

Economics Modeling for Petroleum Exploration and Production Projects Considering Risk and imprecise Data

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Zusammenfassung

Die Struktur der Erdölindustrie unterscheidet sich stark von anderen Branchen aufgrund der großen Risiken und Unsicherheiten bei Öl- und Gasprojekten, in Verbindung mit extremer Änderung im Preisniveau. Darüber hinaus, ist die Anzahl der Unsicherheiten in den Daten der Erdölprojekte sehr hoch, die die Entscheidungsprozesse stark beeinflussen.

Die Erdölunternehmen treffen in der Regel die Entscheidung für ein bestimmtes Erdölprojekt auf Basis der Ökonomie-Modelle. Um den Entscheidungsprozess zu verbessern bzw. die moderne Herausforderungen zu erfüllen ist es zwingend notwendig, eine robuste Lösung für die Ökonomie-Modelle zu entwickeln und eine optimale Einschätzung der verbundenen Risiken vorzunehmen.

Die possibilistischen Methode, die probabilistischen Methode und die Monte-Carlo-Simulation sind Vorgehensweisen für die Risikoeinschätzung, und sie helfen bei der Identifizierung möglicher zukünftiger Probleme im Verlauf der Projektdurchführung und unterstützen das Projektmanagement bei der Implementierung von Korrekturmaßnahmen.

Das entwickelte EcoPetro_Modell stellt ein deterministisches Modell dar, für die Bemessung der Wirtschaftlichkeit der Erdölprojekte vor dem Beginn des Projekts und für Neubemessung der Erdölprojekte nach erfolgreicher Exploration vor der Entwicklung oder Produktionsphase. Darüber hinaus unterstützt das EcoPetro_Modell das Risikomanagement und die Optimierung der Vorbereitung von Strategien, sowie die Finanz-und Investitionspolitik des Unternehmens.

Anhand von zwei Fallstudien wurde die Qualität des EcoPetro_Modells bewertet und die Korrelation mit der Risikoeinschätzung vorgenommen. Der erste Fall, das EcoPetro_Oil Modell, beschreibt einen OPEC-Staat bei Einsatz eines Produktion Sharing Kontrakts. Der zweite Fall, das EcoPetro_Gas Modell, gilt für einen nicht-OPEC-Staat, für den das Konzession System eingesetzt wird. Für die beiden Fallstudien wird eine weiterentwickelte Sensitivitätsanalyse zu deterministischen und unsicher Daten durchgeführt.

Die Studie stellt fest, dass jedes Risikobewertungskonzepte Vor- und Nachteile aufweist. Aber eine Kombination der Konzepte das Risikomanagement und die Entscheidungsträger in die Lage versetzt, mögliche zukünftige Probleme im Projektverlauf zu identifizieren.

Abstract

The economic structure of the petroleum industry differs strongly from other industries due to great risks and uncertainty associated with oil and gas projects, coupled with dangerously volatile price levels. In addition, the number of uncertainties in the data utilized in decision making to invest in petroleum projects is very high, and therefore strongly affects the decision making processes.

The petroleum companies generally make the decision for a certain petroleum project on the base of economics models. And so, to improve the decision making process and to be able to face modern challenges, it is imperative to develop a robust solution of the petroleum economics model and an assessment of the associated risks.

The probabilistic approach, probabilistic approach and the Monte Carlo simulation are approaches to risk assessment and help to identify possible future problems in the course of project implementation and operation, to support the project management to take corrective action to the benefit of the project.

The developed EcoPetro_Model represents a deterministic model to evaluate the economics of petroleum projects before the project starts and to reevaluation of petroleum projects after successful exploration prior to development or production phase. In addition, the EcoOil_Model supports the preparation of strategies helping to optimize risk management and the company's finance and investment policies.

In order to proof the quality of the EcoPetro_Model and to correlate it with the risk assessment approaches two case studies are implement. The first case is EcoPetro_Oil model, where an OPEC country applies the production sharing contract, the second model is EcoPetro_Gas model, where a non OPEC country applies the concession system. For both case studies a sensitivity analysis is performed under deterministic data and imprecise data.

The implied study stated that each risk assessment approaches has its ones advantages and disadvantages. They complete each other to identify the possible future problems in the course of project implementation.

Further efforts are suggested to improve the EcoPetro_Model in order to establish a stand- alone risk assessment tool.

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List of Abbreviations

\$	Dollar of United States of America
\$/bbl	Dollar per barrel of oil
\$/BOE	Dollar per barrel oil equivalent
\$/h	Dollar per hour
\$/hectare	Dollar per hectare
\$/MCF	Dollar per thousand cubic feet
\$/unit	Dollar per unit (utilities unit or materials unit)
%	Percentage
BCF	Billion cubic feet
CAPEX	Capital cost
CCA	Capital cost allowance
CDE	Canadian development expense
CE	Cost of equity
CEE	Canadian exploration expense
CS	Concessionary system
DF	Percentage of debt financing
DF	Cost of debt
EF	Percentage equity financing (%)
EMV	Expected monetary value
EMV_development	Expected monetary value at development phase
EMV_exploration	Expected monetary value at exploration phase
ETR	Effective tax rate
JOA	Joint operating agreement
ITCs	Investment tax credits
m \$	Thousand dollars
m bbl	Thousand barrels of oil
m BOE	Thousand barrels of oil equivalent
MCF	Thousand cubic feet
mm \$	Million dollars
mm bbl	Million barrels oil

mm BOE	Million barrels oil equivalent
mm BOPD	Million barrels oil per day
MMCF	Million cubic feet
NCF	Net cash flow
NNPC	Nigerian National Petroleum Corporation
No.	Number
NPV	Net present value
OPEX	Operating cost
POF	Probability of failure
POS	Probability of success
PSC	Production sharing contract
Reward	Denote to net present value or net cash flow
RiskedCost	Cost which the project could lose in the case of project failure
SC	Service contract
WACC	Weighted average cost of capital (%)

Chapter 1 Introduction

1.1 Objectives

Making the decision to invest in petroleum exploration and production projects is always a very complicated endeavor. These projects are impacted by many high risk factors associated with the petroleum industry, such as relatively high initial investment requirements, long term investment horizons (projects may take up to 20 years or more) and negative cash flow during the first few years, sometimes also during the last years of the project life. These factors, coupled with dangerously volatile price levels, makes the number of uncertainties in the data utilized in decision making to invest in petroleum projects very high, and this therefore weighs heavily on the minds of decision makers.

Most petroleum companies make the decision to invest in a certain petroleum project based on economics models, which are constructed as spreadsheets prepared by internal economists in the company or by external experts based on data available from different sources (such as petroleum engineers, geologists etc.). As a result, each petroleum company has developed its own economics model. These models are characterized by unclear definitions of input variables and the way they are related to the output parameters.

Therefore, to improve the decision making process in petroleum projects and to be able to face modern challenges, it is imperative to develop a robust solution to the petroleum economics model and the associated risks. The main objective of this dissertation is to introduce a unified framework to deal with this problem through the achievement of the following topics:

- Develop the characteristics of petroleum exploration and produce reliable project economics models.
- Determine, clearly and uniformly, the variables of the economics of petroleum projects. Include all relevant cost and revenue variables, their mathematical treatment and functional correlations.
- Develop a generalized economics model that can reflect the detailed and vast economics aspects of petroleum exploration and production projects including flexibility in fiscal regimes.
- Manage uncertainty of the data in the designed model, not only by the use of Monte Carlo simulation (as common in petroleum industry), but by applying some necessary complementary methods, i.e. fuzzy logic and probability theory.

- Evaluate the model and the provided framework to deal with uncertainty using two case studies. Take into account two different fiscal regimes, and the implementation of sensitivity analyses with respect to single/multi-factor perturbations.

1.2 Literature Review

Fiscal regimes of petroleum exploration and production projects

Studies on fiscal regimes associated with petroleum exploration and production projects, such as that provided by Al-Attar & Alomair (2005) and Iledare (2001) have come to the conclusion that the type of the contract between the host government and the contractor does not present substantial issues in evaluating the fiscal regime; it is the structure of the fiscal regime of the contract that is important. For example, the structure of the royalty rate, fixed or variable rate, etc.

Tordo (2007) used a descriptive approach to compare the available fiscal regimes and the impact of these on the profitability of petroleum projects, and provided a framework to design an effective fiscal regime. Another study by Tordo (2010) concluded that there is no appropriate fiscal regime to suit all governments and circumstances.

Adenikinju & Oderinde (2009), Akhigbe (2008), and Kaiser & Pulsipher (2004) used a meta-modelling analysis of fiscal regimes whereby simulations are made in order to represent how the statistics indicators (government take and contractor take) vary as a function of the system parameters. In meta-modelling, a model of the system is first constructed and then meta-data is generated for variables simulated within a specified design space. Linear models are then constructed from the meta-data, Iledare & Kaiser (2006).

Blake and Roberts (2006) compared five petroleum exploration and production fiscal regimes under price uncertainties. The fiscal systems analysed were: Alberta Canada (concessionary system); Papua New Guinea (pre-2003, traditional rate of return system); Sao Tome and Nigerian Joint Development Zone (production sharing contract, PSC); Tanzanian (hybrid system) and Trinidad and Tobago (PSC). They also used Monte Carlo simulation to deal with uncertainty and found that some systems are clearly much better than others. The Alberta Canada and Papua New Guinea fiscal systems provide companies with the highest after-tax values while also being the least distortionary. The Tanzanian system is the lowest in both rankings, providing relatively low after-tax values and introducing strong distortionary effects.

Risk in petroleum projects

Suslick & Schiozer (2004) discussed the historical development of risk analysis in petroleum exploration and production. The first attempts to deal with risk used the statistical and probabilistic approaches based on discounted cash flow calculation were by Krumbein & Graybill (1965), Raiffa (1987), Newendorp (1975), Megill (1979) and Rose (1987). Later, further studies such as those of Galli et al. (1999) and Kvalevag (2009) used real option approaches to evaluate petroleum projects.

Wood (2000) provided a framework which integrates the deterministic and probabilistic approaches to evaluate petroleum exploration and production projects under risk. He considered the Monte Carlo simulation the cornerstone of probabilistic techniques and that it can be effectively used in petroleum projects. The main contribution of his study is the use of political and business risk factors alongside the geologic risk factors in the estimation of the probability of a project success and his suggested schema to estimate each risk factor and integrate it in the project economics model.

Roisenberg et al. (2009) calculated the geologic risk factor as a fuzzy set rather than as a classical set, and used fuzzy-probabilistic software, where the risk can be seen as a stochastic variable whose probability distribution relies on a codified geological argumentation. This approach benefits from fuzzy logic as way of dealing with imprecise data in petroleum exploration.

Koeppen & Lenz (2006) differ between the probability and possibility approach to deal with imprecise data built in a structural equation system. They found that the differences in the results are negligible for linear relationships. And both approaches contribute to improve the accuracy of data.

Shang and Hossen (2013) describe how fuzzy logic can be used in risk aggregation and budgeting.

Known petroleum economics models

The Nigerian economics model as typical example for oil provinces OPEC countries was provided by Meyer (previously Carbon-TF B.V./The Netherlands) in 2010 and represents a deterministic economics model in order to calculate the net cash flow of the contractor and the Nigerian government for a given offshore prospect. The model provides a sensitivity analysis for

a one variable variation at a time (OPEX, CAPEX, price and production) and visualizes its impact on the contractor's cash flow. The model has a clear and simple structure, but it cannot be relied upon in decision making because it includes simplifications which seriously affect the validity of the results. For example, it calculates the yearly cash flow and then discounts the total cash flow at the end of the project life using the Excel discount function. It therefore neglects the effect of yearly discount rate and uses only one long period to discount the total cash flow. In addition to this, it does not include other indicators such as payback period and expected monetary value.

The Nova Scotia gas model is provided by the Nova Scotia department of Energy on its web site¹ as example for non-OPEC countries. This model provides full cycle calculations in order to evaluate oil and gas projects in Nova Scotia, and includes Nova Scotia offshore royalty, provincial and federal corporate income taxes in addition to government take and other economic indicator calculations. It uses values at risk by multiplying each input variable with the estimated probability of success. Additionally, it provides one variable variations at a time for sensitivity analysis.

Other petroleum models can be found in Kemp and Kasim (2003) and Moroney and Berg (1999). Some of the basic structures of the above models are adopted, integrated and expanded in order to include more fiscal regimes, more key business indicators and different calculation methods of model variables in order to produce a standard petroleum economics model.

¹<http://energy.novascotia.ca/oil-and-gas/offshore/petroleum-resources/economic-model>

1.3 Approach

The structure of this dissertation corresponds with the petroleum economics modeling life cycle as shown in figure 1.

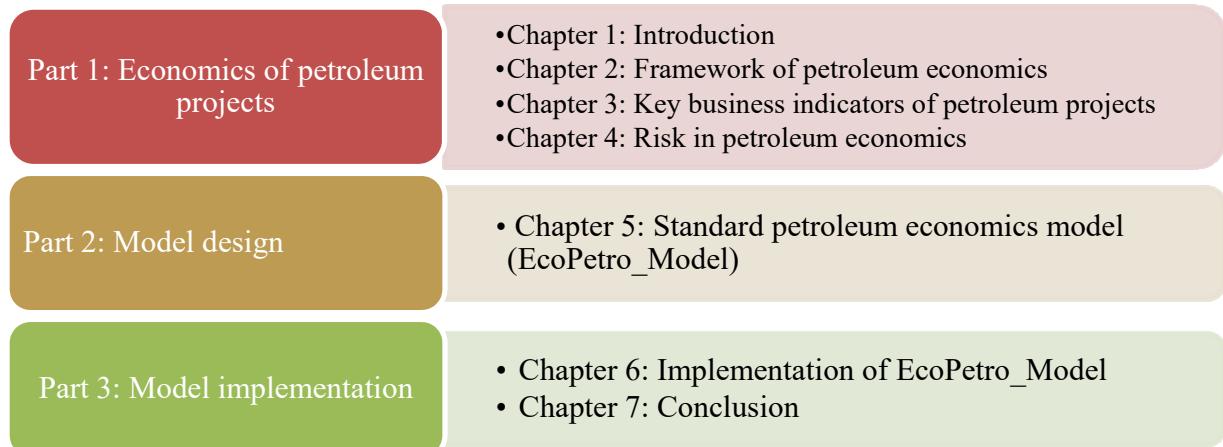


Figure 1: Structure of the dissertation within the scope of petroleum economics modeling life cycle sequence

The first part of the dissertation establishes the fundamentals which are necessary for building a petroleum exploration and production economics model. Chapter 2 covers the life cycle of petroleum projects, the ownership rights of the petroleum resources and the basic concepts of the contracts between investor companies and the government.

In the next chapter, the most commonly used key business indicators in the petroleum projects are introduced, where the net cash flow represents the cornerstone for other key business indicators and the net present value is the most significant indicator of petroleum project evaluation (Kasriel & Wood, 2013).

Chapter 4 describes the risk factors of petroleum projects, and delivers the approaches which are used in this dissertation to assess the risk: the possibility approach, the probability approach and the Monte Carlo simulation. The software applications FuzzyCalc®, Quantor, and Oracle Crystal Ball are used for these approaches.

The second part is the design part. There, the standard petroleum economics model (EcoPetro_Model) is introduced in chapter 5. Firstly, the model assumptions are described and then the revenue and cost variables are determined, labeled as variables in a uniform way. Further, measurement units are added. All variables are part of an equation system which allows the calculation of key business indicators for petroleum projects.

The EcoPetro_Model is implemented in Excel for annual data in order to calculate the annual key business indicators (such as yearly cash flow and yearly discounted cash flow) and other key business indicators such as net present value, internal rate of return, expected monetary value for the exploration and the development phases, and the payback period.

One can take the EcoPetro_Model for running deterministic sensitivity analyses, stepwise manually or by clicking on a macro button to start built-in scenarios for a sensitivity analysis.

The third part of the dissertation considers two case studies by using the EcoPetro_Model. The first case is oil economics model (EcoPetro_Oil model), where the Nigerian government applies the production sharing contract. The second is gas economics model (EcoPetro_Gas model), where the fiscal regime of the petroleum industry in Nova Scotia is the concession system. The values of input variables in both cases are hypothetical, but the cost values are comparable to values used in similar projects in both countries.

Sensitivity analyses under imprecise data in addition to deterministic sensitivity analysis are performed. The final chapter offers conclusions and further suggestions to improve the decision making in petroleum projects considering risk and imprecise data.

Appendix I represents a brief overview of FuzzyCalc, Quantor and Oracle Crystal Ball. Appendix II provides the data repository of the EcoPetro_Model.

Chapter 2 Framework of Petroleum Economics

2.1 Life Cycle of Petroleum Projects

A successful petroleum project typically passes through six phases, as shown in figure 2.

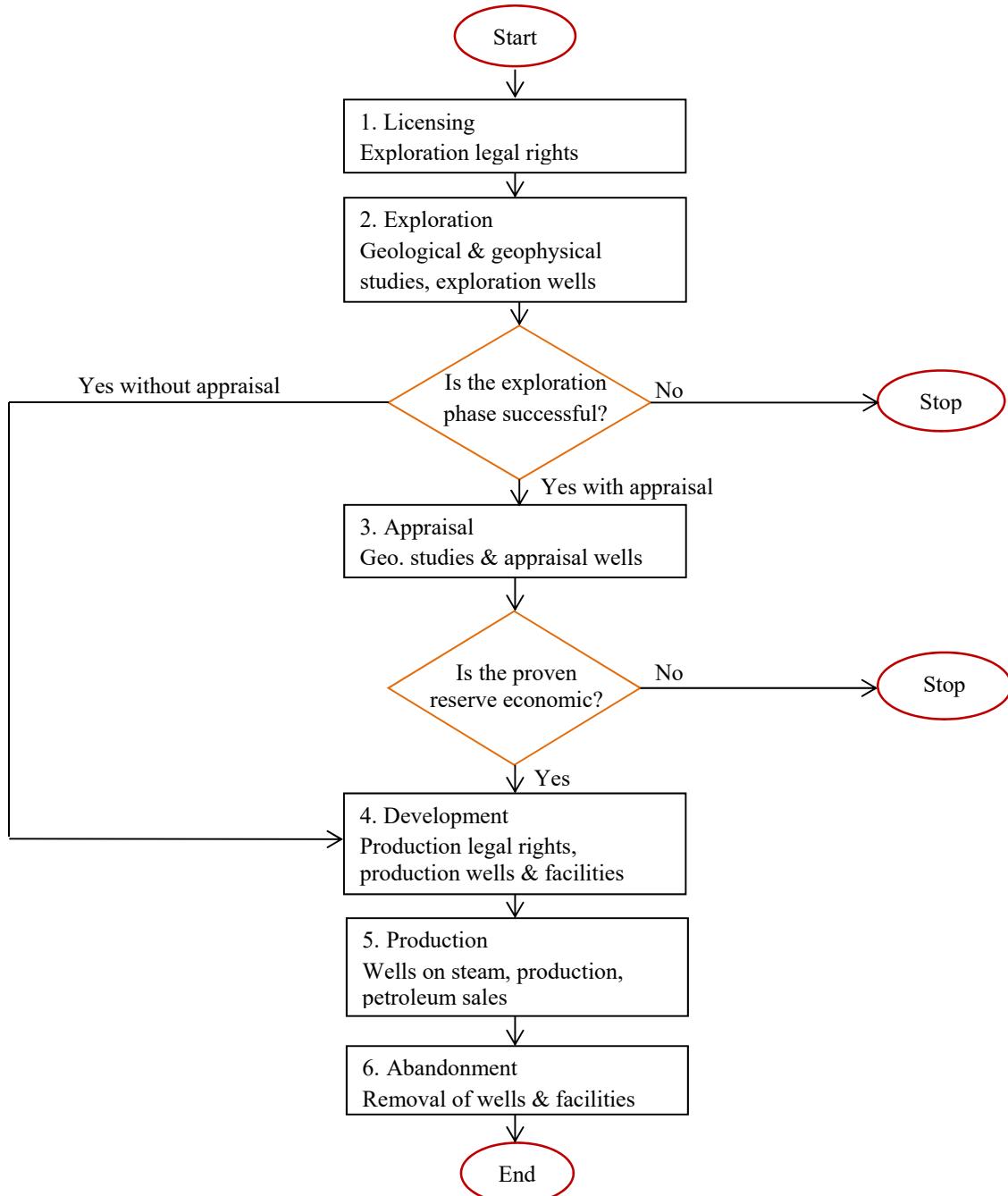


Figure 2: Life cycle of petroleum projects

(modified after Johnston, 2003)

The first phase of the petroleum project is the licensing phase (Tordo, 2007). Here, the petroleum company receives legal rights from the host government to explore petroleum in a specific area.

The second phase is the exploration phase, which aims to proof the existence of petroleum within the granted exploration license. In order to achieve this, several geological and geophysical studies are made and the collected data are analyzed and interpreted. If the likelihood of a sufficient quantity of petroleum is acceptable, one or more exploration wells will be drilled. If the wells are unsuccessful, the project will be stopped.

In case of successful exploration efforts, the appraisal phase begins with more geological studies and sometimes additional wells (appraisal wells), to be drilled in order to enhance the level of confidence in the volume of petroleum and the profitability of the project. If the discovered quantity of petroleum is economic, the decision will be made to proceed with the next phase.

The fourth phase is the development phase. Here, a field development plan is formulated (Rezk, 2006) and evidence on the technical and economic feasibility of the project is provided. On application by the petroleum company the exploration license will be converted to a production license by the government. Then the development plan will be realized, the production wells will be drilled and the production facilities implemented. The development phase represents the phase of highest cost during the entire project life.

