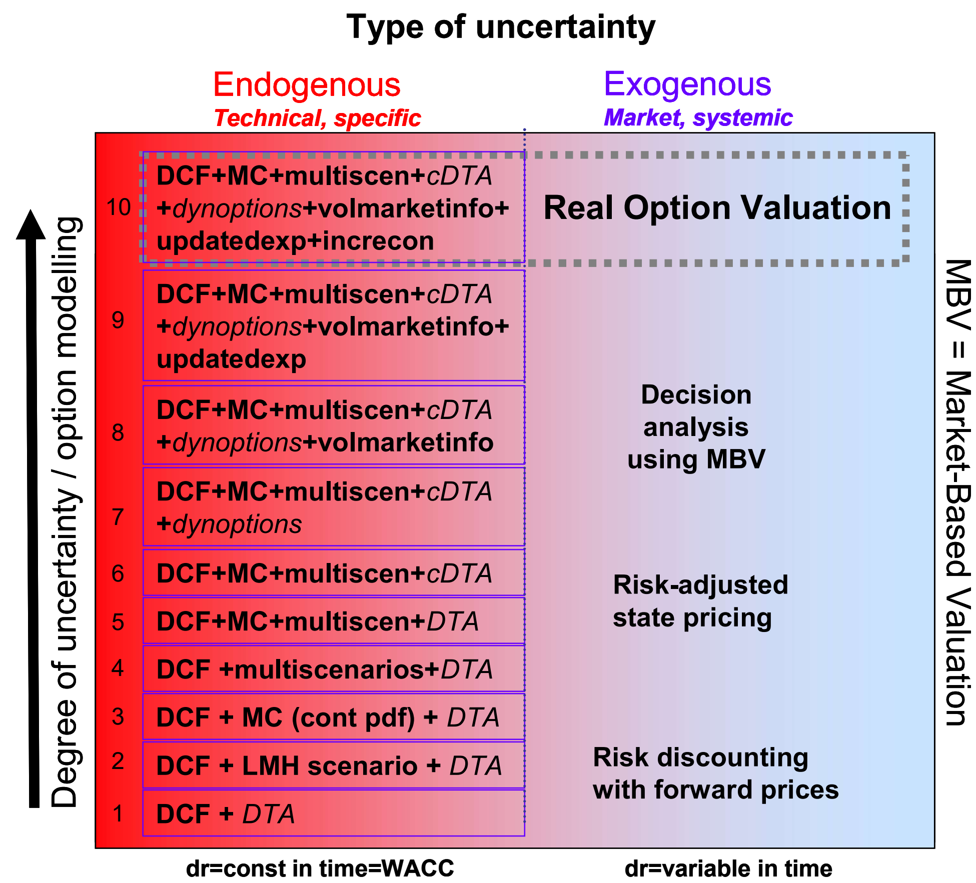


Figure 25 - Taxonomy of methods for the valuation of uncertain, projected cashflows from individual projects

MBV-methods use a discount rate that varies in time to account for the market risks reducing in time

[25] Note that the detailed description of the methods is given in a table at the end of this chapter.

Typical value proposition used:

- Maximizing a deterministic base case NPV, or EMV(mean NPV, i.e. in case of LMH[26]-scenarios, or multi-scenarios, or a stochastic IAM[27]), under some IRR constraint and under various univariate robustness tests; smaller companies may have a different utility function (e.g. minimizing pay-out time, or minimizing time to first production).
- Loose connection to portfolio, i.e. essentially a consistency check: if the project fits the constraints of the deterministic portfolio model it is accepted. If not the project is shifted in time to meet the portfolio constraints. No formal portfolio optimisation (i.e. using an objective function). Typically, the base case of individual project or asset forecasts are rolled-up deterministically without preserving the uncertainty relationships between projects.
- No clear connection to corporate financial targets such as ROACE, EPS, quality of earnings, etc.
- However, for technical corporate targets such as production, reserves, the connection is clear (although the potential errors when consolidating uncertain projected production rates and reserves are often ignored).

Value proposition typically not used:

- A formal measure for risk to rank projects
- A formal measure for risk tolerance to accept/reject projects, or improve project definition.
- Formal constraints for optimising NPV or EMV other than an IRR - sometimes VIR - hurdle rate (e.g. maximum exposure, pay-out time, UTC …).
- A formal process to include the value of optionality.
- A formal process to roll-up projects, including their uncertainties, to the portfolio level and optimise the portfolio (e.g. using Efficient Frontier analysis).
- A different treatment, for valuation purposes, of specific and systemic risk.

Typical methods used:

- In the above figure, Decision Tree Analysis (DTA) methods 2 and 4 would be typical, with sometimes underlying stochastic models (e.g. the reservoir geological model) having generated a number of "multi-scenarios". Most companies do not have IAMs, and if they do, the IAM is typically not run stochastically.
- Loose connection to portfolio optimisation: typically, the "optimised" project solution is consolidated deterministically to the portfolio level. The forecasts of the optimised project may take into account regional constraints (e.g. shared facilities). Portfolio considerations may feedback some further constraints to the project planning, e.g. by influencing the timing.
- Portfolio optimisation is typically the arithmetic sum of the individual deterministic project forecasts. Acceptable projects (IRR > hurdle) are typically prioritised according to their NPV or EMV (sometimes more weight is given to early production), and are shifted in time to meet certain portfolio constraints (cash constraints, production targets etc.).

[26] LMH: Low-Medium-High

[27] IAM: Integrated Asset Model

Typical problems quoted when discussing the current practice:

- Confusion among petroleum and facility engineers about which value definition to optimise, especially if risks, constraints, optionality, "unknown unknowns", train-wrecks and life-cycle and/or portfolio effects also need to be taken into account. A common complaint is the imprecision and volatility of the value proposition, especially the components in the value proposition dealing with uncertainty.
- Confusion about how to align project management goals ("within time, within budget") with asset life-cycle goals (EMV maximisation under some capital efficiency constraint, with EMV including the value from all managerial flexibility options to respond to the various uncertainties being resolved in time).
- Stakeholder alignment: partners, governments may seem to change the rules (i.e. their value proposition) during the game. A common critique is that stakeholders should be engaged and committed much earlier during the project definition / concept selection phase.
- Framing: as most problems seem to come from an inadequate framing process, it is generally felt that much more systematic effort should be put in defining and executing this process.