Once the production wells are completed and the facilities are commissioned, the fifth phase starts, the production phase. The production phase itself passes through three sub-stages as shown in figure 3.

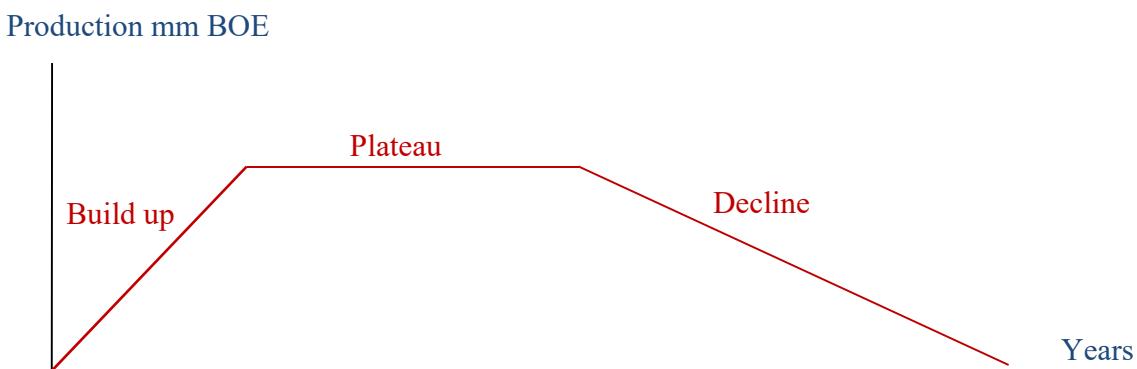


Figure 3: Typical petroleum production curve
(modified after Robelius, 2007)

- Build up stage: During this stage the wells are progressively brought on stream, which means that the production rises at a relatively constant rate until it reaches an anticipated level of production, when all wells are on stream.
- Plateau stage: During this stage the production rate remains steady. The duration of the plateau phase may be difficult to estimate, especially for large fields with long production periods.
- Decline stage: During this stage the production rate declines. This stage lasts longer than other stages of production.

The sixth phase, the final phase in the petroleum project life, is the abandonment phase. This phase starts at the point when the revenue of the project no longer covers operating costs. However, preparations for the abandonment phase usually start earlier than the actual year of abandonment (Jahn et al., 2008).

2.2 Petroleum Exploration and Production Investment Rights

Petroleum resources are usually owned by governments and rarely by individual people such as in the case of private ownership of petroleum e.g. by farmers and landowners in the United States of America. Usually the governments (the so-called host governments) establish a national petroleum company to search for petroleum and to develop it. But due to the high risks and the expensive nature of investment in petroleum exploration and production the national oil company often requires help from international oil companies, the so called contractors. The contractors have the necessary capabilities and staff to search for petroleum and to extract it.

The host governments use licensing systems to distribute the exploration and production investment rights to the contractors. According to Tordo (2010) the licensing systems can be classified in two groups; open-door systems where interested contractors are allowed to submit a proposal with respect to specific areas at any time (mostly annual or bi-annual) and licensing rounds held as an auction or administrative process based on a set of criteria provided by the host governments.

Within all systems; a negotiation process starts between the contractor and the national petroleum company based on the petroleum law in the project country. The petroleum law usually defines the petroleum policy of the host government, the terms of petroleum contracts and the fiscal tools the government uses to capture an appropriate reward from the country's petroleum resources (Babusiaux et al., 2004).

After negotiations, the host government signs a contract with the contractor. This contract organizes the relationship between the host government and the contractor. When the contractor includes a number of companies (partners), then the joint venture (group or consortium) between them is formalized by means of a so called joint operating agreement (JOA).

2.3 Contract Types of Petroleum Exploration and Production

Due to the negotiation of contract terms between the contractor and the host government, in a number of petroleum countries in the world, certain flexibility in petroleum contract types exists. Thus, a contract may have different terms compared to another contract in the same country. However, according to the ownership type of the petroleum resources, petroleum contracts are generally classified into two basic systems (Johnston, 1994): Concessionary and contractual.

2.1 Concessionary System

The concessionary system or so-called royalty/tax system was the first system used in world petroleum contracting and it is used currently by around half of the petroleum producing countries worldwide, including the US, UK, France, Norway, Canada, Australia, New Zealand, Libya, and South Africa.

According to a concessionary contract, the host government transfers ownership of the petroleum resource to the contractor. The contractor pays all exploration, development and operating costs, so the government does not bear any risk during the project. Therefore a contractor gets the total petroleum production but he makes different types of payments which are identified in the laws and regulations of the host government. The host government makes profit from the petroleum project under a concessionary contract by using one of the following fiscal tools (Kaiser & Pulsipher, 2004):

- **Bonus:** A bonus is paid when predetermined events happen. For example, a signature bonus is paid by a contractor when a contract is signed or an exploration license is granted. A production bonus is paid when production is starting or a certain production level is reached in a field. In some countries these bonuses are deductible for tax purposes, whereas in others they are not.
- **Surface fees:** The contractor may be required to pay annual surface fees to the host government, either in the exploration phase or/and in the production phase, based on the area over which the project extends.

- Royalty: A royalty is one of the most commonly used fiscal tools worldwide. It represents an amount paid by the contractor to the host government in cash or in kind. Royalties paid to a private party other than to a host government are called overriding royalties. Calculation principles are the same for both, the difference is only in who receives the payment. The implementation of a royalty rate differs from host government to host government. Some use a flat royalty rate while others use variable royalty rates. These variable rates can be calculated depending upon yearly production, cumulative production, petroleum price, or price and production together, etc. As an example, variable royalty rates based on daily production are shown in table 1.

Table 1: Oil royalty rate under the 2005 Hydrocarbons Law of Algeria

Daily production (thousand barrels per day) ²	Royalty rate (%)
(0-20)	12.5%
20-50	20%
50-100	23%
> 100	20%

(modified and corrected after Agalliu, 2011)

- **Tax on profit:** The contractor is subject to the profit tax laws in the investment country, in addition to other taxes such as those applied to export and import of the commodity. If the tax losses from one contract are used to offset the taxable profit of another contract in the same country, then the tax system used in this country is called tax consolidation or ring-fencing (Kasriel & Wood, 2013).

An example of a concession contract is the Algerian concessionary contract³ presented by Agalliu (2011), in which the contractor pays 20% royalty rate from the total revenue, 30% petroleum revenue tax in addition to 30% income tax as shown in figure 4.

For illustration purposes, daily oil production equal to 5,000 BOPD with a price of 80 \$ per barrel is considered. Firstly, the royalty is deducted from the revenue, and then for petroleum revenue tax purposes the contractor is permitted to subtract his depreciation, while for income tax purpose the contractor is allowed to subtract the operating cost, abandonment cost in addition to

² The royalty is charged based on progressive basis when the daily production is ≤ 100 mm BOPD. When the daily production is > 100 then the royalty is charged based on total production.

³ The values in the given Algerian concessionary contract example are exemplary values to explain the concessionary contract system and the dependencies of specific fiscal term on the relevant fiscal regime.

depreciation cost. The contractor's take is equal to the net revenue after taxes and royalty payments, while the government take represents the sum of royalty, income tax and petroleum revenue tax.

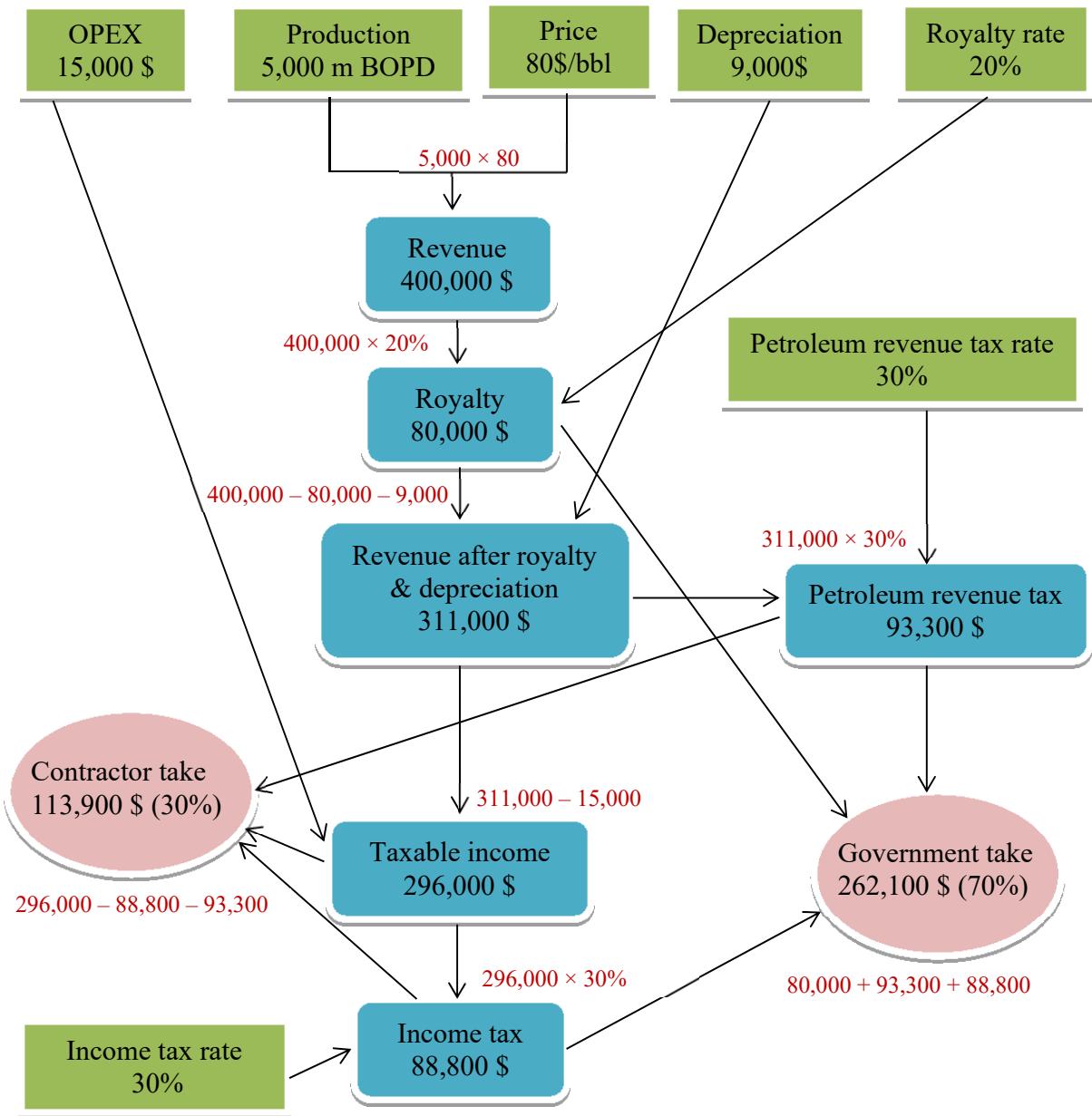


Figure 4: Algeria simplified concessionary contract based on one day production
(modified after Agalliu, 2011)

The structural equations system of the Algeria contract example is given as:

$$\text{Revenue} = \text{Oil production} \cdot \text{Oil price}$$

$$\text{Royalty} = \text{Royalty rate} \cdot \text{Revenue}$$

$$\text{Revenue after royalty \& depreciation} = \text{Revenue} - \text{Royalty} - \text{Depreciation}$$

$$\text{Taxable income} = \text{Revenue after royalty \& depreciation} - \text{OPEX}$$

$$\text{Income tax} = \text{Income tax rate} \cdot \text{Taxable income}$$

$$\text{Petroleum Revenue tax} = \text{Petroleum Revenue Tax Rate} \cdot \text{Revenue after royalty \& depreciation}$$

$$\text{Government take} = \text{Royalty} + \text{Income tax} + \text{Petroleum revenue tax}$$

$$\text{Contractor take} = \text{Taxable income} - \text{Income tax} - \text{Petroleum revenue tax}$$

2.2 Contractual System

In the contractual system the host government retains the ownership rights on the petroleum and shares the petroleum production with the contractor in kind or in cash. The contractual system itself could be classified into production sharing contracts and service contracts.

2.3.3.1 Production Sharing Contracts

The first production sharing contract was established in Indonesia in 1950. This type of contract later became the prevalent contract type worldwide (Johnston, 1994). In both the contractor and concessionary systems the contractor bears the risk of the investment and covers all financing issues, as well as carrying out all petroleum operations. In exchange, the contractor gets an amount of petroleum for recovery of costs as well as an amount of petroleum which represents a share of the profits. The host government gets a share of the petroleum in addition to other fiscal tools, such as royalty and fees. The main fiscal tools to share the profit between the host government and the contractor (based on the production sharing contract) can be summarized as follows (Kaiser & Pulsipher, 2004):

- **Bonus:** The basic concept of a bonus is similar in all contract types
- **Royalty:** The basic concept of a royalty is similar in all contract types
- **Cost recovery (cost petroleum):** The contractor has the right to recover his costs by an appropriate proportion. Sometimes the cost recovery is restricted to a certain upper bound of the annual production, and this is called the cost recovery limit. When the revocable cost is not recovered in the year of occurrence due to the cost recovery limit, then it is generally allowed to be recovered in the following years.

- **Sharing of production (profit petroleum):** Profit petroleum represents the part of the petroleum left after deduction of cost recovery and royalties. There are many ways to share this profit between the host government and the contractor. For example, profit of petroleum is split based on a fixed rate, or based on variable rates according to the daily production rate or cumulative production or production price etc.
- **Tax:** The tax on profit is calculated based on the remaining petroleum production after profit sharing, or is based on the contractor's profit share. In some production sharing contracts the national oil company pays the profit tax on behalf of the contractor in order to encourage petroleum investments in the host government.

The contract signed in Syria in 2008⁴ is an example of a production sharing contract (Fig. 5), and is based on one day production for purpose of simplification.

In an approach similar to the concessionary system, the Syrian government claims a royalty rate equal to 12.5% of the total revenue. Before sharing the production between the contractor and the host government, the contractor recovers his costs from the net revenue of royalty. The profit oil share is 65% - 35% in favor of the host government and the contractor profit share is subject to income tax at a rate of 10%. The contractor oil profit after tax plus the oil cost represents the contractor take and is equal to 34%, while the government take is the sum of government profit share, royalty and profit tax. The structural equations system which represents the simplified Syrian production sharing contract is given as:

$$\text{Revenue} = \text{Oil production} \cdot \text{Oil price}$$

$$\text{Royalty} = \text{Royalty rate} \cdot \text{Revenue}$$

$$\text{Revenue after royalty} = \text{Revenue} - \text{Royalty}$$

$$\text{Profit oil} = \text{Revenue after royalty} - \text{Cost oil}$$

$$\text{Contractor profit oil} = \text{Contractor profit oil rate} \cdot \text{Profit oil}$$

$$\text{Government profit oil} = \text{Government profit oil rate} \cdot \text{Profit oil}$$

$$\text{Income tax} = \text{Income tax rate} \cdot \text{Contractor profit oil}$$

$$\text{Government take} = \text{Royalty} + \text{Government profit oil} + \text{Income tax}$$

$$\text{Contractor take} = \text{Contractor profit oil} + \text{Cost oil} - \text{Income tax}$$

⁴Source: <http://www.proactiveinvestors.co.uk/general/files/companies/gpx.pdf> (Accessed on April 3rd, 2015). The contract was signed between the Syrian national Oil Company and contractor (consortium, Gulfsands Inc. and Emerald Inc.) on 2008 and the production was stopped on 2010 due to the political conflict in Syria. The values in the given Syrian production sharing contract example are exemplary values to explain the production sharing contract and the dependencies of specific fiscal terms on the relevant fiscal regime.

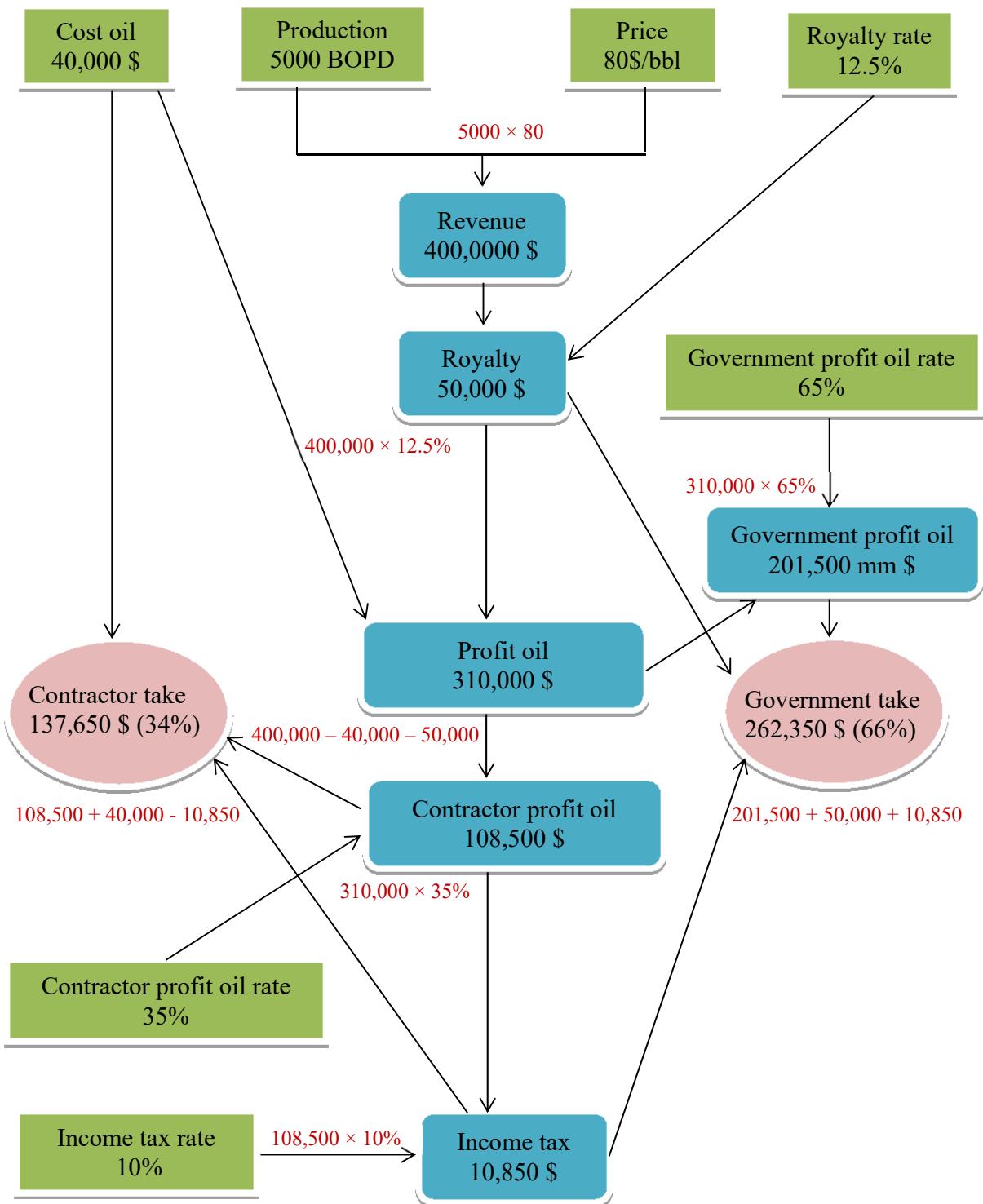


Figure 5: Syrian simplified production sharing contract based on one day production
 (modified after Johnston, 2003)

2.3.3.2 Service Contracts

Under a service contract, the contractor finances and carries out petroleum operations and receives fixed or variable fees for these services. This fee is generally paid in cash (Tordo, 2010). Additionally, the contractor recovers his costs from the total revenue and pays taxes according to the tax laws in the host government.

As example of a service contract, a simplified Iranian service contract⁵ is shown in figure 6, (modified after Van Meurs, 2008 and Bindemann, 1999).

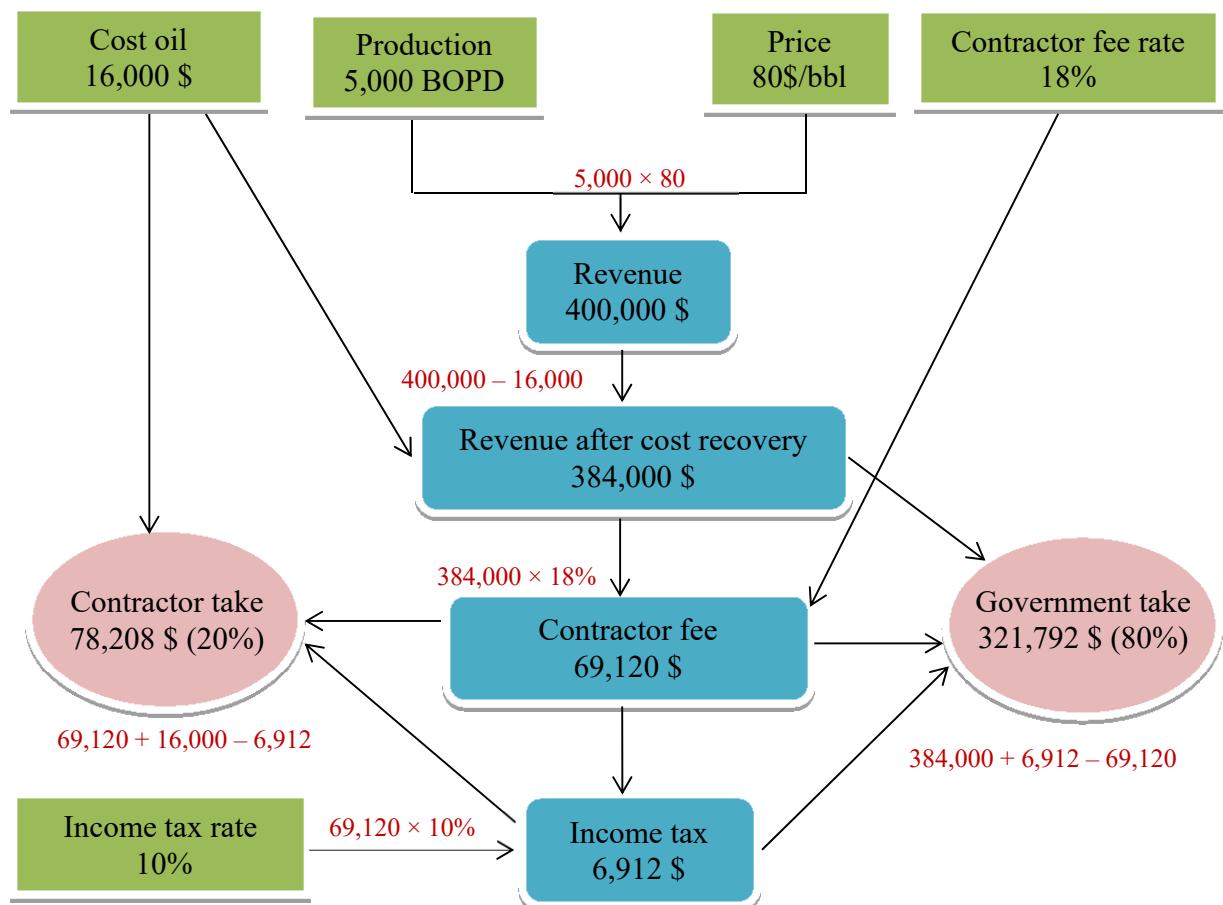


Figure 6: Iranian simplified service contract based on one day production

(modified after Van Meurs, 2008 and Bindemann, 1999)

⁵ The values in the given Iranian service contract example are exemplary values to explain the Iranian service contract and the dependencies of specific fiscal term on the relevant fiscal regime.

The Iranian service contract allows the contractor to recover costs from the total revenue, then the contractor receive a fixed fee from the revenue after cost recovery equal to 18%. The contractor fee is subject to income tax equal to 10%. As a final result, the Iranian government take is equal to 80% and the contractor take is equal to 20%. The structural equations system of the simplified Iranian service contract is given as:

$$\text{Revenue} = \text{Oil production} \cdot \text{Oil price}$$

$$\text{Revenue after cost recovery} = \text{Revenue} - \text{Cost oil}$$

$$\text{Contractor fee} = \text{Revenue after cost recovery} \cdot \text{Contractor fee rate}$$

$$\text{Income tax} = \text{Income tax rate} \cdot \text{Contractor fee}$$

$$\text{Government take} = \text{Revenue after cost recovery} + \text{Income tax} - \text{Contractor fee}$$

$$\text{Contractor take} = \text{Contractor fee} - \text{Income tax}$$

2.3 Comparison of the Different Contract Types

The concessionary and contractual systems are similar in many respects. The host government may use the same fiscal tools (royalty, rental, tax) in order to capture economic reward from the petroleum projects. The main difference between these systems is the ownership of the petroleum. According to the concessionary system the contractor owns the whole production, while under the contractual system the contractor receives a share of production in kind or in cash in return for services. The host government may be responsible for the abandonment according to the contractual system, while the contractor is always responsible for abandonment according to the concessionary system.

The national oil company may pay the income tax on behalf of the contractor under the contractual system, while the contractor pays tax under the concessionary system.

It should be noted that sometimes the government participates in cost payments when either a concessionary or a contractual system is installed. In this case the contractor does not have 100% working interest in the project area and the government achieves more rewards from the petroleum projects; such an agreement is called a joint venture (Johnston, 2003).

According to Iledare (2001), Al-Attar & Alomair (2005) the cornerstone of the fiscal system is the structure (for example, applied tax rates or royalty rates) and not the type of the contract. This means that it can not be easily claimed that one type is better than the other, and each contract must be evaluated separately.

Chapter 3 Key Business Indicators of Petroleum Projects

Key business indicators of petroleum projects present tools utilized in the improvement of the decision making process. The most common used indicators for evaluation of petroleum projects are net cash flow; discounted cash flow; net present value; internal rate of return and payback period.

3.1 Net Cash Flow (NCF)

The net cash flow of a project is defined as the cash remaining after covering all the expenses during one year or one period (Mian, 2011). In order to express the annual NCF associated with a petroleum project, the cash disbursements should be subtracted from cash receipts for the given period.

$$\text{NCF} = \text{cash inflows (revenue)} - \text{cash outflows (cost)} \quad (3.1)$$

Babusiaux & Pierru (2005) classified net cash flow as net cash flow before tax payments and net cash flow after tax payments; also operating cash flow generated only from petroleum sales and associated costs and other net cash flow generated from other unusual cash inflows or outflows such as asset sales or wastage.

A negative cash flow for one year is not necessarily bad for the total investment; it could mean that the company makes a large investment at this period which earns a high return later. For example, the first years of the petroleum project where a lot of money is paid for exploration and development but no reward is achieved.

To build the net cash flow, equation information is required from different sources, (Jahn et al., 1998). This information is summarized in figure 7.

Information resources	Information type
Petroleum engineering	<ul style="list-style-type: none"> • Production profiles • Reserves type
Drilling engineering	<ul style="list-style-type: none"> • Drilling and completion cost
Facilities engineering	<ul style="list-style-type: none"> • Facilities cost
Operating & maintenance engineering	<ul style="list-style-type: none"> • Operating cost • Maintenance cost
Human resources	<ul style="list-style-type: none"> • Manpower types and numbers • Manpower cost
Host government	<ul style="list-style-type: none"> • Fiscal system (Tax, royalty, etc.)
Corporate planning	<ul style="list-style-type: none"> • Forecasts of oil and gas prices • Discount rate, inflation rate, exchange rate , etc.

Figure 7: Resources of necessary information to build cash flow of petroleum projects
(modified after Jahn et al., 2008)

After all required information is collected; the construction of net cash flow is started and the total cash of the project is classified into revenue and cost.

3.1.1 Revenues

Revenue arises from petroleum production sales (oil, gas or condensate) in addition to other activities such as money received from asset sales or interest on the provisions (abandonment, depreciation and others).

In order to calculate the revenue from petroleum sales, the prices should be predicted. For each project the price forecasts should be chosen depending on the expertise of the economist. Some choose a flat real price forecast, others choose flat rate money of the day price forecast etc. According to Jahn et al. (2008) one can say that the petroleum industry analyses so far have been very bad at predicting future petroleum prices.

3.1.2 Costs

In order to produce the petroleum there are two main types of costs: fiscal costs (which include bonuses, royalties and taxes etc. as identified in section 2.3) and field costs, which can be

classified into four elements: exploration costs, development costs, operating costs and abandonment costs. Exploration and development costs together are termed CAPEX, while the operating cost is called OPEX. The abandonment cost is considered to be a special category of cost because it is associated with environmental safety and does not produce any future profit for the company. It is also a very large cost component, and could be equal to or more than the development cost (Mian, 2011).

The allocation of field cost (CAPEX, OPEX) into elements differs from company to company, due to the variable nature of petroleum projects (e.g. different reservoir types) and the fiscal regime applied in the project (e.g. some host governments determine the cost which will be capitalized and the cost which will be depleted). By comparing several studies, for example Babusiaux et al. (2004), Mian (2011), it can be demonstrated in figure 8 how the field cost is classified

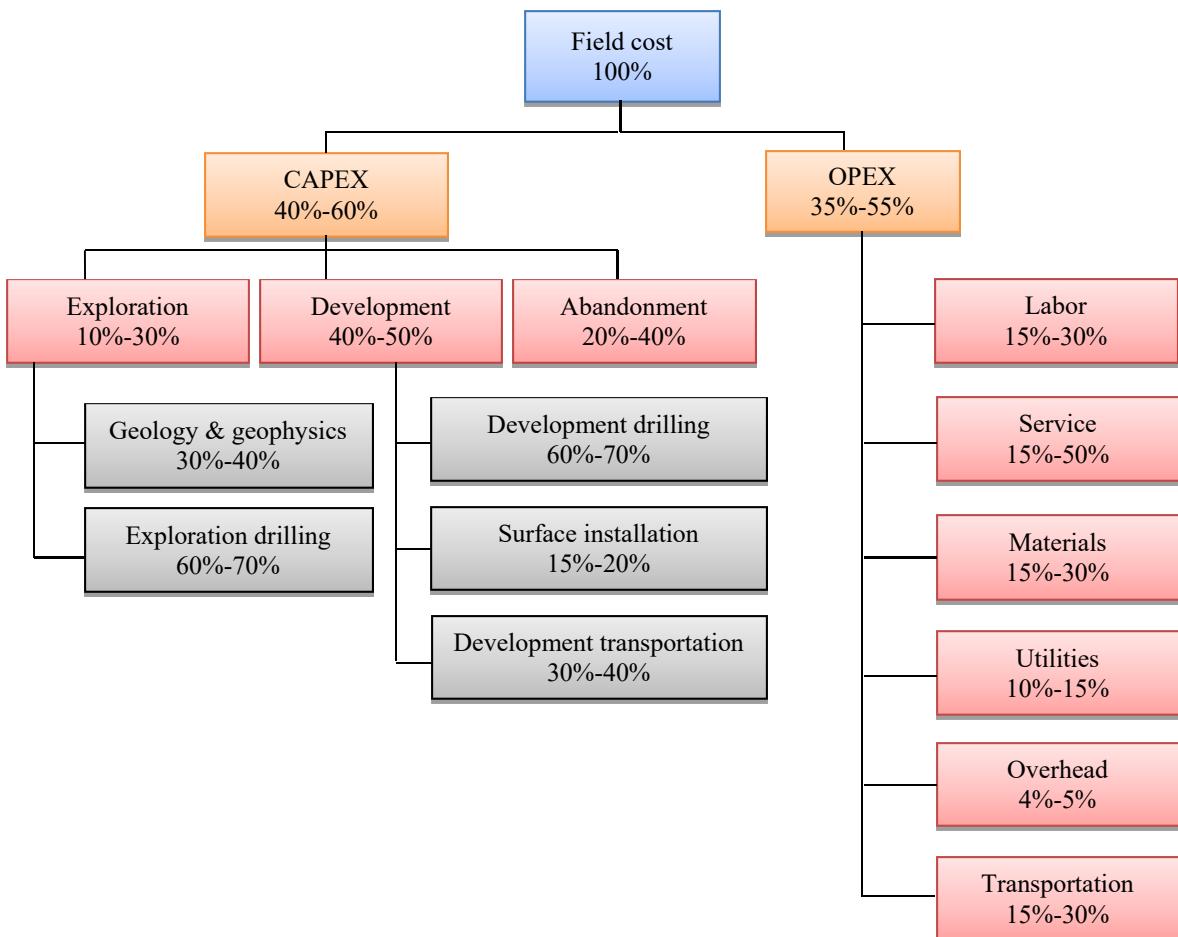


Figure 8: Structure of the field cost

(modified after Babusiaux, 2004 and Mian, 2011)

Capital cost account for a minimum of 40% up to a maximum of 60% of field cost while the operating cost account for a minimum of 35% up to a maximum of 55%. The environmental nature of the project area plays a major role in determining the contribution of capital cost to the total cost.

For example, offshore petroleum projects require more equipment and facilities than onshore projects, and therefore the capital cost could account for up to 60% of the total cost. There is also an inverse relationship between the contribution of the cost of labor, materials and utilities and the contribution of operating service contracts cost.

3.1.2.1 Capital Cost (CAPEX)

Companies expend capital cost in order to obtain capital assets used to produce the petroleum. Usually, it is paid only once at the beginning of the project, although sometimes CAPEX occurs during the economic life of the project; for example, if the project applies new techniques and facilities in order to increase petroleum production.

According to the purpose of the cost, the CAPEX can be broken down into two main categories:

1. Exploration cost

The exploration cost contains the costs of geological and geophysical studies which are made by the company itself or purchased from other parties like service companies. In addition, exploration wells are drilled and their cost is considered as exploration costs. If the exploration effort is unsuccessful, then the cost is called sunk cost. Usually the sunk cost does not appear directly in the project future cash flow evaluation, but it affects the actual financial situation of the project (Babusiaux et al., 2004).

2. Development cost

The development cost consists of three main cost elements: development well drilling cost, production installation cost and cost of facilities required for petroleum transportation. The development methods and techniques differ from project to project depending on various factors, such as onshore/offshore, technologies available, rock type, the size of the oil or gas fields, etc.

3.1.2.2 Operating Cost (OPEX)

The operating cost (OPEX) represents the cost of operating and maintaining the petroleum project. Operating cost may be classified on different basis (Jennings et al., 2000):

- OPEX classification on the basis of time

Operating cost based on time is classified into historical operating cost (determined after it has actually occurred) and predetermined operating cost (calculated before it occurs). The predetermined operating cost is either predicted operating cost or standard operating cost.

- OPEX classification on the basis of the nature of the element incurred

Operating cost based on the nature of the element incurred is classified into six categories:

1. Labor: Labor cost represents the wages and wages benefits for all personnel involved in petroleum production in the field. The number of required personnel and the hourly rate for each person are defined in detail.

The wages benefits generally include all benefits and payments which are provided to employees other than wages for time worked (Jennings et al., 2000).

2. Operating Service: The service cost refers to the cost due to sub-contracts between the contractor and service companies, such as maintenance contracts, pumping contracts, housekeeping contracts, personnel transport contracts etc.

3. Materials: The materials cost contains the cost of all small tools used in petroleum production. These are consumed and cannot be considered to be an asset, e.g. batteries, treatment chemicals and spare parts for any maintenance of the production facilities.

4. Utilities: Utilities include fuel, gas, water etc. used to run the production equipment.

5. Overhead: The annual overhead cost is defined as the cost of business operations which are not directly dependent on a specific project or operation. This cost includes management wages and expenses, public relations, financial, budget and management control, legal issues and insurance administration. The amount of overhead cost which will be allocated in a particular petroleum project is usually defined by the contract between the contractor and the host government and in the JOA between the operator and the partners of a consortium.

6. Production transportation: The transportation cost is incurred in the transport of the produced petroleum from the field to a refinery or processing facility, export terminal, or any other point of sale whether using pipelines or tanker, or both.

- OPEX classification on the basis of traceability

Operating cost based on traceability is classified into direct cost and indirect cost. The direct cost can be directly identified in the petroleum production such as the wages for workers on the well. The indirect cost cannot be directly identified with the petroleum production, for example overhead staff cost.

- OPEX classification on the basis of changes in volume

Some elements of operating cost do not change with changes in the volume of production and are called fixed costs, such as overhead cost. Other elements of operating cost change with the volume of production and therefore are called variable costs e.g. fuel and other utilities which are used in petroleum production.

3.1.2.3 Abandonment

Abandonment cost is the cost paid for cleaning up the wells and facilities, and the restoration of the production site after production ends. This cost is incurred at the end of project life; in some regimes the abandonment payment is allowed to be funded in advance through deductions from annual profits (abandonment provision or contribution).

The abandonment cost covers the cost of wellhead removal in addition to removal of the production and petroleum transport equipment, plugging of the well and treatment and restoration of the production area.

3.2 Discounted Cash Flow

Discounted cash flow is a technique which translates the time value of money by discounting the future cash flow to a present value reference (Kruschwitz & Leöffler, 2005). The discounted cash flow (DCF_a) in the end of the year a is given as:

$$DCF_a = \frac{NCF_a}{(1 + i)^a} \quad (3.2)$$

where,

NCF_a : Net cash flow at the end of year a

i : The discount rate

a : Number of the year $a = 0, 1, 2, \dots, A$

The above equation assumes that the cash flow has occurred at the end of the year. In reality cash flow transactions take place continuously or at least monthly. To deal with this fact, some economists use the mid-year discounted cash flow which is given as:

$$DCF_a = \frac{NCF_a}{(1 + i)^{a-0,5}} \quad (3.3)$$

The discount cash flow at either end of year or mid-year is a significant key business indicator because it presents the base of calculation for other indicators.

3.3 Net Present Value

The net present value (NPV) value is the algebraic sum of discounted annual cash flows associated with the project (Mian, 2011). The NPV is given as:

$$NPV = \sum_{a=0}^A \frac{NCF_a}{(1+i)^a} \quad (3.4)$$

where,

NCF_a : Net cash flow at the end of year a

i : The discount rate

a : Number of the year $a = 0, 1, 2, \dots, A$

When the NPV of an investment at a certain discount rate is positive, the project is acceptable. By evaluating mutually exclusive projects⁶, the project with the highest NPV should be accepted. A negative NPV indicates that the investment is not generating any earnings and the project should be rejected. If the NPV is zero, then the decision maker will be undecided because the investment is generating the same return as the alternative use of the money. The decision should then be based on other criteria, e.g. the degree of risk associated with each project.

The choice of a discount rate to be used to calculate the net present value is a matter of corporate policy. Some companies prefer a fixed discount rate over the project lifetime while other companies use a declining discount rate. However, there are some methods which can be used to determine the appropriate discount rate for a project, such as the weighted average cost of capital (WACC) method, which is one of the most commonly used methods (Kruschwitz & Leoffler, 2005). In order to finance new projects or assets, a debt or equity can be used. The weighted average cost of capital of a company is the average cost of both of these sources of financing weighted by their individual use, and is given as follows:

$$WACC = EF.CE + DF.CD(1-ETR) \quad (3.5)$$

where,

⁶ Mutually exclusive projects mean that the acceptance of one project eliminates the other from investment consideration.

WACC: Weighted average cost of capital (%)

EF: Percentage equity financing (%)

CE: Cost of equity

DF: Percentage debt financing

CD: Cost of debt

ETR: Effective tax rate

3.4 Internal Rate of Return

The internal rate of return of a project is the value of the discount rate which equates the project's NPV to zero.

$$0 = \sum_{a=0}^A \frac{NCF_a}{(1 + IRR)^a} \quad (3.6)$$

If the IRR is greater than the weighted average cost of capital then the NPV is positive, and if the IRR is less than the weighted average cost of capital then the NPV is negative. The NPV is equal to zero when the IRR is equal to the weighted average cost of capital.

Sometimes when a petroleum project has a nonconventional cash flow (negative, positive, negative) a dual rate of return may occur (Mian, 2011). In this case the IRR is a mix of rate of return and rate of reinvestment; other economic indicators must therefore be used to make investment decisions.

3.5 Payback Period

The payback of a project identifies the expected number of years which the company needs to recover its project investments. At this point, the cumulative net cash flow is equal to the total investment. The payback can be defined by using the following equation:

$$\sum_{a=0}^b NCF_a \geq 0 \quad (3.7)$$

where b represents the payback point at which the cumulative net cash flow is positive for the first time in the project life.

When the project achieves a payback point, in principle it will then be a worthwhile investment. When evaluating mutually exclusive projects, short payback points are preferred over long ones. It is worth mentioning that the payback period alone cannot be used to make investment decisions because it does not take into account the cash flow after the recover point. However, it is a useful indicator to be used with other indicators to determine if the project is a favorable investment opportunity.

3.6 Other Indicators

The government and contractor takes are indicators do not directly reflect the economics performance of the project, but are commonly acceptable indicators to help in improve of the decision making process, especially by comparing similar projects (reserves size, field cost etc.) and fiscal regimes in different countries (Mazeel, 2010).

The contractor take is his share from the petroleum project profit commonly expressed as percentage. Government take is the complement of contractor take percentage.

According to Kasriel & Wood (2013) there are different definitions of what is the project profit which is shared between the contractor and the government. The most used terms to express the project profit are; total project revenue from the sales of production and total project revenue net of field cost.

The main difference between the two definitions appears obviously by production sharing contract, where the definition of contractor take based on revenue net of field cost does not consider the cost petroleum as a share for the contractor.

The amount of government take does not change according to the used definition while the percentage of government take it will be change. The necessary equation for the calculation the take indicators according the above definitions will come later in section 5.2.

Chapter 4 Risk in Petroleum Economics

4.1 Risk Factors

Investments in the petroleum industry are made under significant risk circumstances, due to the nature of the exploration and production process. The volatility of petroleum prices also adds a high degree of risk to petroleum investments. These risk factors are the major reason which makes economic data imprecise for project evaluation. Generally, the risk factors are classified into geological risk factors and industry risk factors (Wood, 2000).

4.1.1 Geological Risk Factors

Geological risk factors play an important role in the exploration phase of a petroleum project. The key to success in this phase is the presence of an acceptable likelihood of commercial petroleum, which is based on the existence of four geological factors: presence of sufficient and mature source rock, presence and quality of reservoir rock, presence of a trap, appropriate timing of trap formation, migration and retention of hydrocarbons. These factors represent the most important geological risk factors in exploration, and become less important in the development and production phases.