Typical resistance to formalise decision making as a constrained optimisation process with a more comprehensive objective function:

- KISS attitude (see definition in Glossary of terms), even the very basic Monte Carlo process for uncertainty modelling is sometimes "abhorred".
- Concern that decision support tools become a "black box".
- Lack of time to learn, to study and understand potential of improved decision analysis.
- Too little formalised mid-career learning.
- Universities/ technical universities are not targeted at breadth (systems thinking); we learn to go in-depth and have difficulty thinking laterally.
- Lack of management-pull.
- Decision makers have no time to understand these analytical techniques; they prefer to rely on their intuition as this is what brought them at their current position.
- But then also, apparently (sic!), lack of a compelling business case from the part of researchers, academia etc.
- "Too difficult to implement in our organisation" (despite the fact that others have succeeded).
- "We're just learning to walk, don't try to make us run, let alone fly".
- Engineers are forward looking. DA obtains its value largely from its potential to become a formalised learning process. Look-back / post-mortem analyses are not popular among engineers.
- Portfolio roll-up of stochastic IAMs is technically challenging; doubts prevail about whether one can succeed.

Methods addressing technical (+ market) uncertainties

For the methods addressing technical (+ market) uncertainties (red in the figure), the following breakdown can be given[28]. Note that acronyms referring to uncertainties are given in regular font, while acronyms referring to decisions (or managerial controls) are given in italics. Also note that decisions are always discrete (deterministic); decisions are never uncertain. Decisions are the controls to optimise the value of an asset or of a project[29] and represent a certain course of action.

Table – Description of Decision Tree valuation methods listed in the above figure

Nr	Method acronym	Description
1	DCF+*DTA*	Discounted Cash Flow analysis based on deterministic DCF forecasts without modelling uncertainty in the system parameters. Differences in assumptions (e.g. discount rate) may be varied, however. Simple Decision Tree Analysis (DTA) is used to compare alternative decisions (project definitions).
2	DCF+LMH scenario+*DTA*	DCF analysis based on three scenarios, i.e. three sets of deterministic values for a user-defined number of uncertain system parameters. The user needs to use his judgment to define sensible combinations of parameter values as low-medium-high cases, both if these parameters are correlated and uncorrelated. The problem, however, of not modelling the LMH scenarios stochastically, is that these scenarios are highly unlikely to be equiprobable (which in principle should be the objective of the modeller).
3	DCF+MC (cont pdf) +*DTA*	DCF with uncertain system parameters defined stochastically (as continuous probability density functions, pdf's) rather than deterministically. The Monte Carlo sampling process establishes the parameter value combinations to define "stochastic realisations". Stochastic correlations may be defined for the stochastic parameters.
4	DCF+multiscenarios+*DTA*	As in method 2, but rather than only three deterministic scenarios, a large number of deterministic scenarios are defined to define the "uncertainty space". No stochastic parameters are defined (no Monte Carlo). The deterministic scenarios may be defined using techniques such as Experimental Design.

[28] Note that the methods in red are basically decision tree methods that address both technical and market uncertainties. The blue methods in principle only address market uncertainties and use non-constant discount rates to take into account the risk being reduced as the project advances in time. Also note that the more advanced methods (8, 9, 10) may include dynamic options that respond to market uncertainty being revealed in time.

[29] Sometimes it is contended that e.g. the number of wells an asset will have is uncertain, as the well productivity and field size are uncertain. When comparing alternative decisions, *given the information available at that point in time*, all controllable actions should however be treated as *certain* courses of action.

5	DCF+MC+multiscenarios+*DTA*	Methods 3+4 combined, i.e. a combination of deterministic parameters, combined into multi-scenarios, with other parameters defined stochastically within each of these deterministic scenarios (MC = Monte Carlo). Modelling of "*total uncertainty*" (discrete + continuous uncertainty).
6	DCF+MC+multiscenarios+ *cDTA*	Further connecting the "uncertainty space" to the "decision space" by means of conditional-Decision Tree Analysis (cDTA). Conditional decisions are decisions that depend on one or more previous decisions (the outcome of which depends on the outcome of two or more deterministic scenarios). *Example*: *if* outcome of appraisal is EUR>100 MMbbl, construct 75 Mbpd topside, *else* 50 Mbpd topside. *Note that cDTA can also be used in methods 2,4,5.*
7	DCF+MC+multiscenario+ *cDTA+dynoptions*	As in method 6, but adding *dynamic options* to further model the managerial flexibility that one has in practice. Dynamic options are decisions that are triggered (or not triggered) as a function of the model's time-dependent output state variables. *Example*: *if* total field gas production capacity < target plateau, drill extra well; *else* do not drill. Dynamic options are not modelled in the decision tree, but are an integral part of the model itself. The model goes through the decision algorithm at each time-step (or at some user-defined frequency).
8	DCF+MC+multiscenario+ *cDTA+dynoptions*+ volmarketinfo	As in method 7, but adding time-domain volatility to the market (exogenous) information, such as volatile time-series for the oil price and, as a function of the volatile oil price, volatile cost escalators for various capex, opex items. Note that the triggers for the dynamic options modelled and assessed at each time-step, may be expanded to include market information. *Example*: *if* oil price > $85/bbl *and* drillex cost escalator has not caught up yet with this oil price level (due to time-lag) *and* gas production capacity < target plateau, drill extra well; *else* do not drill. *Other example*: *if* NCF has been <0 for last *n* years, *and* field is in decline / off-plateau, shut-in field & abandon after *x* years.
9	DCF+MC+multiscenario+*cDTA* +*dynoptions*+volmarketinfo+ updatedexp	As in method 8, but adding "updated expectations", that are *conditional on* the current (and/or past) value(s) for certain market variables (e.g. oil price). *Example*: *if* NCF has been <0 for last *n* years, *and* field is in decline / off-plateau, *and* expected oil price of next 5 years < $75/bbl *given* current oil price, shut-in field & abandon after *x* years.
10	DCF+MC+multiscen+c*DTA*+ *dynoptions*+volmarketinfo+ updatedexp+increcon	As in method 9, but adding "incremental economics" as the trigger for striking a dynamic option. *Example*: *if* gas field is in decline / off-plateau, *and* all well