4.1.1 Industry Risk Factors

Industry risk factors affect the exploration phase in addition to development and production phases. However the degree of impact may be higher in the final two phases. These factors include the location risk factor (infrastructure, environment, logistics etc.), technology risk factor (available technology, new technology), fiscal and political risk factors (stable or unpredictable) and business risk factors (petroleum prices, cost and the global economic situation).

4.2 Expected Monetary Value

Expected monetary value (EMV) is a technique to formulate the key business indicators (NPV or NCF), taking into account the probability of project success in order to deal with the risks surrounding the project (Rezk, 2006). In general the EMV is given as:

$$\text{EMV} = \text{Reward.POS} - \text{RiskedCost.(1-POS)} \quad (4.1)$$

where,

Reward: Denotes net present value or the net cash flow.

POS: Probability of success

RiskedCost: Cost which the project could lose in the case of project failure. If the net present value represents the Reward then the discount risked cost must be used.

It is to be noted that the expected monetary value can be calculated for each phase in the life of a petroleum project, and it can then be used to draw a decision tree in order to improve the decision making process. If the EMV is positive then the project can be continued; otherwise the project should be terminated. By evaluating mutually exclusive projects⁷, the project with the highest EMV should be accepted.

4.3 Approaches of Risk Assessment

4.3.1 Possibilistic Approach

The possibility logic through fuzzy set theory presents a useful concept to deal with uncertain data caused by risk factors.

4.3.1.1 Classical Set

A classical set or crisp set is a simple statement demonstrating whether an element with a certain character belong to that particular set (Bothe, 1995).

If the elements of a set B are a subset of universal set X , then set B can be mapped for all elements $x \in X$ by its characteristic function as:

$$u_B(x) = \begin{cases} 1 & \text{if } x \in B \\ 0 & \text{if } x \notin B \end{cases} \quad (4.2)$$

For example, the CAPEX of a petroleum project could be defined as crisp set B , so the set of expected CAPEX, 10 million dollar is a crisp set.

4.3.1.2 Fuzzy Set

A fuzzy set (proposed by Zadeh, 1965) is a set where the elements belong partially or gradually to it. Mathematically, a fuzzy set B on X is defined by the pair $(x, u_B(x))$ and membership function which determines the degree of validity that an element belongs to the set. So every element x in the fuzzy set B has a membership degree: $u_B(x) \in [0,1]$.

⁷ Mutually exclusive projects mean that the acceptance of one project eliminates the other from investment consideration.

For example, the CAPEX set in a petroleum project around 10 million dollars is shown as a fuzzy set. Figure 9 compares CAPEX as crisp set and CAPEX as fuzzy set.

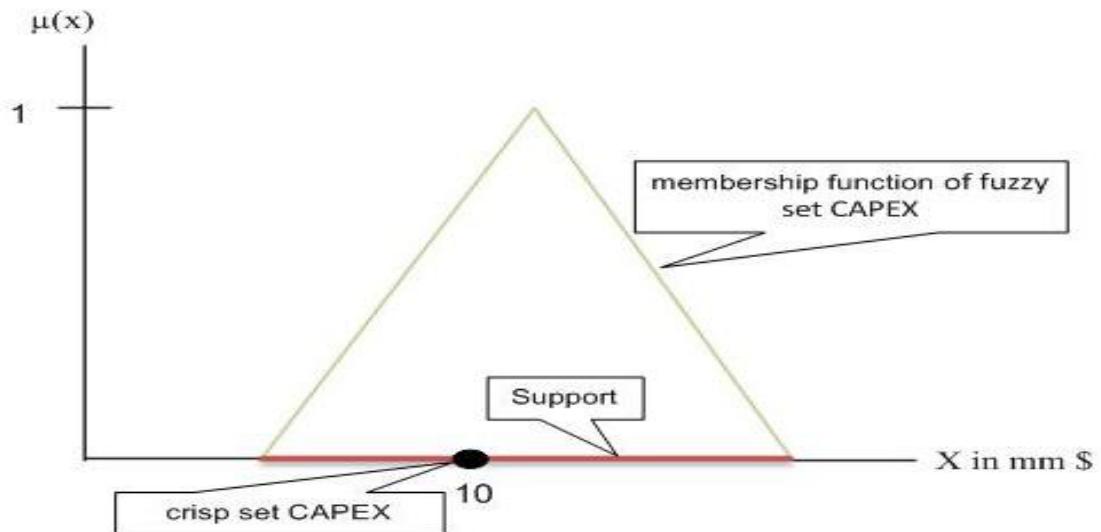


Figure 9: Graphical comparison of crisp set and fuzzy set
(modified after Köppen, 2008)

According to Bzedek (1993) the main concepts of fuzzy set theory are summarized as:

- Universe of discourse: The universe of discourse is the range of all possible values for an element in the fuzzy set.
- Continuous fuzzy sets: When the membership function is continuous then the fuzzy set should also be considered as a continuous set.
- Singleton fuzzy set: A fuzzy set that has a nonzero membership value for only one element of the universe of discourse is defined as a singleton fuzzy set. Figure 10 shows a singleton fuzzy set whose membership value is just at $x = 4.5$ and it is equal to zero everywhere else.

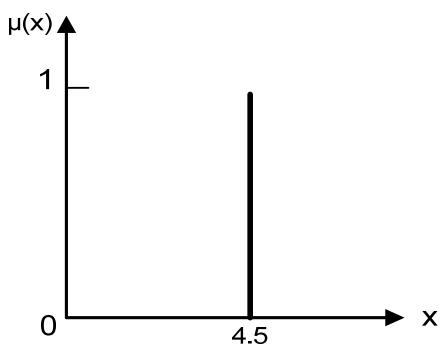


Figure 10: Example of the membership function of a singleton fuzzy set
(modified after Shang & Hossen, 2013)

- Support of fuzzy set: If the membership function of a fuzzy set is not zero, the support of this fuzzy set is a crisp set of all elements in the universe of discourse.
- Height of a fuzzy set: The highest membership value of a fuzzy set is defined as the height of the fuzzy set. For example, the height of the fuzzy set in figure 10 is 1. The height of the fuzzy set used in the fuzzy models is almost always 1.
- Normal fuzzy set and subnormal fuzzy set: A normal fuzzy set has a height equal to 1, while the subnormal fuzzy set has a height smaller than 1 for all elements in the domain.
- Center of a fuzzy set: the fuzzy set has four situations to define its center.
 1. The maximum value of membership function is achieved at only one element of the universe of discourse; this element is defined as the center of the fuzzy set.
 2. The maximum value of membership function is achieved at several elements of the universe of discourse and all elements are bounded; the center is the middle point of the elements.
 3. The maximum value of membership function is achieved at several elements of the universe of discourse and not all elements are bounded; the center is the largest point of the elements if it is bounded.
 4. The maximum value of membership function is achieved at several elements of the universe of discourse and not all elements are bounded; also the largest element is not bounded and the center is the smallest point of the elements.
- Convex fuzzy sets: A fuzzy set A is convex if all its a -level sets axes are convex (Bezdek, 1993). It is important to note that the membership function of a convex fuzzy set is not necessarily a convex function, while if the membership function of a fuzzy set is convex the fuzzy set is also convex.
- Types of membership functions: there are many types of membership functions, but the most commonly used in fuzzy modeling are: trapezoidal, triangular and Gaussian. Figure 11 represents a graphical instance of each type.

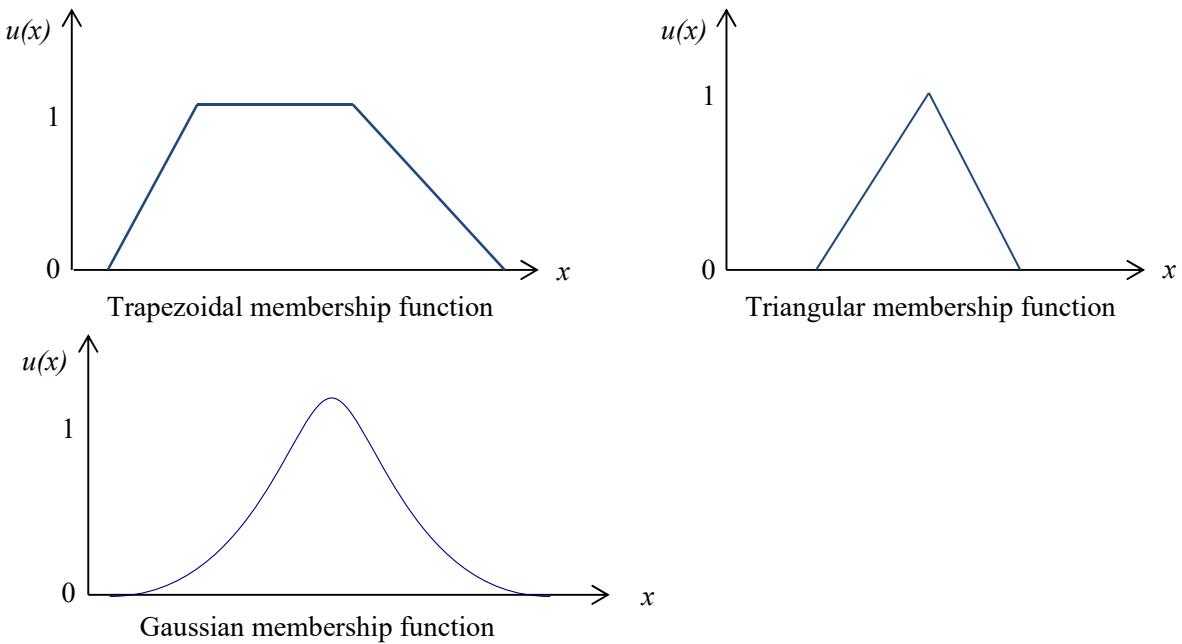


Figure 11: Example of three commonly used fuzzy membership functions
 (modified after Bothe, 1995)

- **Fuzzy numbers:** Fuzzy number A is a fuzzy set of the universe of a numerical number that satisfies the condition for normality and convexity.
- **Operation on fuzzy set:** There are many operations on a fuzzy set. The most important are union, intersection, and complementation.
 - Define a fuzzy set C in the space X . Then the fuzzy set \bar{C} is the complement of the fuzzy set C , if for all x in the set X , $\bar{C}(x) = 1 - C(x)$
 - Define two fuzzy sets A and B in the space X . The union of A and B is denoted by $(A \cup B)$ and is defined as the smallest fuzzy set that contains both A and B . In other words: for all x in the set X , $(A \cup B)(x) = \min(A(x), B(x))$
 - Define two fuzzy sets A and B in the space X . The intersection of A and B is denoted by $(A \cap B)$ and is defined as the largest fuzzy set that contains both A and B . In other words: for all x in the set X , $(A \cap B)(x) = \max(A(x), B(x))$
- **Fuzzification:** Mathematical procedure for converting an element in the universe of discourse into the membership value of the fuzzy set

- Fuzzy basic arithmetic operations (Kruse, Gebhardt, & Klawonn, 1995): the basic arithmetic operations on real numbers can be realized on the fuzzy number by combining the intervals of α -cuts. So, the following operations are applicable:

$\forall a, b, c, d \in \mathbb{R}$:

$$[a, b] + [c, d] = [a + c, b + d] \quad (4.3)$$

$$[a, b] - [c, d] = [a - d, b - c] \quad (4.4)$$

$$[a, b] \cdot [c, d] = \begin{cases} [ac, bd] & a \geq 0 \wedge c \geq 0 \\ [bd, ac] & b \geq 0 \wedge d \geq 0 \\ [\min\{ad, bc\}, \max\{ad, bc\}] & a \geq 0 \wedge cd \geq 0 \wedge ac < 0 \\ [\min\{ad, bc\}, \max\{ac, bd\}] & ab < 0 \vee cd < 0 \end{cases} \quad (4.5)$$

$$\frac{1}{[a, b]} = \begin{cases} \left[\frac{1}{b}, \frac{1}{a}\right] & 0 \notin [a, b] \\ \left[\frac{1}{b}, \infty\right) \cup (-\infty, \frac{1}{a}] & a < 0 \wedge d > 0 \\ \left[\frac{1}{b}, \infty\right) & a = 0 \wedge b > 0 \\ \left(-\infty, \frac{1}{a}\right] & a < 0 \wedge b = 0 \end{cases} \quad (4.6)$$

In order to implement the fuzzy logic the FuzzyCalc application is used. FuzzyCalc is user-friendly software and is available as an Excel add-on; it was developed by Müller (1999), Lenz and Müller (2000) and Müller et al. (2003) as a method for planning, forecasting, controlling and analyzing fuzzy data. The main idea of the FuzzyCalc algorithm is to fuse or merge the different alternative fuzzy sets resulting from the fuzzy structural equation systems; figure 12 shows how the FuzzyCalc algorithm works. (More characteristics of FuzzyCalc are described in Appendix I).

Fuzzy Calc Algorithm

Input: one observation per Fuzzy variable (number), equation system, fully specified membership functions (missing values allowed)
Output: adjusted Fuzzy sets (variables)
<pre> 1: repeat 2: for all equations do 3: for all variables in current equation do 4: Resolve (separation step) equation for each variable 5: Compute Fuzzy set of variable using Zadeh's extension principle 6: end for 7: end for 8: for all variables do 9: Compute the intersection of Fuzzy sets of variable for all related equations 10: if intersection is empty then 11: notify user: "M-inconsistent!" 12: else 13: re-normalize the corresponding membership function 14: end if 15: end for 16: until (M-inconsistency notification) or (no corrections of any Fuzzy sets occur) </pre>

Figure 12: Algorithm of FuzzyCalc
(adopted after Köppen, 2008)

4.3.2 Probabilistic Approach

Probability theory provides a rigorous foundation for the management of risk, and is used as an estimate of the likelihood of an event or value to occur. It deals with random variables and describes them by density or distribution function.

4.3.2.1 Normal Probability Distribution

The normal probability distribution is also referred to as Gaussian distribution. It is one of the most commonly used distributions due to its ability to accurately approximate many natural phenomena. For example, the errors of real-valued observations are often normal distributed. The probability density function $f(x)$ of the normal distribution with a mean \bar{x} and a standard deviation σ is denoted by $N(\bar{x}, \sigma)$

$$f(x) = \frac{1}{\sqrt{2\pi}\sigma} \exp\left[-\frac{1}{2}\left(\frac{x-\bar{x}}{\sigma}\right)^2\right]$$

The normal distribution is symmetrical around the mean \bar{x} ; and the mean value divides the area into two halves. Additionally, the total area under the curve is equal to 1. This distribution is suitable for use when the distribution of the data is not known, but it is known that the available data is symmetrical around a mean value and is more likely to be near the center than the extremes (Rodger & Petch, 1999).

4.3.2.2 Statistical Quality Analysis⁸

The statistical quality analysis aims to control the data in order to detect the contradictions between the variable values and the structural relations between them.

According to the probabilistic approach each variable is modeled as follows:

$$x = \xi + u$$

where x is the measurement of variable X , ξ is a non-observable (true) or error free value and u is the measurement error, i.e. (Gaussian) random variable with expectation $E(u) = 0$ and variance $E(u^2) = \sigma_u^2$ (Lenz & Rödel, 1992).

Using the corresponding balance equations, i.e. the structural equation system, one is able to detect the contradictions between the data and the model by estimation and test procedures.

Let be \underline{x} an observed state vector (Lenz, et al., 2006), $\underline{\xi}$ an unobservable (error-free) state vector, $\underline{\zeta}$ a dependent vector, $\underline{\zeta} = \underline{H}\underline{\xi}$, \underline{z} an observed vector of ζ , and \underline{v} , \underline{w} vectors of measurement errors. The state space equation is $\underline{x} = \underline{\xi} + \underline{v}$ and observational equation $\underline{z} = \underline{H}\underline{\xi} + \underline{w}$. For sake of simplicity of description linear relationships are assumed to represent by the matrix H .

The next step is to estimate the unknown parameters $\underline{\xi}$ and $\underline{\zeta}$. This can be simply achieved by generalized least squares (GLS) estimation approach⁹.

Let $\underline{u} = (\underline{v}, \underline{w})$, $E(\underline{u}) = \underline{0}$, and $E(\underline{v} \underline{w}) = \underline{0}$ due to partial information from independent data sources. It follows

$$G = E(\underline{u}\underline{u}^\top) = \begin{bmatrix} P & 0 \\ 0 & Q \end{bmatrix}$$

where P , Q are covariance matrices of the measurement-error vectors \underline{v} and \underline{w} .

Let $\underline{y}^\top = (\underline{x}^\top, \underline{z}^\top)$ and $J = (\underline{I}, \underline{H})$, then $\underline{\xi}$ is estimated by solving GLS: $\min \|\underline{y} - \underline{J}\underline{\xi}\|_G$ subject to the linear constraint $\underline{\zeta} = \underline{H}\underline{\xi}$.

⁸ Sub-chapter 4.3.2.2 principally is based on the research of Prof. H.-J. Lenz, one of the supervisors of the PhD thesis

⁹ GLS estimators called Kalmen Filter equation and Kalmen Gain.

Note: If the variables are connected by nonlinear operations (multiplication or division) then the constraint $\zeta = \underline{H}(\xi)$ is to be used.

The constraints lead to smaller (or equal) error intervals of the estimates compared with the original measurements. The estimates can be affected in several ways which are of interest to data cleansing (Lenz et al., 2006):

- The estimates are shifted to the “right” direction if a constraint is not fulfilled. The shifts are proportional to the standard deviation of the errors a priori fixed.
- Estimates are equal to its observation if the measurement is error-free, i.e. the value is crisp.
- The estimates fulfill the system of equation up to numerical errors.

In order to implement the probabilistic approach the Quantor application is used. Quantor (quantitative reasoning or QR), was developed by Schmid & Müller (1993) as a method to deal with the uncertainty data based on the probabilistic approach. (The application is also described in Appendix I).

4.3.3 Monte Carlo Simulation

Monte Carlo simulation represents a type of computational algorithm for simulating the behaviour of real processes in order to support the decision making process (Metropolis and Ulam, 1949). In other words, it is a technique that based on a proper model of the real world, repeated random sampling and statistical analysis.

It was named after the town’s casino Monte Carlo in Monaco. The random behaviour in games of chance (roulette wheels, dice games and slot machines) is similar to the way in which the Monte Carlo simulation values of variables are generated at random to simulate a real system using a model.

This is the same with random variables for which the distribution and range is known but the value for a specific value (or event), however, cannot be predicted with certainty (e.g. interest rates, oil, gas or stock prices, inventory and number of telephone calls). Monte Carlo simulation has been widely used by physicists, mathematicians and economists to simulate random phenomena.

4.3.3.1 Monte Carlo Simulation of Structural Equations System

Economics models of oil or gas exploration and production are mostly based on spread sheets, and their input variables can be assumed to be random variables. According to Glasserman (2003) the general steps in order to perform a Monte Carlo simulation study of an economics model are the following: The real system is represented as a structural equations system. Therefore the study begins with identifying the state (input / output) variables, their ranges and specifies completely an appropriate distribution function for each random input variable. Fixing the relevant parameters of a planned simulation experiment the output values are generated from the joint probability distribution by running the following gross algorithm as many times as the analyst specifies has planned for each experiment, i.e. according to the sample size (simulation length) and number of runs:

- **begin**
- **repeat**
 - Generate a random number (value) for each random variable
 - Insert values into the structural equations system
 - compute key performance indicators
- **until** simulation end
- Produce tabular output of estimates and visualize main characteristics
- **end.**

On each iteration and for each random variable the Monte Carlo simulator generates a value from the relevant probability distribution. The Law of Large Numbers of Tchebychev guarantees that for a great number of (independent) repetitions under reasonable conditions (like identical distribution etc.) the empirical distribution of the variables converges to the true underlying probability distribution (Ross, 2014). For instance, if an input variable X is modeled as a normal distribution with mean=10 and standard deviation = 4, i.e. $X \sim N(10, 4^2)$, the simulated distribution will have approximately the same parameters. According to the above law the more simulations are run the closer the empirical distribution approaches the true but unknown one.

The probability distributions of the output variables of the model enable quantifying the uncertainty of the variables of interest, for instance by computing corresponding confidence intervals for the key business indicators.

Oracle Crystal Ball is used as a simulation tool for running such a Monte Carlo study. It is widely used software suitable for the evaluating of petroleum projects under risk (Kasriel & Wood, 2013). The system is available as an Excel add-on, and is described in Appendix I.

Chapter 5 Standard Petroleum Economics Model (EcoPetro_Model)

The standard petroleum economics model (EcoPetro_Model) represents a comprehensive deterministic model which combines all the necessary variables for economics evaluation of petroleum exploration and production projects in order to use this as a base model to help with decision making processes under risk and imprecise data.

5.1 Model Assumption

Every economics model contains simplifications of reality. These simplifications are acceptable as long as they do not distort the essence of the model. In the EcoPetro_Model it is assumed that the production of a petroleum project could consist of either oil or gas or both; condensate accompanying the main product are included in the oil production volumes.

Furthermore, the contractor represents a single entity and has a 100% working interest. In reality the government could have a working interest and the contractor could consist of more than one company. Additionally, the net cash flow which is represented in EcoPetro_Model refers to the operating cash flow of the project. The depreciation is calculated in parallel to the production start year.

It is also assumed that the variable values of costs, prices and production are estimated by petroleum engineers and geologists, and the model represents the linear correlation between these values.