		slots are in use *and* □NPV of compression < 0 *given* expected gas price of next *y* years *given* current gas price, shut-in field & abandon after *x* years. This method could be even expanded to include "probabilistic incremental economics": *if* gas field is in decline / off-plateau, *and* all well slots are in use *and* ΔEMV of compression < 0 *given* expected gas price range of next *y* years *given* current gas price, shut-in field & abandon after *x* years.

In principle, all these methods use the corporate WACC as the project discount rate[30], since project-specific risks should not be implied in the discount rate: project-specific risks are calculated explicitly (i.e. using the various KPI-histograms as output by the model) and compared to a user-defined risk-tolerance measure that acts as a formal optimisation constraint. Such approach may be helpful to mitigate and/or diversify away technical risks. Risk can be defined in many ways, e.g. as[31]:

$$\text{Project Risk} = \int_{-\infty}^{\text{WACC}} \text{IRR} \times \text{pdf(IRR)}.\text{d}(\text{IRR}), \textit{ or as}$$

$$\text{Project Risk} = \int_{-\infty}^{0} \text{NPV} \times \text{pdf(NPV)}.\text{d}(\text{NPV})$$

This measure can be simply calculated given the KPI-histogram as output by the probabilistic (Monte Carlo) IAM. The above integrals seem more meaningful than using the traditional standard deviation of the KPI-histogram as risk metric. This is because in such integral formulation risk pertains to the truly undesired consequence, viz. an IRR<WACC[32] and a NPV<0, respectively. In case of using the histogram's standard deviation as a risk metric, i.e. the more conventional approach for defining risk, then also desired outcomes could be penalised[33].

[30] If a project is not financed from the corporate balance sheet, a different cost of capital may apply.

[31] Note that in the case of IRR-risk, the IRR is not defined if the NPV<0. A possible way to resolve this is to set IRR=0 if NPV<0. IRR-risk may also be defined by some higher upper boundary for the integral: WACC+ to include a minimum required mark-up for capital efficiency.

[32] To include a profit margin, obviously a higher boundary condition may be specified: WACC+.

[33] Using the standard deviation as a risk metric is a measure for *uncertainty*, not necessarily for *risk*. The two should not be confused.

A risk tolerance measure can then be specified as an acceptance/rejection criterion. Where systemic uncertainties are higher (e.g. in politically unstable countries), this risk tolerance can be set higher.

Market-based valuation methods

Market-based valuation methods (MBV) are not necessarily based on DCF analysis. They will use a variable discount rate to take into account the gradual reduction of systemic risk as a project moves closer to its end: systemic risk is initially high, and as sunk costs become history, the remaining cashflow is subject to gradually decreasing systemic risk.

The problem of valuation can be approached in three ways, viz. Market-based approach, Income-based approach, and Cost-based approach. It was explained that the income-based approach best fits the E&P project decision-making process and that, hence, this approach in principle is the way to do decision analysis in E&P. A potentially interesting exception here is Real Option Valuation (ROV), a method to value managerial flexibility options that can be struck in response to market (not technical) information being revealed in time. For example, Proved Undeveloped Reserves being upgraded very fast to Proved Developed Reserves if the oil price comes above a certain threshold level, and before the capex/opex escalators have caught up with the higher oil price.

Real options can be valuated using the Black & Scholes option pricing formula, or with Binomial lattices. Reference is made to the literature.

13 BANKABILITY OF (GEOTHERMAL) PROJECTS

13.1 INTRODUCTION

New investments (capital expenditure or 'capex') need to be financed[34]. In principle, if the company cannot mobilize sufficient capital from internal resources, the capital can be obtained on the capital markets in a number of ways, e.g. 1) Equity (share) capital; 2) Loan capital; 3) Project financing; 4) Development Bank financing. From the loan-taker's point of view, all have their advantages and disadvantages. In many cases, a private company will opt for loan capital, as this is typically less expensive than equity capital and project capital. Moreover, the existing private and institutional shareholders often prefer not to dilute their equity with new shares. In case of a 100% Government-owned national company, a loan would be the only option, i.e. if the Government's objective is to remain the only shareholder. Loans by commercial banks require adequate collateral. However, if a (private or national) company does not have adequate collateral from its existing portfolio of assets, or the company's overall track record (i.e. its historical economic performance) is not adequate to give sufficient security to banks, *project financing* may provide a solution.

Typically, projects that are financed by *bank loans* (rather than floating new share capital) will have to satisfy a great deal of conditions as stipulated by the loan-provider (i.e. the bank). In case of loan capital, the loan is consolidated with the company's corporate balance sheet and the total company provides the collateral for the loan. But if *project financing* is opted for, then the project itself, rather than the total company owning the project, provides the collateral. Typically, this requires a great deal of direct bank involvement, typically more than loans that are consolidated with the company's corporate balance sheet. The fourth option is a loan from a *Development Bank*, which may provide 'soft loans', such as from the World Bank (WB) with, typically, lower costs (i.e. interest rate etc.) as compared to commercial banks. However, more severe terms and conditions related to managing the project and direct bank involvement would typically apply. From a recent example of a World Bank[35] loan to the Government of

[34] Depending on the forecast total cashflow of the project, early operating expenditure ('opex') may also need to be financed by banks.