5.2 Structural Equations System

The structural equation system of the EcoPetro_Model contains seven main groups of equations: revenue, costs, fiscal regimes, depreciation (capital cost allowances), key business indicators, government and contractor take indicators and expected monetary values. The variables of the EcoPetro_Model are divided into three groups:

- A. Exogenous variables contain only variables which are independent from other variables and their values are determined by external and non-controllable conditions. Therefore they are the input values in the model, e.g. oil price, discounted rate, production profile etc.
- B. Endogenous variables appear as dependent variables in at least one equation in the structural equations model and therefore their values are determined from other variables. This

endogenous variable group is used to calculate other variables in the model, for example, the revenue is an endogenous variable and it is used in the calculation of the cash flow.

C. Decision variables are also dependent variables and used in the decision making process such as discounted cash flow. These variables may or may not be used in farther calculations.

The variables used in the structural equation system are collected in data repository tables, see appendix II. The structural equation is built on the annual basis in addition to the aggregation of the whole project.

1. Revenue

Let $BOPD_w$ be oil production per day per well, and DOP_{w_a} , $OPd\%_w$, Ody_w are index of days of oil production per well per year a , oil production decline rate per well, the start year of oil production decline per well respectively. And let w be the index of production wells, where $w=1,2..W$, and then oil production per year per well OP_{wa} is given as:

$$OP_{wa} = \begin{cases} BOPD_w \cdot DOP_{w_a} (100\% - OPd\%_w) & \text{if } a = Ody_w \\ DOP_{w_{a-1}} (100\% - OPd\%_w) & \text{if } a > Ody_w \\ BOPD_w \cdot DOP_{w_a} & \text{else} \end{cases} \quad (5.1)$$

Let $CFPD_w$ be gas production per day per well, and DGP_{w_a} , $GPd\%_w$, Gdy_w are index of days of gas production per well per year a , gas production decline rate per well, the year of start gas production decline per well respectively. Then gas production per year per well GP_{wa} is given as:

$$GP_{wa} = \begin{cases} CFPD_w \cdot DGP_{w_a} (100\% - GPd\%_w) & \text{if } a = Gdy_w \\ DGP_{w_{a-1}} (100\% - GPd\%_w) & \text{if } a > Gdy_w \\ CFPD_w \cdot DGP_{w_a} & \text{else} \end{cases} \quad (5.2)$$

It is well a known method to calculate the total production of a project which produces the oil and gas together by converting the gas production from cubic feet into barrel of oil. In this case the unit used is called barrel of oil equivalent. Generally one barrel of oil equivalent ≈ 6000 cubic feet of gas, and vice versa, is used as conversion factor from cubic feet to barrel of oil equivalent and denoted as BOE_{factor} . Let GP_{BOE_wa} be the gas production measured by the barrel oil equivalent and given as:

$$GP_{BOE_wa} = GP_{wa} / BOE_{factor} \quad (5.3)$$

The total production (P_a) per year a is given as:

$$P_a = \sum_{w=1}^W OP_{wa} + \sum_{w=1}^W GP_{BOE_wa} \quad (5.4)$$

Let PO_{ra} be the real oil price per barrel per year a , and PG_{ra} is the real gas price per thousand cubic feet per year a , then the nominal oil price per barrel PO_a and nominal gas price per barrel PG_a based on inflation rate (Inf_r) are given as:

$$PO_a = PO_{ra}(1 + Inf_r)^{a+0,5} \quad (5.5)$$

$$PG_a = PG_{ra}(1 + Inf_r)^{a+0,5} \quad (5.6)$$

Project revenue per year a (Rev_a) is given as:

$$Rev_a = PO_a \cdot \sum_{w=1}^W OP_{wa} + PG_a \cdot \sum_{w=1}^W GP_{wa} \quad (5.7)$$

2. Field cost

Let $CAPEX_{ra}$, $OPEX_{ra}$ and $Abandon_{ra}$ be the capital cost, operating cost and the abandonment cost in real values per year a , then the nominal field cost ($FieldCost_a$) per year a is given as:

$$FieldCost_a = CAPEX_{ra}(1 + Inf_r)^{a,5} + OPEX_{ra}(1 + Inf_r)^{a,5} + Abandon_{ra}(1 + Inf_r)^{a,5} \quad (5.8)$$

Let $Explor_a$, $Develop_a$ be the exploration cost and the development cost per year a respectively, then the capital cost per the same year a is given as:

$$CAPEX_{ra} = Explor_a + Develop_a \quad (5.9)$$

Let $G\&G_a$ be geological and geophysical cost per year a , and the $G\&G_Ser_a$, $G_Studies_a$, and Geo_a are geological studies cost, geological and geophysical service contract cost, and geophysics cost respectively in the same year, then the geological and geophysical cost per year a is given as:

$$G\&G_a = G\&G_Ser_a + G_Studies_a + Geo_a \quad (5.10)$$

Let $ExplorDrill_a$ be the exploration drilling cost per year a , and the $ExplorDrill_Log_a$, $ExplorDrill_Staff_a$, $ExplorDrill_Rig_a$, $ExplorDrill_Supp_a$ and $ExplorDrill_Ser_a$, the exploration logistic cost, exploration staff cost, exploration rental of rig and equipment, exploration supplies cost, and the exploration drilling service contract cost respectively in the same year, then the exploration drilling cost per year a is given as:

$$ExplorDrill_a = ExplorDrill_Log_a + ExplorDrill_Staff_a + ExplorDrill_Rig_a + ExplorDrill_Supp_a + ExplorDrill_Ser_a \quad (5.11)$$

Let $Explor_a$ be the exploration cost per year a , and $G\&G_a$, $ExplorDrill_a$, the geological and geophysical cost, and exploration drilling cost respectively in the same year, then the exploration cost per year a is given as:

$$Explor_a = G\&G_a + ExplorDrill_a \quad (5.12)$$

Let $Develop_a$ be the development cost per year a , and the $DevelopDrill_a$, $DevelopSurface_a$, $DevelopTrans_a$ and $DevelopOther_a$, the development well drilling cost, surface installation cost, transportation facilities cost and other development cost used in development phase respectively in the same year a , then the development cost per year a is given as:

$$Develop_a = DevelopDrill_a + DevelopSurface_a + DevelopTrans_a + DevelopOther_a \quad (5.13)$$

For depreciation purpose it is useful to classify the above capital costs into tangible and intangible. The intangible capital cost ($IntangCAPEX_a$) is equal to geology and geophysics costs, while the tangible capital cost ($TangCAPEX_a$) is equal to exploration drilling cost plus development cost.

$$IntangCAPEX_a = G\&G_a \quad (5.14)$$

$$TangCAPEX_a = ExplorDrill_a + Develop_a \quad (5.15)$$

Let $Abandon_a$ be the real abandonment cost in the year a , and let $Remove_a$, $Plug_a$ and $Treat_a$ be removal of equipment cost, well plugging cost and treatment cost of the production area cost respectively in the same year, then the abandonment cost per year a is given as:

$$Abandon_a = Remove_a + Plug_a + Treat_a \quad (5.16)$$

Let τ be the index used to calculate the operating cost

$$\tau = \begin{cases} 1 & \text{if OPEX based on nature of elements} \\ 2 & \text{if OPEX based on traceability} \\ 3 & \text{if OPEX based on change in volume} \\ 4 & \text{if OPEX based on unit of production} \end{cases} \quad (5.17)$$

Let $OPEX_{a\tau}$ be the operating cost per year a per τ , and let LC_a ; SC_a ; MC_a ; UC_a ; OC_a ; TC_a be the labor cost, operating service contracts cost, materials cost, utilities cost, overhead cost and petroleum transport cost respectively at the same year a . The direct operating cost, the indirect operating cost, the fixed operating cost, the variable operating cost per unit of production and the operating cost per unit are denote respectively as: $OPEX_{direct}$, $OPEX_{indirect}$, $OPEX_{fixed}$, $OPEX_{perUnit}$, $OPEX_{variable}$, then the operating cost per year a given τ ($OPEX_{a\tau}$) is:

$$OPEX_{a\tau} = \begin{cases} LC_a + SC_a + MC_a + UC_a + OC_a + TC_a & \text{if } \tau = 1 \\ OPEX_{direct} + OPEX_{indirect} & \text{if } \tau = 2 \\ OPEX_{fixed} + OPEX_{variable} \cdot P_a & \text{if } \tau = 3 \\ OPEX_{perUnit} \cdot P & \text{if } \tau = 4 \end{cases} \quad (5.18)$$

Where the elements of OPEX by its nature are given as:

- Labor Cost (LC_a): Let e be annual index of employees, where $e = 1, 2, \dots, E$, and let $Hour_{ae}$; Wa_{ae} ; Ben_{ae} are working hours per employee, wages rate per hour per employee, wages benefits rate per employee per year a respectively, then the labor cost for the same year is given as:

$$LC_a = (1 + Ben_{ae}) \sum_{e=1}^E (Hour_{ae} \cdot Wa_{ae}) \quad (5.19)$$

- Operating service contract cost (SC_a): Let s be the index of operating service contracts per year a , where $s = 0, 1, \dots, S$, and the let OSC_{as} be the cost per operating service per contract s per year a , then the annual operating service contract cost is given as:

$$SC_a = \sum_{s=0}^S OSC_{as} \quad (5.20)$$

- Materials cost (MC_a): Let qm_{ma} be the quantity of material m required per year a , and let pm_{ma} be the price of the unit material m , where M is index of the materials used per year a , $m=0,1..M$. Then the materials cost per year a is given as:

$$MC_a = \sum_{m=0}^M qm_{ma} \cdot pm_{ma} \quad (5.21)$$

- Utilities cost (UC_a): Let uc_{ua} be quantity of the utility u consumption per year a , and let up_{ua} be the price of unit utility u , where U index of the utilities used per year a , $u=0,1..U$. Then the utilities cost per year a is given as:

$$UC_a = \sum_{u=0}^U uc_{ua} \cdot up_{ua} \quad (5.22)$$

- Overhead cost (OC_a): Let or_a be the overhead factor used to determine the amount of general overhead cost from revenue per year a , which is usually determined in the contract between the government and the contractor, then the overhead cost per year a is given as:

$$OC_a = or_a \cdot Rev_a \quad (5.23)$$

- Petroleum transport (TC_a): Let TCT_a , TCP_a be petroleum transport cost per tanker, petroleum transport cost per pipeline per year a respectively, then the petroleum transport cost in the same year is given as:

$$TC_a = TCT_a + TCP_a \quad (5.24)$$

3. Fiscal cost

Let $SurfaceFee_a$, $Bonus_a$, Roy_{aw} and TAX_a be surface fee, bonus, royalty and tax in the year a respectively, then the fiscal cost per year a ($FiscalCost_a$) is given as:

$$FiscalCost_a = SurfaceFee_a + Bonus_a + Roy_{aw} + TAX_a \quad (5.25)$$

Let $Area$ be the size of the project area, and let $Surfacefee_1_a$, $Surfacefee_2_a$ be the surface fee rate pre-production per hectare, surface fee rate after-production per unit of production per year a respectively. Also, let P_a be the total production per year a , then the surface fee in the year a is given as:

$$Surfacefee_a = Area \cdot Surfacefee_1_a + Surfacefee_2_a \cdot P_a \quad (5.26)$$

Let $Bonus1_a$; $Bonus2_a$; $Bonus3_a$; $Bonus4_a$; $Bonus5_a$; $Bonus6_a$ be commercial bonus, bonus at first commercial production, bonus based on cumulative production (as amount), bonus based on cumulative production (as percentage), bonus based on production rate for specified period and signature bonus respectively in the same year a , then the total bonus per year a is given as:

$$Bonus_a = Bonus1_a + Bonus2_a + Bonus3_a + Bonus4_a + Bonus5_a + Bonus6_a \quad (5.27)$$

Let ω be the index used to calculate the royalty, and it is defined as follows.

$$\omega = \begin{cases} 1 & \text{if Royalty based on revenue} \\ 2 & \text{if Royalty based on production} \end{cases} \quad (5.28)$$

Let Roy_{ra} , Roy_{fa} are royalty rate per year a , royalty factor per unit of production per year a , then the royalty per year a is given as:

$$Roy_{a\omega} = \begin{cases} Roy_{ra} \cdot Rev_a & \text{if } \omega = 1 \\ Roy_{fa} \cdot P_a & \text{if } \omega = 2 \end{cases} \quad (5.29)$$

Let TAX_a be the taxes per year a , let $TAXin_{ya}$, $TAXrate_{ya}$, be the taxable income per tax y per year a , tax rate per tax y per year a respectively; and let y be the index of tax types applied year a , where $y = 0, 1, \dots, Y$, then the yearly tax (TAX_a) is given as:

$$TAX_a = \sum_{y=0}^Y TAXin_{ya} TAXrate_{ya} \quad (5.30)$$

The depreciation method for tax purposes is called capital allowances and is determined either by the tax law in the country or is defined in the contract between the host government and the petroleum company. In the EcoPetro_Model the intangible CAPEX is depreciated in the year of

occurrence, and the tangible CAPEX is depreciated using one of the following depreciation methods:

- Straight line depreciation: Let bv be the book value of the depreciable assets, $Ulife$ is the useful life of the depreciable assets, then the depreciation charge per year a (De_a) is given as:

$$De_a = \frac{bv}{Ulife} \quad (5.31)$$

- Declining Balance: Let bv be the book value of the depreciable asset, $Cuml.DBDB_{a-1}$ be the cumulative declining balance depreciation per year $a-1$, and let $DepRate$ be the yearly depreciation rate, then the depreciation charge per year a (De_a) is given as:

$$De_a = DepRate \times (bv - Cuml.DBDB_{a-1}) \quad (5.32)$$

- Unit of production: Let bv be the book value of the depreciable asset, P_a is the production per year a , $ResRemStart_a$ is the reserves remaining at the begin of year a then the depreciation charge per year a (De_a) is given as:

$$De_a = \frac{P_a}{ResRemStart_a} \times bv \quad (5.33)$$

4. Economic indicators

Let φ be the index of methods which are available to share the revenue between the contractor and the host government (fiscal regime type)

$$\varphi = \begin{cases} 1 & \text{if service contract is used} \\ 2 & \text{if production sharing contract is used} \end{cases} \quad (5.34)$$

And let $NCF_{a\varphi}$ be net cash flow per year a given method φ , and $OPEX_{at}$, $CAPEX_a$, $Bonus_a$, Roy_a , $Surfeacefee_a$, REV_a , CPS_a , $Costpetroleum_a$, TAX_a , $Aband_a$ be operating cost, capital cost, bonus, royalty, rental, revenue, contractor profit share, cost recovery, tax and abandonment respectively in the same year, then $NCF_{\varphi a}$ is given as:

$$NCF_{a\varphi} = \begin{cases} (CPS_a + Costpetroleum_a) - (OPEX_{at} + CAPEX_a + TAX_a + Aband_a + Bonus_a) & \text{if } \varphi = 1 \\ REV_a - (OPEX_{at} + CAPEX_a + TAX_a + Aband_a + Bonus_a + Roy_a + Rental_a) & \text{if } \varphi = 2 \end{cases} \quad (5.35)$$

It must be noted that the cost recovery $Costpetroleum_a$ per year a is given as:

$$Costpetroleum_a = UnCostRec_a + OPEX_a + De_a + Others_a \quad (5.36)$$

where $UnCostRec_a$ is unrecovered costs carried over from previous periods to year a , $OPEX_a$ is operating cost per year a ; De_a is depreciation per year a ; $Others_a$, other costs which can be recovered per year a .

Let i be the discount rate and $NCF_{a\varphi}$ the net cash flow in the year a , then the discounted cash flow in the same year is given as:¹⁰

$$DCF_a = NCF_{a\varphi} / (1 + i)^{a+0.5} \quad (5.37)$$

The net present value (NPV) for the total project is given as:

$$NPV = \sum_{a=0}^A DCF_a \quad (5.38)$$

The internal rate of return (IRR) of a project is the value of the discounted rate which equates the project's NPV to zero and is given as:

$$0 = \sum_{a=0}^A \frac{NCF_{a\varphi}}{(1 + IRR)^a} \quad (5.39)$$

Let b be the Payback period of the project used to fulfil the following equation:

$$\sum_{a=0}^b NCF_{a\varphi} \geq 0 \quad (5.40)$$

5. Government and contractor take indicators

Let $CT_{\pi\varpi a}$ be the contractor take in the year a based on the fiscal regime type π and method ϖ , where π is given as:

$$\pi = \begin{cases} 1 & \text{if the fiscal regimes is production sharing contrcat} \\ 0 & \text{else} \end{cases} \quad (5.41)$$

¹⁰ The mid-year discounted cash flow is used as mentioned previously in section 3.2

$$\varpi = \begin{cases} 1 & \text{if the contractor take based on revenue} \\ 0 & \text{if the contractor take based on net cash flow} \end{cases} \quad (5.42)$$

Let $CostPetroleum_a$, CPS_a , REV_a , $Bonus_a$, $Surfacefee_a$, Roy_a and Tax_a be the cost petroleum, contractor profit share, revenue, bonus, surface fee, royalty and tax respectively in the same year a , then the $CT_{\pi a}$ is given as:

$$CT_{\pi \varpi a} = \begin{cases} CPS_a + CostPetroleum_a - TAX_a - Bonus_a & \text{if } \pi = 1 \text{ and } \varpi = 1 \\ NCF_{a\varphi} & \text{if } \pi = 1 \text{ and } \varpi = 0 \\ Rev_a - Bonus_a - Surfacefee_a - Roy_a - TAX_a & \text{if } \pi = 0 \text{ and } \varpi = 1 \\ NCF_{a\varphi} & \text{if } \pi = 0 \text{ and } \varpi = 0 \end{cases} \quad (5.43)$$

Let CPS_{rate} be the contractor profit share rate, then the contractor profit share (CPS_a) in the same year a is given as:

$$CPS_a = CPS_{rate} \cdot (Rev_a - Roy_a - CostPetroleum_a) \quad (5.44)$$

Let $GT_{\pi a}$ be the government take in the year a based on the fiscal regime type π ; let $Bonus_a$, Roy_a , GPS_a , TAX_a , $SurfaceFee_a$ be bonus, royalty, government profit share, tax and surface fee respectively in the same year a , then the $GT_{\pi a}$ is given as¹¹:

$$GT_{\pi a} = \begin{cases} Roy_a + SurfaceFee_a + Bonus_a + TAX_a + GPS_a & \text{if } \pi = 1 \\ Roy_a + SurfaceFee_a + Bonus_a + TAX_a & \text{if } \pi = 0 \end{cases} \quad (5.45)$$

Let GPS_{rate} be the Government profit share rate, then the contractor profit share (GPS_a) in the same year a is given as:

$$GPS_a = GPS_{rate} \cdot (Rev_a - Roy_a - CostPetroleum_a) \quad (5.46)$$

It is common in the petroleum industry to express the take indicators as a percentage:

$$CT\%_{\pi \varpi a} = \begin{cases} \frac{CT_{\pi \varpi a}}{Rev_a} \cdot 100 & \text{if } \varpi = 1 \\ \frac{CT_{\pi \varpi a}}{NCF_{a\varphi} + GT} \cdot 100 & \text{if } \varpi = 0 \end{cases} \quad (5.47)$$

¹¹ The total amount of the Government take does not change regardless of the method applied to calculate the take indicator, either based on the revenue or based on the net cash flow.

$$GT\%_{\pi a} = \begin{cases} \frac{GT_{\pi a}}{Rev_a} \cdot 100 & \text{if } \varpi = 1 \\ \frac{GT_{\pi a}}{NCF_{a\varphi} + GT} \cdot 100 & \text{if } \varpi = 0 \end{cases} \quad (5.48)$$

6. Expected monetary value

Let ς be the index to calculate the expected monetary value for one phase of petroleum project life and is given as:

$$\varsigma = \begin{cases} 1 & \text{if the expected monetary value calculated based on NPV} \\ 0 & \text{if the expected monetary value calculated based on NCF} \end{cases}$$

Let $POS_exploration$ be the probability of success for the exploration phase. Let $Explor$, $Explor_{discounted}$ be the undiscounted exploration cost, discounted exploration cost respectively, let NPV , NCF the net present value, net cash flow of the total project life respectively, and then the expected monetary value of the project for the exploration phase ($EMV_exploration_\varsigma$) is given as:

$$EMV_exploration_\varsigma = \begin{cases} NPV \cdot POS_exploration - Explor_{discounted} (1 - POS_exploration) & \text{if } \varsigma = 1 \\ NCF \cdot POS_exploration - Explor (1 - POS_exploration) & \text{if } \varsigma = 0 \end{cases} \quad (5.49)$$

Let $POS_development$ be the probability of success for the development phase. Let $CAPEX$, $CAPEX_{discounted}$ be the undiscounted capital cost, discounted capital cost respectively, and then the expected monetary value of the project in the development phase ($EMV_evelopment_\varsigma$) is given as:

$$EMV_evelopment_\varsigma = \begin{cases} NPV \cdot POS_development - CAPEX_{discounted} (1 - POS_development) & \text{if } \varsigma = 1 \\ NCF \cdot POS_development - CAPEX (1 - POS_development) & \text{if } \varsigma = 0 \end{cases} \quad (5.50)$$

where $(1 - POS_exploration)$ represents the probability of failure for the exploration phase and $(1 - POS_development)$ represents the probability of failure for the development phase.

5.3 Modeling with Excel

Economics models based on Excel are widely used by petroleum companies to evaluate current and future projects. The functionality provided with current integrated software packages allows developing very flexible and comprehensive petroleum economic models. Therefore, the EcoPetro_Model is based on Excel 2010.

The model provides economics analysis of petroleum exploration and production projects based on deterministic data in order to establish a base model that can be used in further analysis to deal with the risk in petroleum projects. The user can navigate the EcoPetro_Model using Excel tabs, or using an index sheet.

The model is organized into four sets that are color coded. The first set (metadata set) includes one sheet (in gray) which provides a good support in order to better understand the model. This gives a brief overview of the model in addition to be a navigation tool for the other sheets. It also summarizes the model variables and their codes; furthermore, the named ranges used in the functions of the model are described.

The second set (input set) also includes one sheet (colored in plum), where all input in the input sheet is defined. To fill in the data, the user can click on the boxes at the top of the sheet to be navigated directly into the input cells set. Manual input cells are shown with blue text against a gold background. Previously defined input cells can be identified by using the control boxes (e.g. the spin button), so the user can select the method of calculation of some variables such as royalty rate, or the unit of production.

The third set (computation set) includes fourteen sheets (colored in cyan), so that each main endogenous variable (e.g. total production) is computed in a single sheet to represent in clear form the computation of model variables, while computation of the decision variables is summarized in a single sheet called indicators sheet.

The fourth set (output set) includes two sheets (colored in red), displaying the results and the sensitivity analysis.

To better understand the structure of the EcoPetro_Model, the input values are classified into 6 groups: production; price; field cost; surface fee and bonus; royalty, depreciation and tax; in addition to decision variables.

To begin with the implementation of the EcoPetro_Model, the production data must be entered, as shown in figure 13, including project type (offshore, onshore), production type (oil, gas, gas and oil), the number of drilled wells and also the daily production per well is then

entered in addition to the selection of the appropriate unit for the production. The time schedule (start year of the project, start of production decline, license end year, etc.).

All of this input data flows to the production sheet which then computes the annual production of the project, and then the yearly production is involved in the course of revenue calculation, also as contribution to royalty or profit share computation.

Revenue, royalty and profit share are part of the indicators sheet, the essential components for the calculation of the final results of the model.

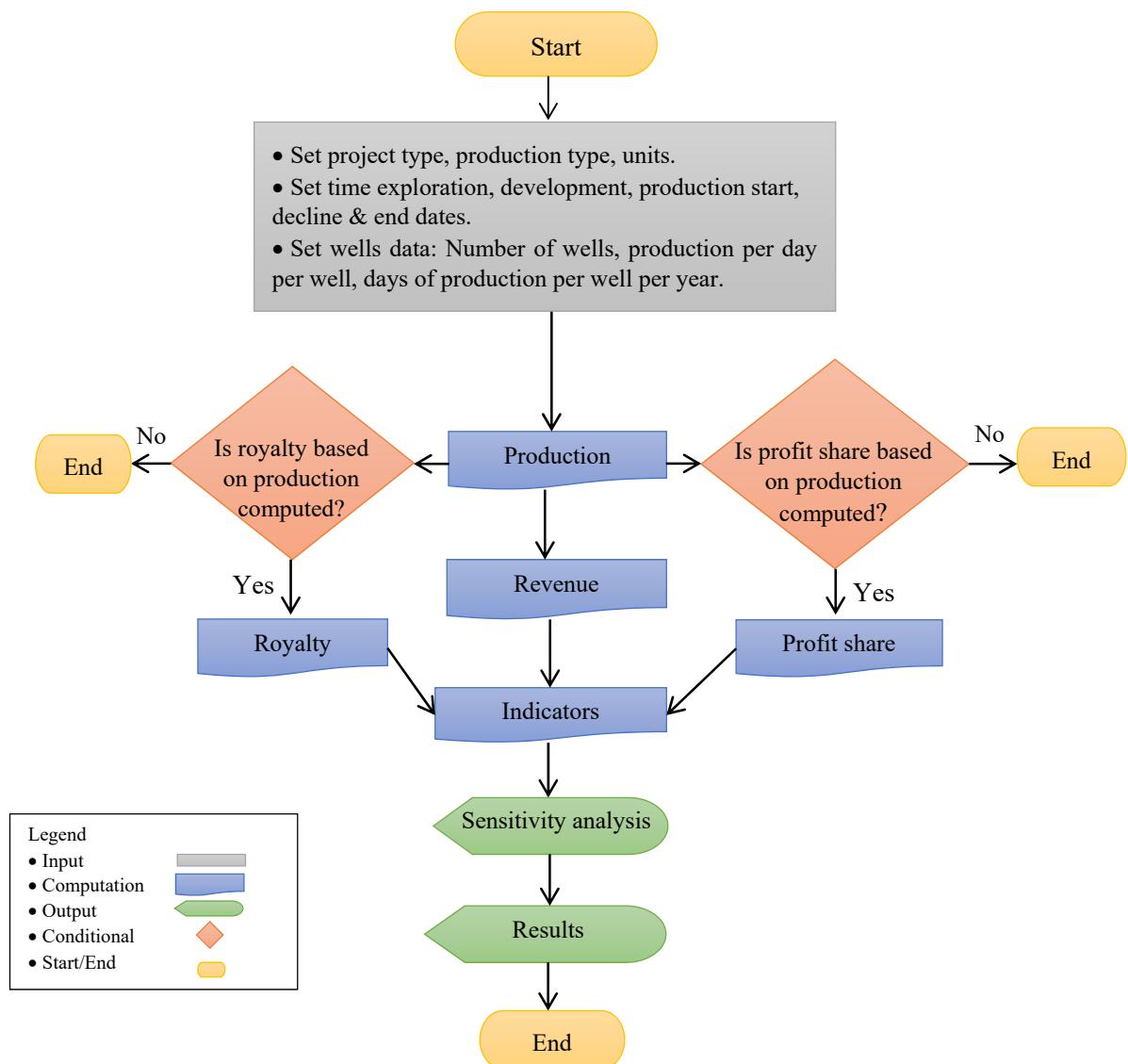


Figure 13: Flowchart of the first input group of the EcoPetro_Model

The second group of input data represents the price forecasts. It is feasible to apply three price scenarios: high, low and medium in real value (Fig. 14). In order to obtain the price values in money of the day (nominal value), the inflation rate must be chosen also.



Figure 14: Flowchart of the second input group of the EcoPetro_Model

Figure 14 illustrates also the flow of nominal petroleum prices in EcoPetro_Model. Nominal prices instead of production data could be used in the computation of the profit share and royalty. It is important to mention that the user can identify only one basis to calculate royalty rate or profit share. For example, the royalty rate is defined based on the production rate or based on the price level. The flow of the data from computation sheets into the output sheets remains the same.

Next, the third group of data must be entered; figure 15 shows the necessary field cost input data. For CAPEX computation in nominal value it is necessary to enter the available real exploration costs and actual development costs in accordance with the planned timing.

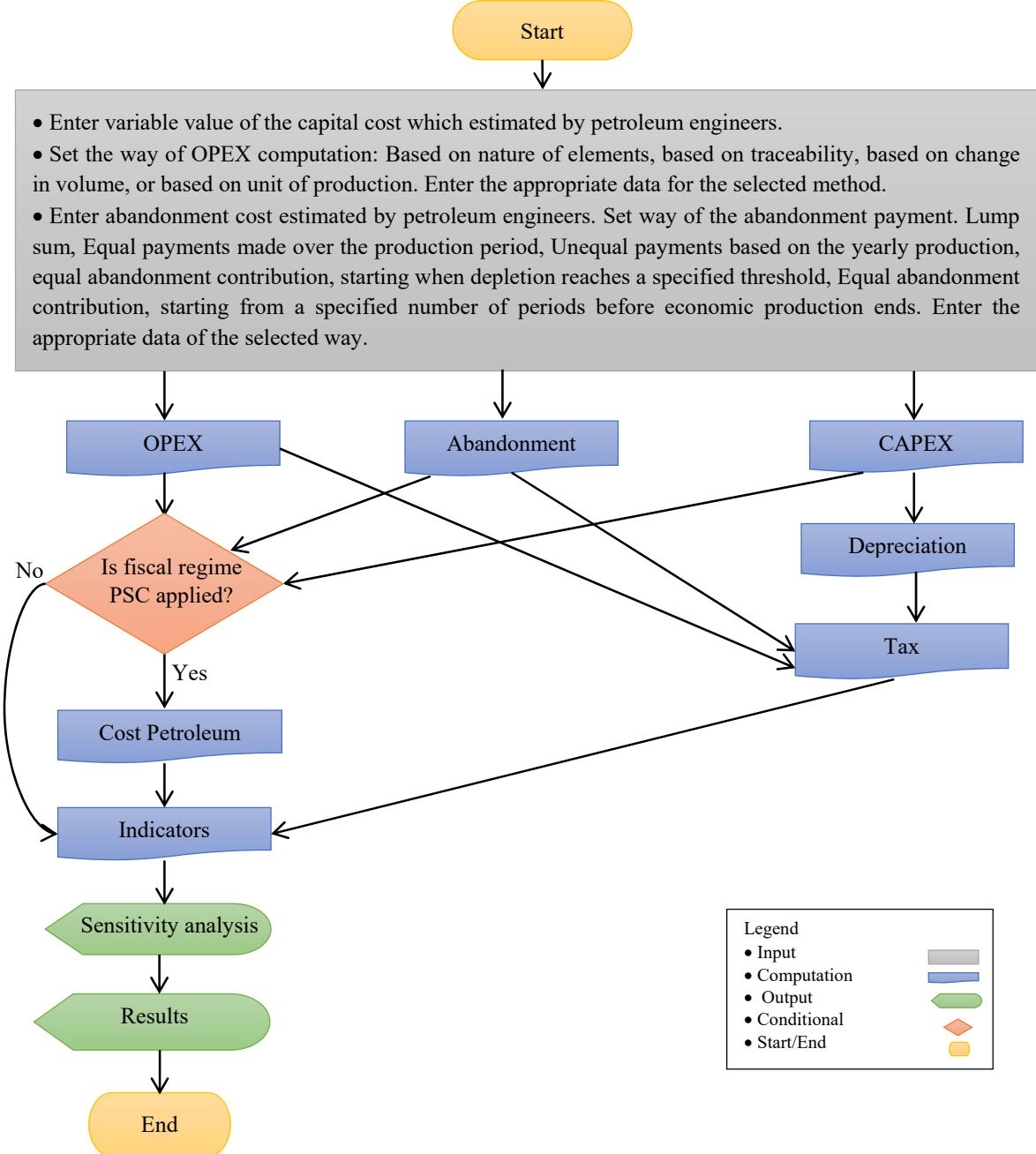


Figure 15: Flowchart of the third input group of the EcoPetro_Model

In order to compute the nominal operating cost, a method must be selected from four options (OPEX based on nature of elements, OPEX based on traceability, OPEX based on change in

volume, and OPEX based on unit of production) and the appropriate values entered accordingly. The choice of the appropriate OPEX computation method depends on the data available to the user and must be appropriate to the situation.

Abandonment cost data must then be entered and the method of the abandonment payment schedule selected; this sometimes depends on the fiscal regime of the host government as mentioned in section 3.2.1.2. It is also clear that field cost contributes in the computation of depreciation, cost petroleum and indicators.

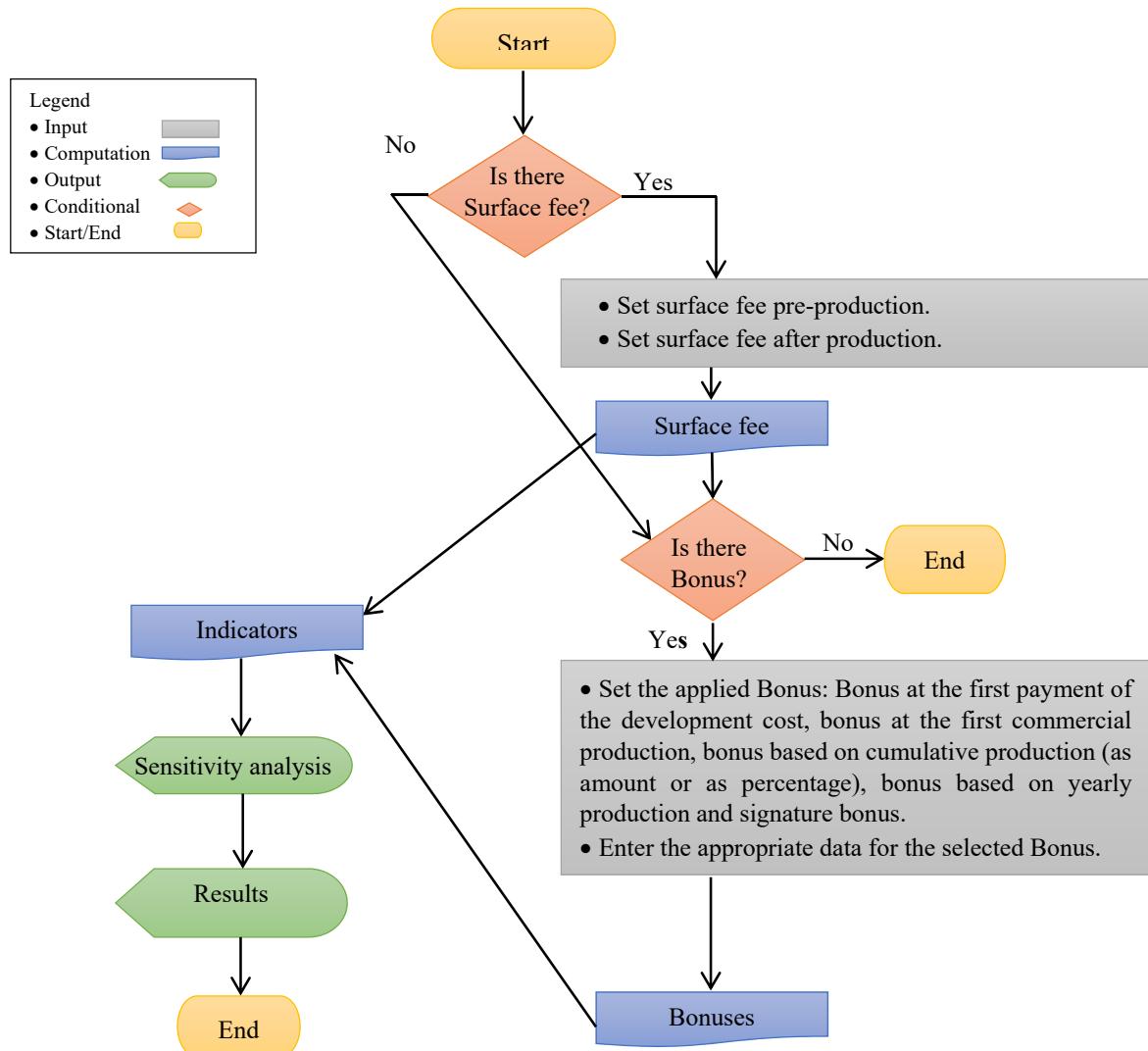


Figure 16: Flowchart of the fourth input group of EcoPetro_Model

Figure 16 illustrates the fourth group of input data, where it must be defined whether the surface fee or bonus is applied, and then the appropriate variable values must be entered.

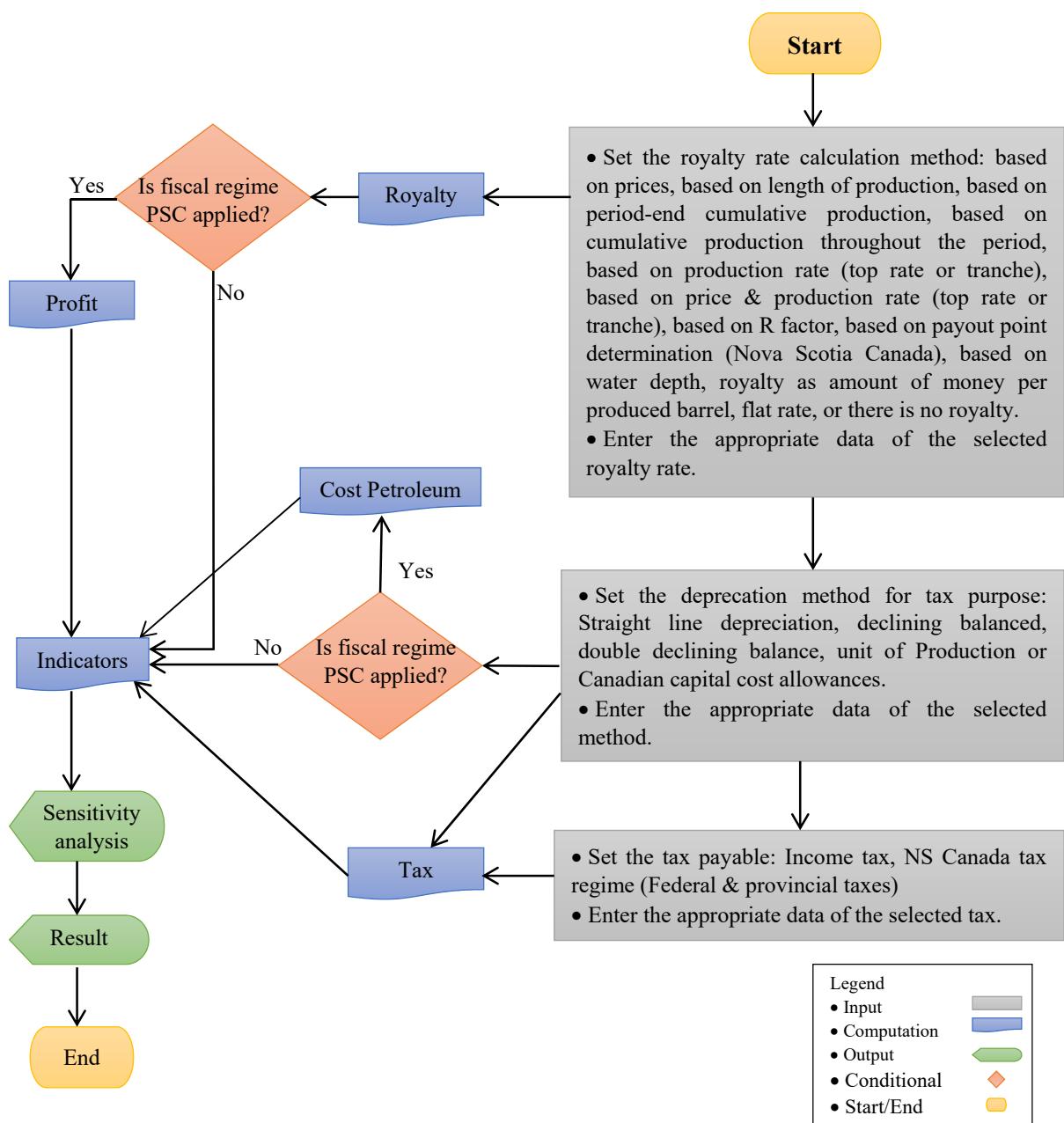


Figure 17: Flowchart of the fifth input group of the EcoPetro_Model

The royalty rate computation method must be chosen, as shown in figure 17; EcoPetro_Model allows the user to choose one of fourteen alternative royalty rates. The appropriate data of the selected royalty rate must be entered.

The depreciation must then be defined, as one of five available depreciation methods. Depreciation represents an important variable when computing the liable taxes; EcoPetro_Model

provides several alternatives to calculate the taxes. All of these input data contribute to the computation of the final output.

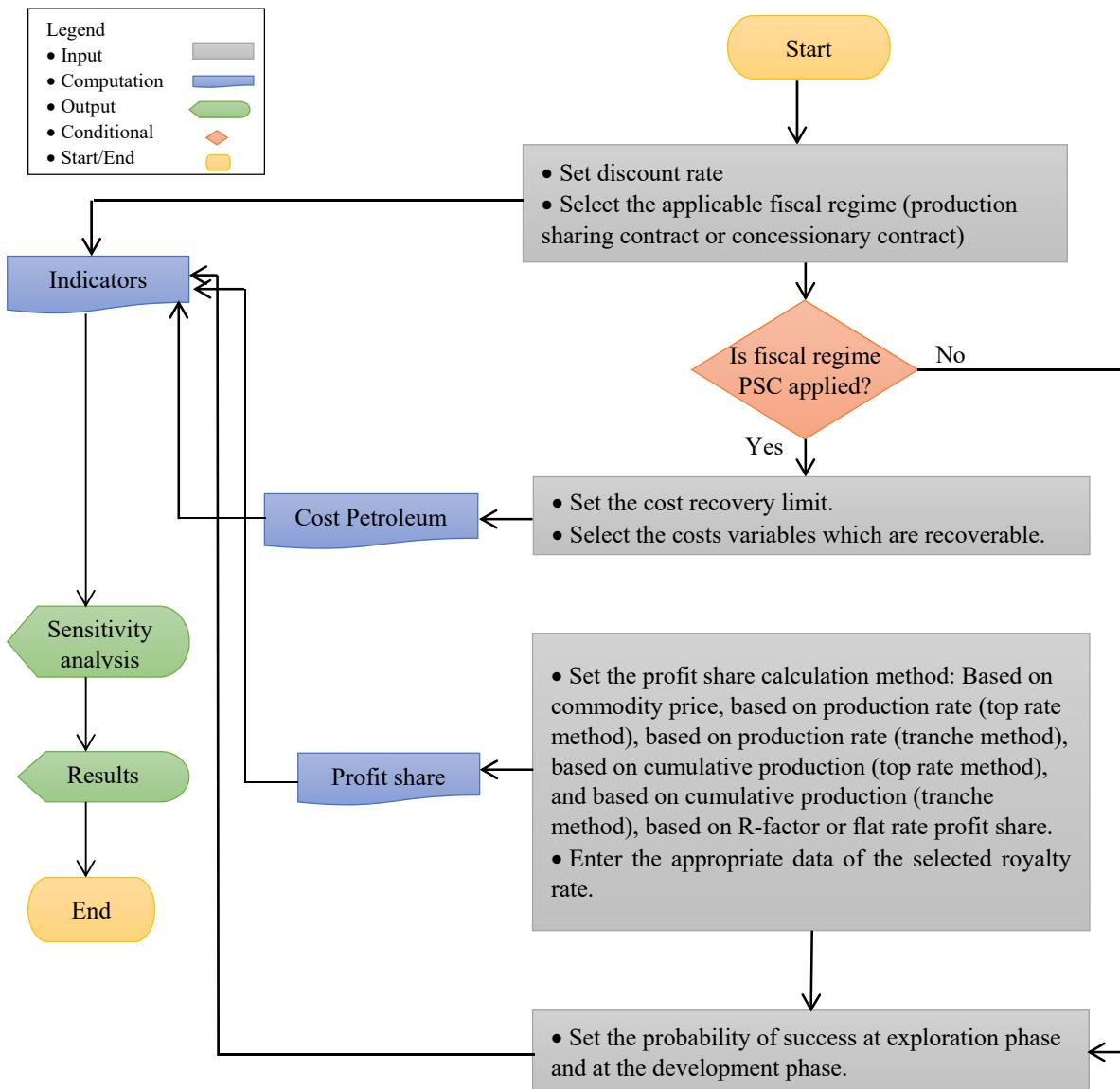


Figure 18: Flowchart of the sixth input group of the EcoPetro_Model

Finally, the discount rate which is used to discount the future values into the present value must be entered, in addition to the fiscal regime which is applied in the project. When the production sharing contract (PSA) is applied then the appropriate variable values must be entered to compute the cost petroleum and the profit share. In order to compute the expected monetary value of the project at different phases of the project life cycle, the probability of success of the total project at each phase must be defined (see figure 18).