[35] Ref: PAD DATA SHEET, Indonesia, Geothermal Clean Energy Investment Project (Total Project Development in Ulubelu Units 3 & 4 and Lahendong Units 5 & 6). *PROJECT APPRAISAL DOCUMENT* East Asia and Pacific Region, Indonesia Sustainable Development Unit (EASIS), Sustainable Development Department

Indonesia to a finance a number of geothermal projects, we list a number of these terms and conditions in the following section.

13.2 WB TERMS AND CONDITIONS FOR LOANS TO GEOTHERMAL PROJECTS

(See also footnote 35)

- Main conditions:
  - Approved project implementation plan, responsibilities of parent company with respect to subsidiary company receiving and managing the loan, interest rate + debt repayment schedule, company solvency, tendering process, accountancy standards + financial monitoring plan, HSSE&SR safeguards[36], dispute settlement, etc.
  - Consistency with WB's Country Partnership Strategy and overall WB objectives
- Description of strategic context to assess *country risk* and overcome hurdles
  - Country - description of political situation, political / social / economic stability, judgment of outlook for the country, outlook economic growth, sovereign debt, government budget, rating agencies' assessments of country risk, infrastructure status and outlook, etc.
  - Sectoral and institutional – applicable laws (e.g. electricity law, geothermal law), financial situation of national power company, monopolies, private companies active in sector, competition, track record /performance (reliability, costs, HSSE&SR), need for subsidies, vulnerability to international commodity prices, etc. Recent developments, investments, loans, needs for diversification (e.g. diversify from petroleum and coal to geothermal), ambitions of government vs. realization, etc. Institutional organization (state companies, Ministry, etc.), analysis of barriers that prevent the government's aspirations from being realized. In this particular case (footnote 35), the WB says:
    - Momentous investment needs higher than current capital availability.
    - Insufficient policy and regulatory support for implementing Geothermal Law.
    - Inadequate incentives and pricing mechanisms to achieve an acceptable risk / reward for investors.

[36] HSSE&SR = Health, Safety, Security, Environment & Social Responsibility

        - Limited institutional capability to properly plan geothermal development and sufficiently engage suitable developers.
            - Weak domestic capacity in the areas of resource assessment, equipment manufacturing, construction, and operation and maintenance of geothermal energy facilities.
    - The Government of Indonesia has requested the World Bank to provide assistance so as to overcome these hurdles. WB strategy: 1) policy reforms to enhance investment climate; 2) direct project / investment support.
- Project development objectives, beneficiaries, KPIs
    - Upon commissioning of the new installations, success criteria for assessing the results of the project could be, for example, installed MW capacity and GHGs & SOx & NOx emissions avoided.
- Project description
    - Description of finances involved + schedule for capex items, but also for costs such as staff capacity building. Loan maturity period, grace period, mark-up % on interest rate the parent company is allowed to charge to subsidiary company for managing the loan, etc.
- Project implementation
    - Ministries, government institutes, national companies, subsidiaries, project implementation unit, procurement departments, consultants, etc. involved + tasks and responsibilities.
    - Monitoring of project progress and HSSE-SR impacts
- Risk mitigation measures
    - Operational Risk Assessment Framework
    - Know-how required to manage WB loan
    - Finances required for risk mitigation measures
    - Final assessment of overall project risk.
- Appraisal
    - Financial and Economic analysis: lack of a predictable pricing policy, solvency of parent company, risk of making a loss on the project, accounting for externalities, etc.

- Technical analysis: GT-resource assessment, well potential, development plan, power station, grid connection, operational plan, project organization, project cost, detailed risk assessment, due diligence, project specs vs. industry standards.
- Financial management + capabilities of subsidiary and parent company executing the project, meeting WB-standards, auditing, dependencies (e.g. Parliamentary approval).
- Procurement: assessment of procurement capabilities vs. WB Guidelines.
- Social Safeguards: stakeholder analysis. Land purchase / expropriation, etc.
- Environmental safeguards: WB operational policy standards, H2S, international standards, HV-transmission lines, etc.

13.3 Discussion

The above World Bank terms and conditions are rather detailed, but typical for such 'soft loan' development projects. Indeed, 'due diligence' also implies that if the financial risks cannot be guaranteed by collateral, then the project's implementation and operations should meet a great deal of detailed conditions. A development bank such as the WB is specialized in this type of detailed financial arrangements, and in monitoring progress. If necessary, they have all the expertise to intervene and correct the project's execution mid-course.

Commercial banks would typically have a different approach and focus more on securing adequate collateral so as to monetize their claim in case the loan-taker defaults.

In the end, whether to go for a Development Bank loan, or for a Commercial Bank loan, is a management judgment and, in case of national companies, a governmental judgment. Commercial Bank loans would be typically more expensive (i.e. a higher interest rate), but easier to service the loan if the loan-taker has adequate solvency and expertise. Development Bank loans are less expensive, but involve a great deal of supervision and institution / capability building by the loan provider. For many development countries, however, the latter may be the only feasible option.

14 GLOSSARY OF TERMS

50/50 cost estimate	estimate with equal likelihood of overrun and under-run
accuracy	The degree to which the mean of an IAM output KPI-histogram matches the "truth", as observed by reality revealing itself in time. However, all controllable parameters (i.e. decisions, actions) changed in reality should be exactly replicated by the IAM to retro-actively test the accuracy.
base case	the set of values and conditions which are assumed to be the most likely
base year cost (BYC)	the cost of an item today (usually at the time of making the estimate, but anyway referred to a base year)
beta value (β)	used in the CAPM; the covariance of the stock value of the company with that of the market, reflecting relative volatility
break-even price	the oil or gas price required for the project to achieve a specified real rate of return
capital allowance	a fiscal allowance (or deductible) for investment in capital items, which can be offset against revenue
capital asset pricing model (CAPM)	a method of calculating the cost of capital which includes the historical performance of the company and the industry
capital expenditure (capex)	expenditure on capital items (those items with a lifetime of a number of years)
cash deficit	the annual amount by which expenditure exceeds revenue
cash surplus or **net cash flow**	the annual amount by which revenue exceeds expenditure
cashflow	an annual forecast of the project cash surplus/cash deficit

cDTA	Conditional-Decision Tree Analysis, i.e. including decisions that depend on the outcome of previous decisions.
chance node	point on a decision tree where multiple outcomes are possible
cost of capital	the cost of financing debt and shareholder's equity
cost oil	the payment for the cost of operations under a PSC
cost per barrel	the sum of capex plus opex per barrel of production
cumulative cash surplus or **field life net cashflow**	the cumulative amount of money accruing to the company at the end of the project
DA	Decision Analysis, a formal project evaluation process
DCF	Discounted Cash Flow
decision node	point describing a number of possible actions that are under the control of the company
decision tree analysis (DTA)	technique for assisting decision making, allowing many options (alternative courses of action) to be logically investigated and compared
discount factor	factor by which a future sum of money must be muitiplied to calculate its present value
discount rate	the effective interest rate used for calculating the present value (PV)
discounted cashflow (DCF)	a cashflow whose numbers are the present values of the undiscounted cashflow
discounting	a technique for calculating present values of future sums of money, which allows money spent at different times to be compared consistently.
dr	Discount rate (a parameter going into DCF analysis) to take into account the time-value of money and the systemic risks. Typically, the WACC is used as discount rate.

DRB	Decision Review Board, a board of E&P decision makers that, at the programmed “decision gates”, vets and coaches the analyses done by the “project team”.
DTA	Decision Tree Analysis, a graphical method to describe the logic between uncertain events and decisions.
economic lifetime	the point in time when the project cashflow turns permanently negative
EF	Efficient Frontier, a term from Modern Portfolio Theory. The EF is the locus on the portfolio’s Risk vs. Expected Return graph, where for a given Expected Return no portfolios can be established that have a lower Risk / where for a given Risk no portfolios can be established that have a higher Expected Return. The EF can only be established experimentally (i.e. by running many possible project-portfolios with a probabilistic portfolio model).
EPS	Earnings per share
expectation curve	a presentation of the cumulative probability of occurrence of a parameter (e.g. reserves); normally the expectation curve represents the probability of *exceeding* the indicated amount (1 – cumulative probability)
expectation value or **mean**	the probability-weighted average of the range of a parameter; sometimes this can be approximated by the arithmetic average of low, medium and high values from the expectation curve
expected monetary value (EMV)	the probability-weighted average of the range of NPVs of the project. For an exploration prospect : EMV = POS*unrisked NPV - (1-POS) * risk money
exposure based profitability index (PI_e)	ratio of the PV cash surplus to the PV maximum exposure
farming in/out	acquiring/disposing of an interest in a licence or venture
fiscal status	the status of the company or project for tax purposes
fiscal system	the prevailing system of taxation
fixed opex	that part of opex which is proportional to the capital cost

	of the items being operated
full year discounting	method of discounting, appropriate when payments are made in twelve month intervals (lump sums) relative to the reference date
general rate of inflation (GRI)	the inflation rate calculated from a major index
GIIP	gas initially in place (standard cubic feet, or billion m^3, normal or standard conditions)
half year discounting	method of discounting, appropriate when payments are spread evenly over the year relative to the reference date
host government take	the total of payments made to the government on behalf of the project
IAM	Integrated Asset Model. Same as T2B model. Input data (defined deterministically and/or stochastically) are processed by the IAM to compute KPIs that are used for decision making.
incremental project	a project which is an addition or modification to an existing project
inflation rate	percentage year-on-year change in a specified price index (e.g. retail price index – RPI, or the US Consumer Price Index - CPI)
IRR - internal rate of return	the discount rate which, when applied to a money of the day (MOD) cashflow, reduces the net present value (NPV) to zero
KISS	Keep It Simple Stupid, i.e. an attitude with both a positive and a negative connotation, but only too often used to hide one's laziness / intellectual boundaries / lack of time to study the potential value of improved analysis. Too often used as an alibi to stick to the current (simplistic) practice. The practitioner's propensity for simplicity is thus not critically reviewed for its impact on decision-making.
KPI	Key Performance Indicator, an output quantity of the IAM that can be used as decision-making criterion.
KPI – Key Performance Indicator	economic indicator that gives a quantitative value for (added) value of a project or investment proposal

LMH	Low-Medium-High, discrete scenarios defined to describe the uncertainty range of IAM input parameters.
market factor	factor used in escalating costs to reflect the fact that due to market conditions some items do not increase in price in line with inflation
maximum cash exposure	the most negative point on the cumulative cashflow
MBV	Market-Based Valuation, a term to describe valuation methods that focus on market uncertainties and commodity prices.
MC	Monte Carlo, a stochastic sampling process
MOD discount rate (r_{MOD})	the discount rate applied to an MOD cashflow $(1 + r_{MOD}) = (1 + r) * (1 + GRI)$
money of the day (MOD)	actual amount of money (e.g. notes) which change hands (MOD has a variable purchasing power over time)
national oil company (NOC)	the company representing the oil and gas interests of the host government
NCF	Net Cash Flow
net income	an accountant's term which incorporates depreciation; net income = cash surplus + capex - depreciation
net present value (NPV)	the ultimate present value of a discounted cashflow (also the total discounted cash surplus)
NPV	Net Present Value (a KPI resulting from DCF analysis)
operating expenditure (OPEX)	expenditure on non-capital items (services, assets with a lifetime of less than one year)
opportunity cost of capital	the rate of return of alternative investment opportunities
payout time or **payback time**	the time from *first* expenditure when the cumulative net revenue equals the cumulative investment
Pdf	Probability density function
precision	A measure for the range of a predictive model's output KPI-histogram. The standard deviation of the output