Chapter 6 Implementation of EcoPetro_Model

6.1 Oil Economics Model (EcoPetro_Oil)

For the implementation of the oil economics model (EcoPetro_Oil) the OPEC country Nigeria was chosen as exemplary, where petroleum production represents a primary cornerstone in the Nigerian economy, and Nigeria stands among the top 10 nations in proven petroleum reserves (Abdel-Aal & Alsahlawi, 2014). In order to organize investments in the petroleum sector, the Nigerian government operates both a concession and a contractual system.

6.1.1 Nigeria Production Sharing Contract

According to Akhigbe (2008), production sharing contracts have recently become the preferred choice for Nigeria in participation in the exploration of petroleum resources, particularly for offshore areas. The production sharing contract (PSA) is signed by Nigerian National Petroleum Corporation (NNPC) and any foreign petroleum company or group of companies (consortium). In most cases the operator for the consortium is the contractor.

Contractors are taxed under the Petroleum Profits Tax Act (PPTA) 2004. The taxable income of the petroleum companies is subject to tax at 85%, but this percentage is lowered to 65.75% during the first 5 years of operation. Petroleum companies who operate under production sharing contracts will be liable to tax at a rate of 50% from their own profit from the oil share (Lawal, 2013).¹²

The accounting depreciation for contractor companies is not allowed as capital allowances, and another annual allowance rates for tangible capital costs are applied: during the first four years 20% yearly, paid from the depreciable capital, 19% paid for the fifth year, and intangible capital cost is to be depreciated in the year of occurrence.

The contractor is also liable to pay signature and/or production bonuses. Since the year 2000 the amount of bonuses has varied from about one million dollars for early production sharing contracts to 30 million dollars (Adenikinju & Oderinde, 2009), so the bonus values and type represent an item for negotiation between the contractor and the Nigerian government.

The applied royalty rate is a variable rate based on the water depth for the offshore projects, while for onshore projects the royalty rate is fixed, as shown in table 2.

¹² The new petroleum Law in Nigeria (Petroleum Industry Bill) is delayed because many reasons, one of the most important reasons is the political corruption in Nigeria.

After royalty payments, the contractor recovers costs. Operating cost is recoverable in the year of occurrence, while the capital cost is recoverable in equal instalments over a five year period.

Table 2: Nigerian royalty rates

Area	Royalty rate %
Up to 200 meters water depth	16.67%
In areas from 201 to 500 meters water depth	12%
In areas from 501 to 800 meters water depth	8%
In areas from 801 to 1,000 meters water depth	4%
In areas in excess of 1,000 meters water depth	0%
Onshore	10%

(modified after Lawal, 2013)

The revenue remaining after royalty payment and cost recovery is shared between the contractor and the Nigerian government using one of the rates shown in table 3. It is obvious that according to the Nigerian fiscal regimes, the increase of possible investment costs raises the rate of the contractor share where investments in deep offshore projects are more difficult and costly.

Table 3: Nigerian profit oil share rates

Area	Production (mm bbl)	Government profit share %	Contractor profit share %
Onshore	> 100	52%	48%
	100 – 200	57%	43%
	> 200	60%	40%
Shallow Offshore (< 200 m)	> 30	60%	40%
	30 – 50	62%	38%
	> 50	65%	35%
Deep Offshore (> 200 m)	> 350	20%	80%
	351 – 750	35%	65%
	751-1000	45%	55%
	1001-1500	50%	50%
	> 1500	60%	40%

(adopted from Akhigbe, 2008)

6.1.2 Structural Equations System

The structural equations system of the EcoPetro_Oil model is an extract from the structural equations system of the standard petroleum economics model (EcoPetro_Model) in Chapter 5. The variable codes remain the same, as defined in Chapter 5.2 and listed in Appendix II. In order

to focus on the core of the model, in the following equations oil price and cost are given in nominal values.

- Oil production and revenue equations are defined as:

$$OP_{wa} = \begin{cases} BOPD_w \cdot DOP_w a (100\% - OPd\%_w) & \text{if } a = Ody_w \\ DOP_w a - 1 (100\% - OPd\%_w) & \text{if } a > Ody_w \\ BOPD_w \cdot DOP_w a & \text{else} \end{cases} \quad (6.1)$$

$$P_a = \sum_{w=1}^W OP_{wa} \quad (6.2)$$

$$Rev_a = PO_a \cdot P_a \quad (6.3)$$

- Field cost and its correlated variables are defined as:

$$FieldCost_a = CAPEX_a + OPEX_a + Abandon_a \quad (6.4)$$

$$CAPEX_{ra} = Explor_a + Develop_a \quad (6.5)$$

$$Explor_a = G&G_Ser_a + ExplorDrill_Ser_a \quad (6.6)$$

$$Develop_a = Develop_Drill_a + Develop_Surface_a + Develop_Trans_a + Develop_other_a \quad (6.7)$$

$$OPEX_a = OPEX_{perUnit} \cdot P_a \quad (6.8)$$

$$Abandon_a = Remove_a + Plug_a + Treat_a \quad (6.9)$$

- Fiscal cost and its correlated variables are defined as:

$$Bonus_a = BonusI_a \quad (6.10)$$

$$Roy_a = Roy_{ra} \cdot Rev_a \quad (6.11)$$

$$TAX_a = \sum_{y=0}^Y TAXin_{ya} TAXrate_{ya} \quad (6.12)$$

- Key business indicators and the expected monetary values are defined as:

$$NCF_a = (CPS_a + Costpetroleum_a) - (OPEX_a + CAPEX_a + TAX_a + Aband_a + Bonus_a) \quad (6.13)$$

$$Costpetroleum_a = UnCostRec_a + OPEX_a + De_a + Others_a \quad (6.14)$$

$$De_a = bv / Ulife \quad (6.15)$$

$$DCF_a = NCF_a / (1 + i)^{a+0,5} \quad (6.16)$$

$$NPV = \sum_{a=0}^{a=A} DCF_a \quad (6.17)$$

$$0 = \sum_{a=0}^A \frac{NCF_a}{(1 + IRR)^a} \quad (6.18)$$

$$EMV_exploration = NPV \cdot POS_exploration - Explor_{discounted} (1 - POS_exploration) \quad (6.19)$$

$$EMV_development = \\ NPV \cdot POS_development - CAPEX_{discounted} (1 - POS_development) \quad (6.20)$$

- The government and contractor take indicators are defined as:

$$CT_a = CPS_a + CostPetroleum_a - TAX_a - Bonus_a \quad (6.21)$$

$$CPS_a = CPS_{rate} \cdot (Rev_a - Roy_a - CostPetroleum_a) \quad (6.22)$$

$$GT_a = GPS_a + Roy_a + Bonus_a + TAX_a \quad (6.23)$$

$$GPS_a = GPS_{rate} \cdot (Rev_a - Roy_a - CostPetroleum_a) \quad (6.24)$$

The dependencies between the variables of EcoPetro_Oil model are visualized in figure 19, where the variables which are shown in box form represent exogenous variables, the variables

which are shown in boxes with rounded corners are endogenous variables and the decision variables are shown in oval forms.

The annual depreciation is shown as an exogenous variable in the model graph, while it is an endogenous variable in the structural equations system in order to simplify the model graph.

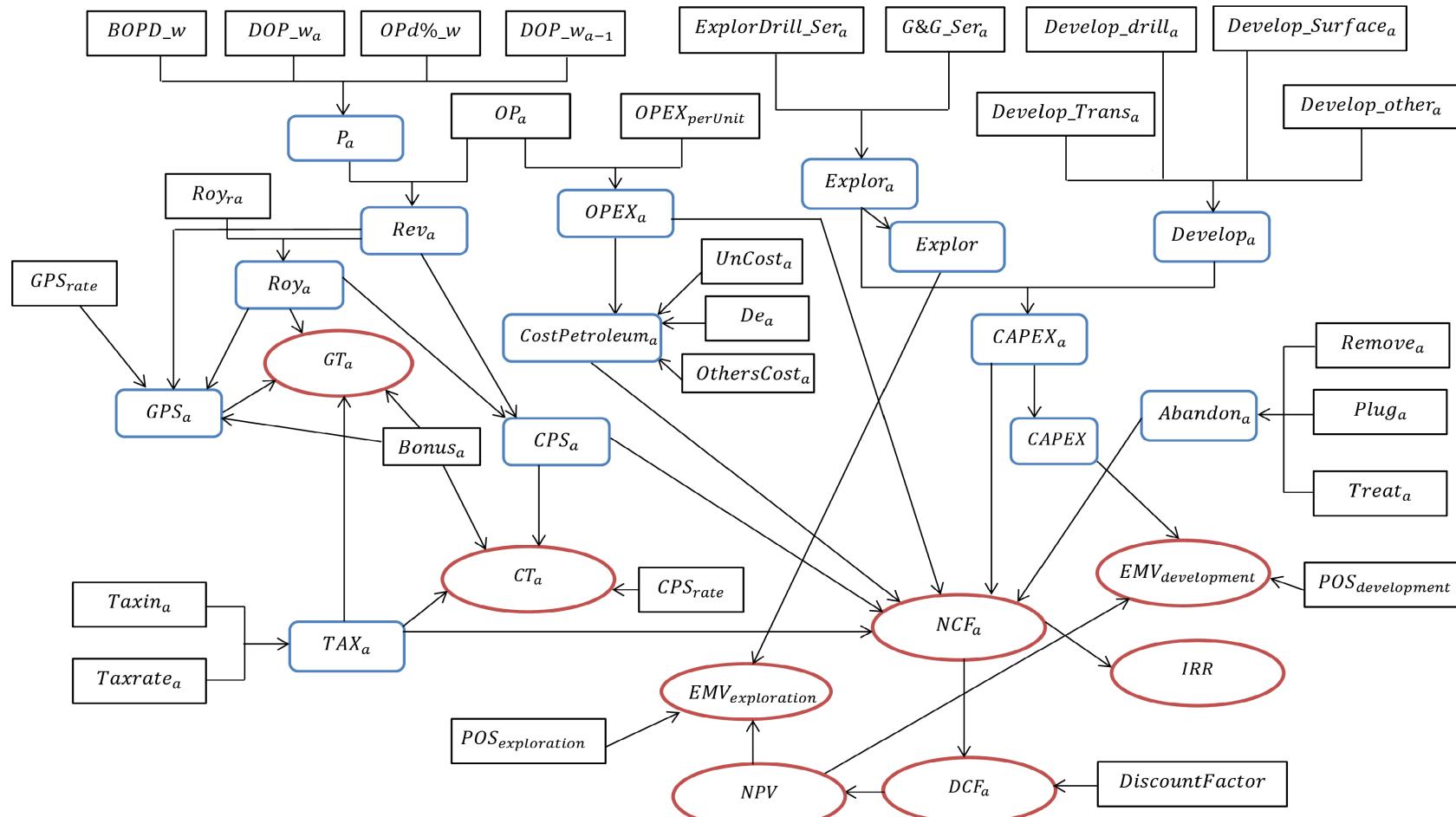


Figure 19: Model graph of the EcoPetro_Oil

6.1.3 Input & Output of EcoPetro_Oil model (Base Case)

The oil reserves (proven and recoverable) of EcoPetro_Oil model are estimated at 353 mm bbl, with a probability of success (POS) for the exploration phase equal to 12% and a probability of success for the development phase equal to 60% considering the total of risk factors remaining after a successful exploration phase such as technical, financial and political risks. The exploration phase will start in 2016 and will last for four years, with total exploration costs of 380 million dollars. The development phase is planned for the period from 2020 to 2023, with total development cost estimated to be 1,910 mm \$. The production curve of EcoPetro_Oil model is shown in figure 20.

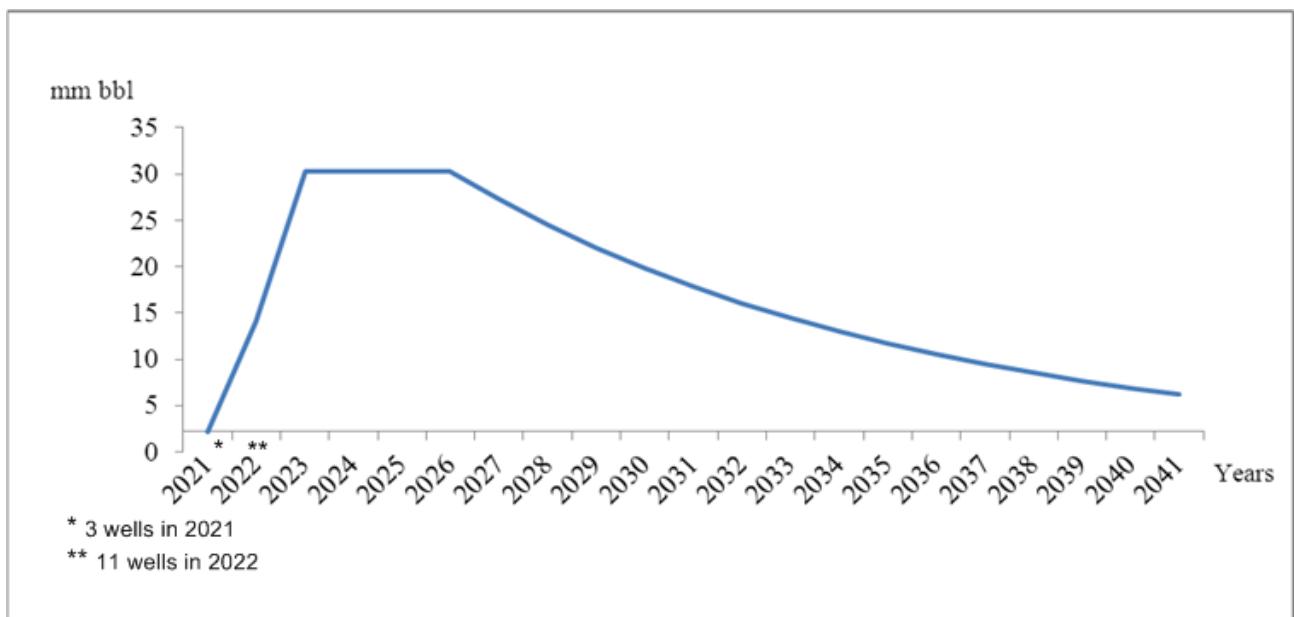


Figure 20: Production curve of EcoPetro_Oil model base case

First production will begin in 2021 and extraction initially will be from 3 wells until the following year, where 11 production wells will be achieved by 2022. The plateau phase is estimated to last for 4 years, and then production will start to decline in 2027 with a decline rate of 10% until the year 2041 (production end year). In the last year all wells will be abandoned.

A yearly abandonment provision equal to 30 mm \$ is taken into account as cost of oil over 10 years from 2031 to 2041. The oil price in real value is given as a flat rate equal to 80 \$ per barrel; the inflation rate is estimated as 2%. The net cash flow of EcoPetro_Oil model is discounted at 15% discount rate, the OPEX per barrel is estimated at 7.5 \$/bbl in real value.

All of the input data, in addition to the associated output, are denoted as base case (BC) of the EcoPetro_Oil model.

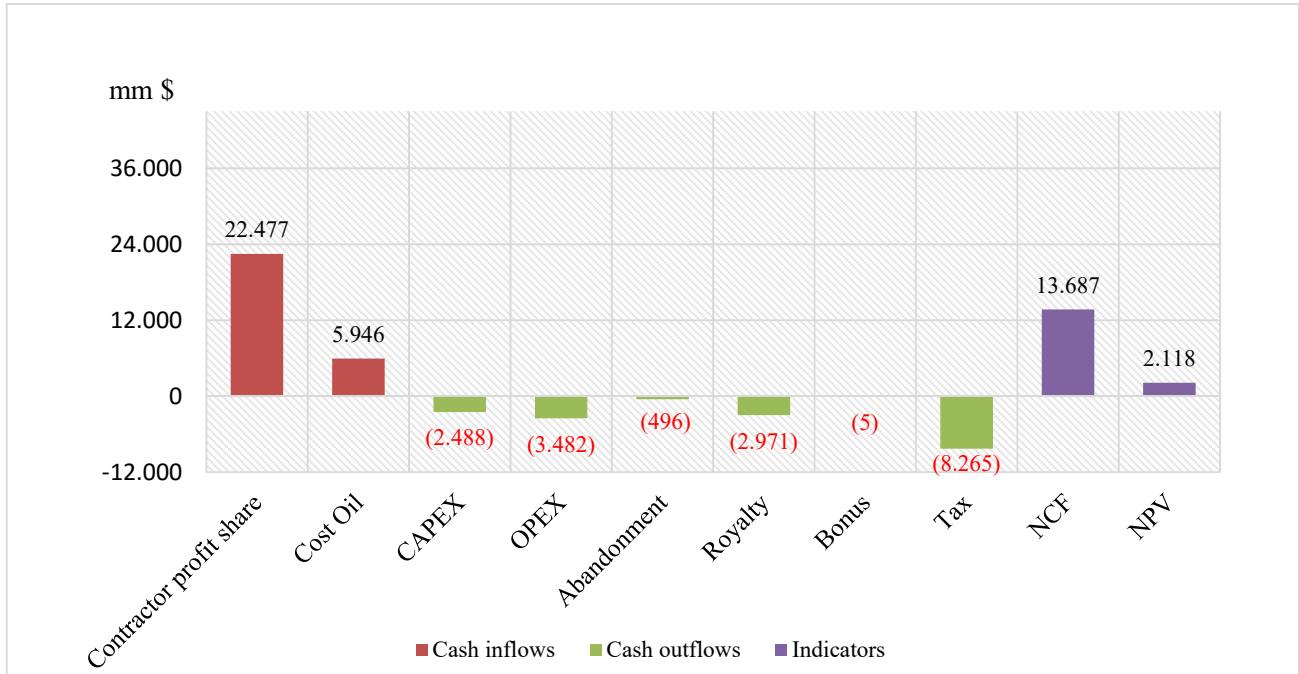


Figure 21: NPV of EcoPetro_Oil model (base case)

In order to better understand the correlation between the NPV and other variables for EcoPetro_Oil model base case, figure 21 illustrates the mechanism of the NPV calculation, where the contractor gets profit oil share and cost oil instead of the revenue from oil sales. In addition to field cost (CAPEX, OPEX, and Abandonment), the contractor pays a fiscal cost (royalty, bonus and tax). It is interesting to note that tax is the greatest cost for the contractor, and abandonment cost is considered to be insignificant for the EcoPetro_Oil model base case compared to other field cost variables. The same applies to bonus cost compared with other fiscal cost variables.

In figure 22 the cumulative NCF of the EcoPetro_Oil model base case is shown and the year 2023 as the payback period year, where for the first time the project achieves a positive cumulative net cash flow.