	histogram may serve as this measure: the smaller the standard deviation, the more precise the model. The "truth" does not necessarily lie in this range. See also "accuracy" and **Error! Reference source not found.**.
present value (PV)	the PV (at a reference date) of a given amount of money at a future date is that sum which would have to be invested at a compound interest rate (equal to the discount rate) to yield that amount of money at the future date
PRMS	Petroleum Resource Management System
probability density function (PDF)	a function describing the frequency of occurrence of a value of a parameter against the parameter value
probability of success (POS)	the estimated probability of an exploration prospect containing commercially developable hydrocarbons
production sharing contract (PSC)	one type of agreement between host government and company
profit oil	oil remaining after costs and royalty have been deducted under a PSC agreement
profit-to-investment ratio (PIR)	ratio of net profit to total investment (most useful on a discounted basis)
proven reserves	those reserves of which there is high confidence (typically 85-95% certainty) that they will be recovered economically
PUDRO	Proved UnDeveloped Real Option, a reserves category that can be quickly turned into "Proved Developed" if the market conditions are right to proceed.
PV risk money	the net cost of exploration and appraisal activity
ranking	a process of placing proposed projects in order of desirability (usually using some measure of "value", or a set of measures, as a criterion)
real rate of return (RROR)	the discount rate which, when applied to a real terms (RT) cashflow, reduces the net present value (NPV) to zero
real term discount rate (r)	the discount rate applied to a real terms cashflow

real terms (RT)	the phrase used for a sum of money in a specified year as an amount with the equivalent purchasing power in the reference year
recovery factor	the estimated ratio of recoverable reserves to the hydrocarbons initially in place
reserves	hydrocarbons remaining in the reservoir which will be produced
revenue	proceeds from sale of oil, gas, NGLs (production times price)
ring-fenced	treated in isolation for tax purposes
risk	Probability of an undesired consequence, multiplied by its consequence. In DA, a quantity derived from an IAM's output KPI-pdf (or histogram). The decision maker is free to choose his/her definition. Example: $\text{Project Risk} = \int_{-\infty}^{\text{WACC}^{+}} \text{IRR} \times \text{pdf(IRR).d(IRR)}$, or $\text{Project Risk} = \int_{-\infty}^{0} \text{NPV} \times \text{pdf(NPV).d(NPV)}$
risk factor	An IAM input parameter having a potentially significant impact on "risk".
risk tolerance	The amount of risk the decision maker is prepared to incur. In the DA process, this quantity is used as optimisation constraint (acceptance/rejection criterion). See also "utility function".
RO	Real Option, a managerial flexibility option that responds to market information being revealed in time.
ROACE	Return on average capital employed
ROV	Real Option Valuation, a method to value managerial flexibility options that respond to market information being revealed in time. The valuation is done using Black & Scholes's option pricing theory (adapted to real assets), or using a binomial lattice model with a discount rate that

	reduces in time to take into account the market risks being gradually resolved.
royalty	payment to host government for the production of hydrocarbons and depletion of a non-renewable host-country asset (paid in cash as a % of gross revenues or in production)
SA	Sensitivity Analysis, part of the DA process to rank the various IAM stochastic input parameters and understand their relative or absolute importance for the downside or upside of a KPI-distribution.
scenario	A deterministic definition of one or more uncertain IAM input parameters. A scenario features as a discrete branch of a chance node in a decision tree, and has a probability of occurrence associated with it.
screening	a method of determining, whether economic performance of the proposed projects pass a threshold (usually based on rate of return on investment).
sensitivity analysis	method of determining how the project economics are affected by deviations from base case assumptions (see spider diagram, tornado diagram, derivative analysis)
SPE	Society of Petroleum Engineers
STOIIP	stock tank oil initially in place (stock tank barrels)
straight line capital allowance method	a method in which the cost of capital items are claimed as a capital allowance in equal amounts over a number of years
T2B model	Technical-to-Business model. Same as IAM.
systemic risk	The probability x undesired outcome of a project, due to *exogenous* uncertainties. Exogenous uncertainties are the same as non-technical risk and include market risk.
tariff	payment for the use of services or facilities ($/bbl)
tax	payment due to the host government; a fraction (determined by the taxrate) of taxable income
taxable income	gross revenues less fiscal costs (e.g. royalty, capital allowance, operating costs)

technical cost or **total cost**	operating expenditure plus capital expenditure
total uncertainty	The merged, probability-weighted Monte-Carlo IAM-realisations from different scenarios (i.e. discrete + continuous uncertainty).
ultimate recovery	the amount of hydrocarbons which will be produced by the end of the field's economic lifetime
uplift	a fiscal factor by which early capex is multiplied to compensate for the effect of inflation on a delayed capital allowance claim
utility (function)	The objective function to be optimised through decision-making; it contains at least one KPI to be optimised and may contain other KPI hurdle rates as constraint. It may also contain probabilistic measures such as mean-KPIs or risk tolerances. In case of multi-criteria to be optimised it will also contain the relative weights for the KPIs. The utility function is a scalar. If a time-domain KPI-target is to be met, then the relationship between this time-series (i.e. vector) and the utility function is to be expressed as a scalar (e.g. a L2-norm).
value drivers	Set of one IAM mean-KPI to be optimised under the constraint of various other mean-KPIs, and/or under the constraint of one or more "risk tolerances".
variable opex	that part of opex which is (linearly) proportional to throughput (production of electricity, fluids, etc.).
VIR	Value-to-Investment Ratio; ratio of net profit to total investment (most useful on a discounted basis: VIR = NPV/PVcapex).
VoF	Value of Flexibility
VoI	Value of Information
WACC	Weighted Average Cost of Capital, a quantity resulting from the Capital Asset Pricing Model (CAPM); a method of calculating the cost of capital which combines the cost of each source of capital (debt and equity) in their respective ratios

15 APPENDIX 1 – COURSE PROGRAM

Tentative programme 30 October-03 November 2017

15.1 Course structure

The daily structure of the five-day on-campus course will consist of the following elements:

– Interactive, participative lectures
– Discussions: plenary and small group engagement sessions
– Exercises (XL, Crystal Ball, other)

The preliminary daily schedule is as follows:

Pre-reading	Study load some 8 hrs for pre-reading and preparing questions				
On-campus	*Monday*	*Tuesday*	*Wednesday*	*Thursday*	*Friday*
08:30 - 10:15	Intro /Q/L	L	L	L	L
10:15 - 10:30	B	B	B	B	B
10:30 - 12:30	L&D	L&D	L&D	L&D	L&D
12:30 - 13:15	B	B	B	B	B
13:15 - 15:00	L&E	L&E	L&E	L&E	L&E
15:00 - 15:15	B	B	B	B	B
15:15 - 17:00	E&D	E&D	E&D	E&D	Q/Wrap-up
Post-course	Establish with course participants any further activities				

Note: L = Lecture; B = Break; D = Discussion, E = Exercise; Q = Questionnaire

15.2 Daily program

Draft Course Curriculum WP 1.07

Planned Time: 30, 31 October and 1,2,3 November 2017

Venue:PPSDM Jakarta

Time		Trainers		Programme		Lesson Hours	
Day 1, 30 October 2017							
08:00	08:45		1.	Briefing on Program, Introduction & Logistics		1	LH
				1.1	Ice Breaking		
				1.2	Review of Programme		
				1.3	Participants Background and Expectation		
				1.4	Preparation of Action Plan Development		
08:45	10:15		2.	Briefing on program, recent changes in Indonesian Geothermal Law & Electricity Law		2	LH
				2.1	Introductions, expectations, essence of the course, overview of weekly program		
				2.2	Overview geothermal industry in Indonesia		
10:15	10:45	*Break*					
				2.3	Geothermal Law and Indonesian Electricity Law	2	LH
12:15	13:30	*Lunch*					
13:30	15:00		3.	DA/DQ, Geothermal Asset Life Cycle and DCF Analysis		3	LH
				3.1	Decision Analysis process and Decision Quality		
				3.2	Geothermal Asset Project Maturation		
				3.3	Discounted Cashflow Analysis + Capital Asset Pricing Model		
				3.4	Capital Asset Pricing Model		
				3.4	Government Take (Tax etc)		
				3.5	Decision Metrics (KPI)		
15:00	15:30	*Break*					
			4	Exercise DCF Modelling (XL)		1	LH
				4.1	DCF and CAPM		
				4.2	Tax and Royalty		
		Total Lesson Hour Day 1				*9*	*LH*
Day 2, 31 October 2017							
8:00	09:30		5.	Uncertainty Analysis (Part 1)		2	LH
				5.1	Introduction to Uncertainty Estimation and Modelling		
				5.2	Monte Carlo Sampling Process		
				5.3	Stochastic Correlation		
09:30	10:00	*Break*					
				5.4	Decision Tree Analysis	2	LH
				5.5	Integrated Asset Modelling (IAM)		
11:30	13:00	*Lunch*					
13:00	14:30		6.	Exercise Uncertainty Modelling (Part 1)		2	LH
				6.1	Introduction to Crystal Ball software (XL plug-in)		
				6.2	Exercise using Crystal Ball		
14:30	15:00	*Break*					

15:00	16:30			6.3	Introduction to geothermal field IAM (XL tool)	2	LH
				6.4	Exercise using IAM XL model		
		Total Lesson Hour Day 2				*8*	*LH*
Day 3, 1 November 2017							
08:00	09:30		7.	Uncertainty Analysis (Part 2)		2	LH
				7.1	DTA Exercise Value of Exploration License		
				7.2	Value of Information (VoI)		
				7.3	Value of Flexibility (VoF)		
				7.4	Multi-Criteria Decision Analysis		
				7.5	Psychology, bias, group think		
09:30	10:00	*Break*					
10:00	11:30			7.4	Multi-Criteria Decision Analysis	2	LH
				7.5	Psychology, bias, group think		
11:30	13:00	*Lunch*					
13:00	14:30		8.	Exercise Uncertainty Modelling (Part 2)		2	LH
				8.1	Prior Estimation of Uncertainties		
				8.2	Geothermal Field IAM (XL Tool) exercise: sensitivity analysis		
14:30	15:00	*Break*					
15:00	16:30			8.3	Ditto: Optimization	2	LH
				8.4	Discussion: IAM Improvement		
		Total Lesson Hour Day 2				*8*	*LH*
Day 4, 2 November 2017							
08:00	09:30		9.	Framing, Option, Valuation, DQ		2	LH
				9.1	Framing the Problem		
				9.2	Dynamic Option		
09:30	10:00	*Break*					
10:00	11:30			9.3	Decision Quality	2	LH
				9.4	Discussion		
11:30	13:00	*Lunch*					
13:00	14:30		10.	Exercise Indonesia Case Study (IAM)		2	LH
				10.1	Developing Upside Potential		
				10.2	Sensitivity Analysis		
14:30	15:00	*Break*					
				10.3	Discussion Investment Climate	2	LH
		Total Lesson Hour Day 2				*8*	*LH*
Day 5, 3 November 2017							
08:00	09:30		11.	Portfolio Analysis, Corporate Metrics		2	LH
				11.1	Modern Portfolio Theory (Efficient Frontier)		
				11.2	Discussion Long-term vs Short Term Objective and Constraints		
09:30	10:00	*Break*					
10:00	11:30			11.3	Corporate Key Performance Indicators	2	LH

				11.4	Geothermal Resource Classification		
				11.5	Discussion Government/Company Collaboration		
11:30	13:00	*Lunch*					
13:00	14:30		12.	Wrap Up		2	LH
				12.1	Q&A Session/Discussion		
				12.2	Main Take-away Messages		
14:30	15:00	*Break*					
15:00	16:30			12.3	Discussion Investment Climate	2	LH
				12.4	Questionnaire		
					Total Lesson Hour Day 2	*8*	*LH*
					Total Lesson Hours	41	

16 APPENDIX 2 – KEY LEARNING POINTS

Key Learning Points for "Introduction"

1. Economics plays a key role in decision making, and affects all disciplines
2. All disciplines should maintain a commercial perspective on their activities petroleum economics are performed on a base case, from which sensitivities are investigated
3. Project cashflow is initially dominated by capital expenditure (capex) and later by revenues from sales and operating expenditure (opex)
4. Gross revenue is derived from the sale of hydrocarbons and services
5. Opex and host -government take are taken out of gross revenues; the remainder is cash surplus which the company may pay out as dividend to shareholders or reinvest in the business
6. Constructing a project cashflow requires much data gathering
7. The relationship between revenues, fiscal costs, taxable income and tax payable the fiscal status of the company influences the cashflow
8. Capital allowances are not a cashflow item; there are different methods of calculating capital allowances
9. The relationship between revenues, opex, royalty, tax, capex and cash surplus depreciation is a term best left to the accountants and is not the same as capital allowance
10. Economic indicators which can be derived from the cashflow include
    - economic lifetime
    - maximum cash exposure
    - payback time
    - cumulative cash surplus
    - profit to investment ratio (PIR)

Key Learning Points for "DCF analysis"

1. The "time value of money" concept
2. The mechanics of discounting future cashflows
3. Importance of quoting discount rate and reference date
4. Setting the discount rate to reflect the cost of capital and an allowance for risk
5. Methods of estimating the cost of capital (WACC and CAPM)
6. Opportunity cost of capital
7. Full year and half year discounting
8. Net present value (NPV)
9. Sensitivities of NPV to oil/gas price and discount rate

Key Learning Points for "profitability indicators"

1. Profitability indicators from the annual cashflow and their limitations
2. Indicators which show value and those which reflect efficiency
3. Use of the PV profile to determine the *real rate of return* (RROR) of a project
4. RROR as a project screening tool
5. NPV as a measure of value, not efficiency, and its use as a tool for ranking based on value
6. Limitations on the use of RROR; importance of inspecting NPVs at various discount rates

---

Key Learning Points for "inflation and types of money"

1. Effect of inflation is to increase costs and reduce purchasing power
2. Estimation of costs in Estimate Date Money (EDM) or Base Year Costs (BYC).
3. Escalation of BYC to Money Of the Day (MOD) to allow for inflation and market forces.
4. Importance of (MOD) for actual cashflows and tax calculations
5. Conversion of MOD to real terms (RT) money using a deflator.
6. Finally discounting RT money to work out NPV and profitability indicators.
7. Methods of estimating inflation rate based on historic trends.
8. Discount rate which reduces a real terms cashflow to zero is the real rate of return (RROR).
9. Discount rate which reduces the MOD cashflow to zero is the internal rate of return (IRR).
10. Inflation reduces the RROR of a project.
11. Incorporating exchange rates into cashflow and discounted cashflow calculations

---

Key Learning Points for "Bankability of (geothermal) projects"

1. Different types of financing: a) equity financing; b) loan financing, which can be further broken down into b1) commercial bank loans; b2) project financing; b3) development bank loans
2. Different types have different applications, depending on country risk, financial situation of loan-taker, country development phase, etc.

Key Learning Points for "Project screening and ranking"

3. Screening projects using the RROR.

4. Selection of the discount rate to act as the hurdle for screening should incorporate the cost of capital and an element to reflect risk.
5. Ranking on the basis of value using the NPV, to choose between projects.
6. Importance of the appropriate discount rate for ranking,
7. Value is not the only criterion for ranking a project; there may be other constraints such as cash availability, manpower, production ceilings.
8. Use of ratios to reflect efficiency.

Key Learning Points for “Sensitivity analysis”

1. Sensitivities are usually based on changes to the economic base case, and parameters are usually changed one at a time.
2. Those parameters to which the project economics are most sensitive will be studied in detail to determine how the project can be protected from downside and take advantage of upside.
3. Use of the sensitivity diagram to display impact of parameter changes
4. Trade-offs between parameters as part of project optimisation
5. Use of scenario planning, in portfolio management.

Short curriculum vitae of Christian Bos (petroleum reservoir engineer)

Christian Bos (1954, Geneva) joined the Netherlands Organisation of Applied Scientific Research TNO in 1991 to engage in consultancy and R&D on petroleum reservoir simulation, (probabilistic) reserves estimation, oil & gas production forecast uncertainty quantification, petroleum economics and decision-making under uncertainty. He has 11 years of operational practice with various Shell E&P companies (1981-1991), where he held positions in drilling operations and in reservoir engineering. While at Shell, he was reserves coordinator for 2 operating companies (Thai Shell, Petroleum Development Oman).

Currently (2017) he is a senior researcher / reservoir engineer for TNO's Applied Geosciences division, where he is responsible for R&D on subsurface asset production forecasting, environmental risk assessment, investment decision support, gas market liberalisation & security of supply and, more generally, technical-to-business integration. He regularly lectures investment Decision Analysis and Petroleum Economics at various universities and industry courses. During 2006-2007, he was a Member of the UNECE Ad Hoc Group of Experts on Harmonization of Fossil Energy and Mineral Resources Terminology, further developing a global methodology and industry guidelines for hydrocarbon resource categorization.

Apart from a regular visitor and speaker on Hydrocarbons Reserves conferences, Bos is a member of the Society of Petroleum Engineers and is a reviewer of the SPE Economics and Management Magazine. He is also a member of the SPE's Production Forecasting steering committee, organizing a series of Global Integrated Workshops and aiming eventually at developing industry-wide production forecasting guidelines. In 2011, he joined the board of the European Decision Professionals Network (www.edpn.org), organizing conferences and workshops on Decision Analysis. Until 2011 he participated as a member of the ministerial Working Group "The roadmap of the Gas Hub". A recent focus area in his research has become a systems-dynamics approach to the energy transition, using Agent-Based Modelling, in which the relationship between physics, market dynamics, actor behaviour and market regulation is a key concept. Similarly, modelling the EU Emission Trading Scheme has become one of his research topics, as well as the economics of CCS (Carbon Capture and Storage).

In the past, Bos has performed a number of oil and gas reserves audits and re-determinations, both in expert procedures and as a 'Competent Person'.

Bos holds an MS degree in mining and petroleum engineering (1980) from Delft U. of Technology, The Netherlands.