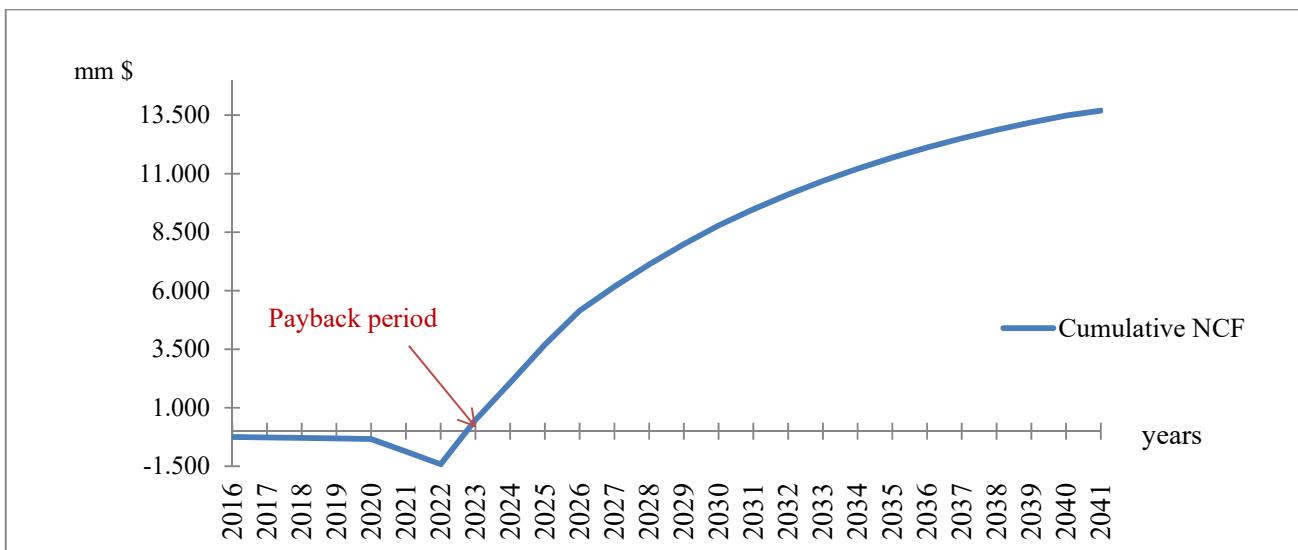


Figure 22: Cumulative NCF/Payback period of EcoPetro_Oil model base case

The yearly government and contractor take as a percentage are shown in figure 23, where it is obvious that the government take in the early years of the production is clearly less than the contractor take because the contractor recovers his intangible capital cost from available revenue before the share of oil profit is made.

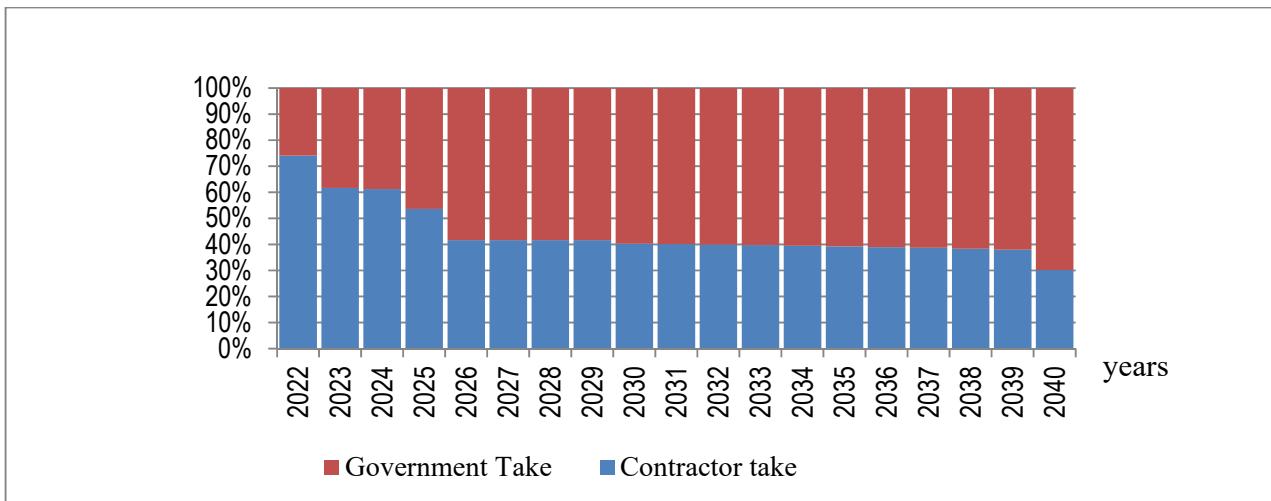


Figure 23: Government & contractor take of EcoPetro_Oil model base case

By using expected monetary values (EMV) calculated based on NPV@ 15%, a decision tree is drawn in figure 24, so that decision makers can see the possible loss and reward of each planned phase in addition to its expected monetary value. It is obvious that the deterministic base case of EcoPetro_Oil model achieves positive EMVs for the exploration and the development phases.

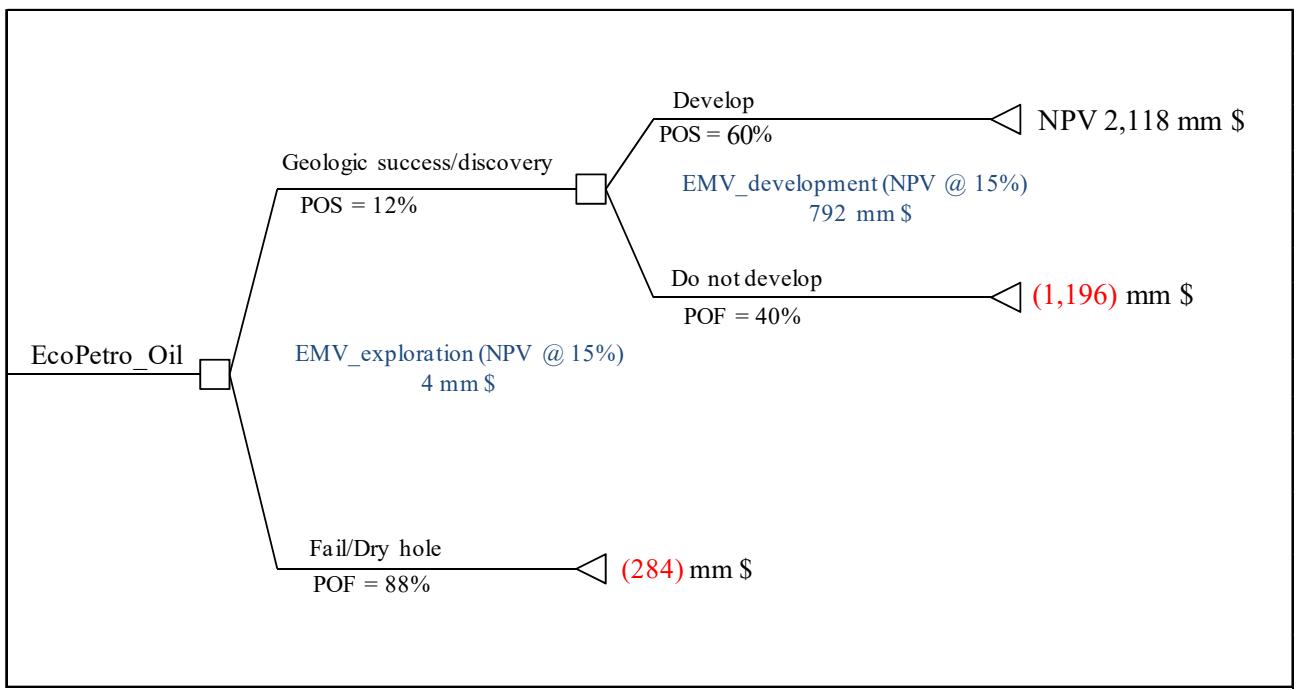


Figure 24: Decision tree of EcoPetro_Oil model base case

Figure 25 shows an extract from the Excel sheet (Summary). The aggregate values of inflow and outflow variables are shown in nominal values and discounted values.

It can be stated that the base case of EcoPetro_Oil model is an acceptable project based on the initial evaluation, where the NPV is equal to 2,118 mm \$; the payback period is seven years and the internal rate of return is equal to 42%.

Additionally, expected monetary values of the exploration and development phases are positive for net present value discounted at 15%.

The contractor take as percentage of revenue is 54% and the government take as percentage of revenue is 46%, while the contractor take as percentage of net cash flow is 45%; government take is equal to 55%. The reduction in contractor take percentage in the second calculation method due to not considering the field cost as take (share) for the contractor.

Summary of EcoPetro_Oil model output (base case)			
Net Cash Flow (NCF) mm \$		Discounted Cash Flow (DCF) mm \$	
Item	mm \$	Item	mm \$
Revenue	37,141	Revenue	6,545
Contractor profit share	22,477	Contractor profit share	3,684
Cost Oil	5,946	Cost Oil	1,413
Subtotal	28,423	Subtotal	5,097
CAPEX	(2,488)	CAPEX	(1,196)
OPEX	(3,482)	OPEX	(614)
Abandonment	(496)	Abandonment	(30)
Field cost	(6,466)	Field cost	(1,840)
Royalty	(2,971)	Royalty	(524)
Bonus	(5)	Bonus	(4)
Surface fee	0	Surface fee	0
Tax	(8,265)	Tax	(1,140)
Fiscal cost	(11,241)	Fiscal cost	(1,667)
Contractor NCF (NPV @ 0%)	13,687	Contractor NPV @ 15%	2,118
IRR	42%		-
Payback period (year)	7		
EMV_exploration mm \$ (NPV @ 15%)	4		
EMV_development mm \$ (NPV @ 15%)	792		
Contractor take as percentage of revenue net of field cost (mm \$)	13,687		45%
Government take as percentage of revenue net of field cost (mm \$)	16,988		55%
Contractor take as percentage of revenue (mm \$)	20,153		54%
Government take as percentage of revenue (mm \$)	16,988		46%

Figure 25: Summary of EcoPetro_Oil model output (base case)

6.1.4 Sensitivity Analysis

6.1.4.1 Deterministic Sensitivity Analysis

A sensitivity analysis based on deterministic data is a common approach used in the petroleum industry to evaluate exploration and production projects. In the EcoPetro_Oil model, oil production, oil price and field cost (CAPEX, OPEX and abandonment) are assumed to be the key variables of key business indicators.

Two types of deterministic sensitivity analyses are implemented; variation of one variable at a time and variation of more than one variable at a time (multi-variable variations)¹³. In the case of variation of one variable at a time, increase rate (maximum value) and decrease rate (minimum value) for each key variable are defined dependent upon the real values, as shown in table 4.

¹³ The implemented scenarios and variation rates are based on available knowledge in literature and analysts' experience.

Table 4: Input scenarios of deterministic sensitivity analysis, case: one variable variation at a time (EcoPetro_Oil model)

Key variables	Unit	Input value (Medium)	Increase rate	Increase value (maximum)	Decrease rate	Decrease value (minimum)
Oil price	\$/bbl	80	+ 40%	112	- 40%	48
Oil production	BOPD/well	6,000	+ 20%	7,200	- 20%	4,800
OPEX	mm \$	2,650	+ 20%	3,444	- 20%	1,855
CAPEX	mm \$	2,232	+ 20%	2,678	- 20%	1,786
Abandonment	mm \$	330	+ 20%	396	- 20%	264

The NCFs resulting from the single factor sensitivity analysis are shown in figure 26; the vertical axis represents only the value NCF at the deterministic base case of EcoPetro_Oil model, each of the bars to the right of the figure reflects the increase of NCF generated by the change of one factor at a time. A decrease in the field cost by 20% increased the NCF by 4%, from 13,687 mm \$ to 14,213 mm \$, while a decrease in the oil price by 40% decreased the NCF by 40% from 13,687 mm \$ to 8,242 mm \$. A rise in the oil production by 20% increased the NCF by 14% from 13,687 mm \$ to 15,866 mm \$.

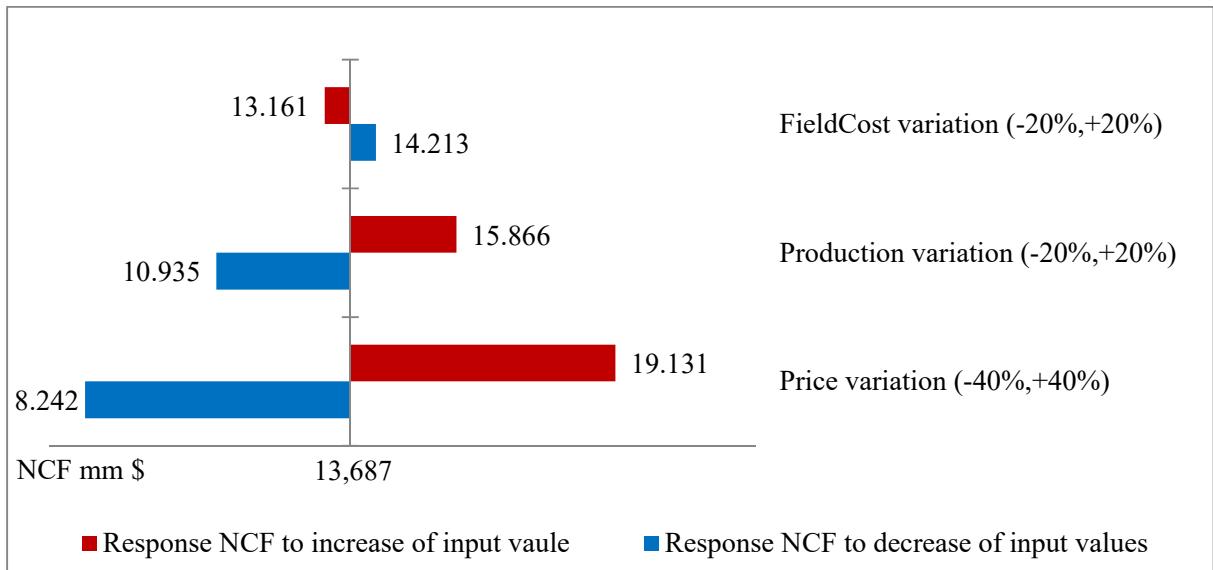


Figure 26: Response of NCF to one variable variation at a time (EcoPetro_Oil model)

Figure 27 shows the NPVs response to the variation of one variable at a time, and it is interpreted in a similar way to figure 26. A rise in the oil price by 40% increased the NPV by 46% from 2,118 mm \$ to 3,096 mm \$, a reduction in the field cost by 20% increased the NPV by

11% from 2,118 mm \$ to 2,352 mm \$ and a reduction in the production by 20% decreased the NPV by 24% from 2,118 mm \$ to 1,613 mm \$.

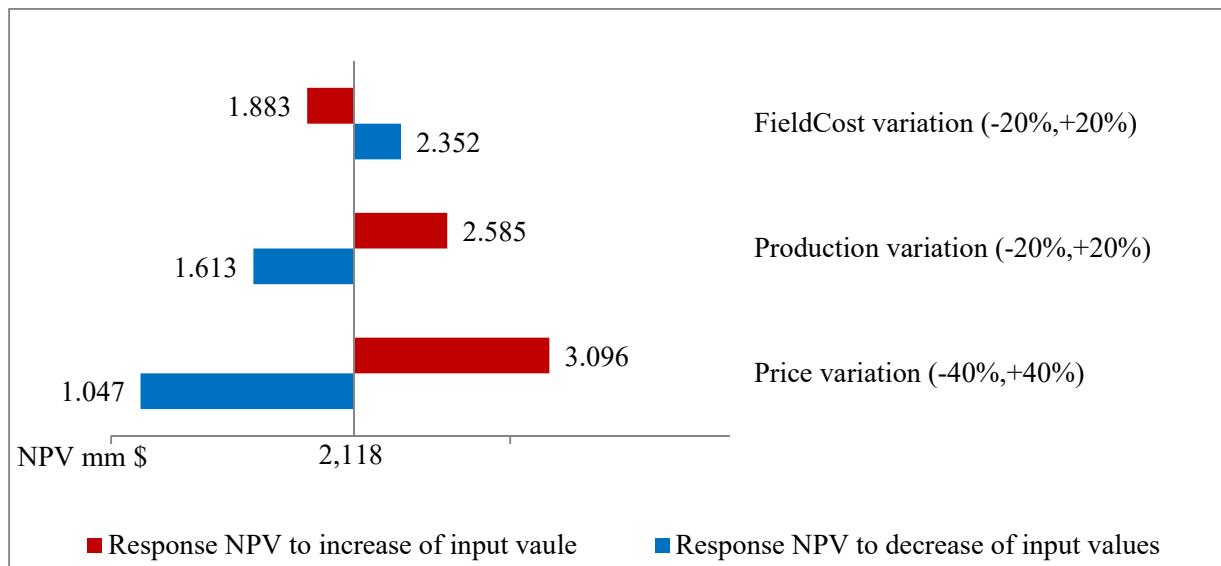


Figure 27: Response of NPV to one variable variation at a time (EcoPetro_Oil model)

The IRR was more sensitive to the decrease of field cost, as shown in figure 28, where the IRR raised from 42% to 52% when the field cost decreased by 20%. A reduction of production by 20% reduced the IRR by 11%, from 42% to 37% and a price reduction by 40% reduced the IRR by 29%, from 42% to 30%.

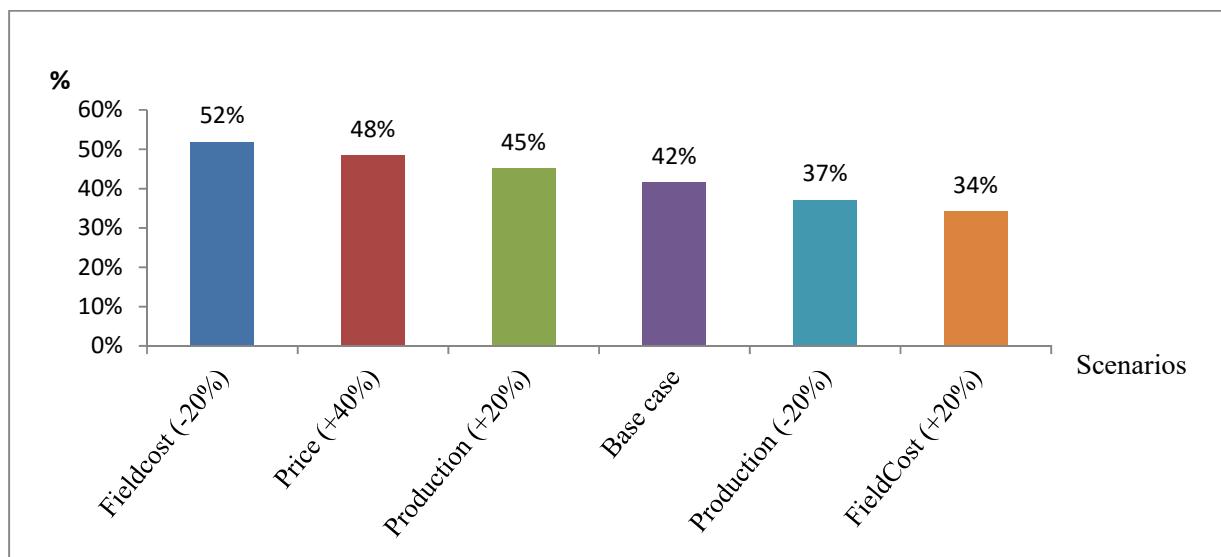


Figure 28: Response of IRR to one variable variation at a time (EcoPetro_Oil model)

In figure 29, it is shown that the payback period of EcoPetro_Oil model base case increased from seven to eight years when the field cost increased by 20% or price reduced by 40% otherwise the payback period remains 7 years.

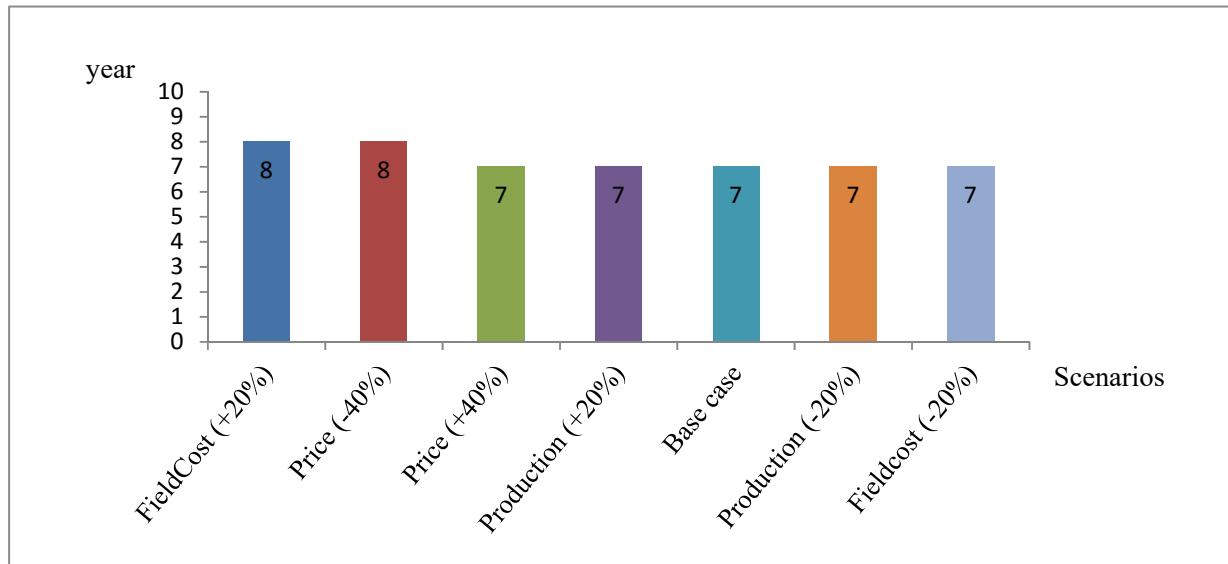


Figure 29: Response of payback period to one variable variation at a time (EcoPetro_Oil model)

The contractor take percentage based on net cash flow (increases with the decrease of oil price or the decrease of oil production, which means the currently fiscal regime of Nigeria is in favour to the contractor (Fig. 30) in particular in offshore and deepwater projects. A rise in price or production has a negative impact on the contractor take percentage. For example, the contractor take percentage is reduced from 45% to 42% if the price increases by 7%.

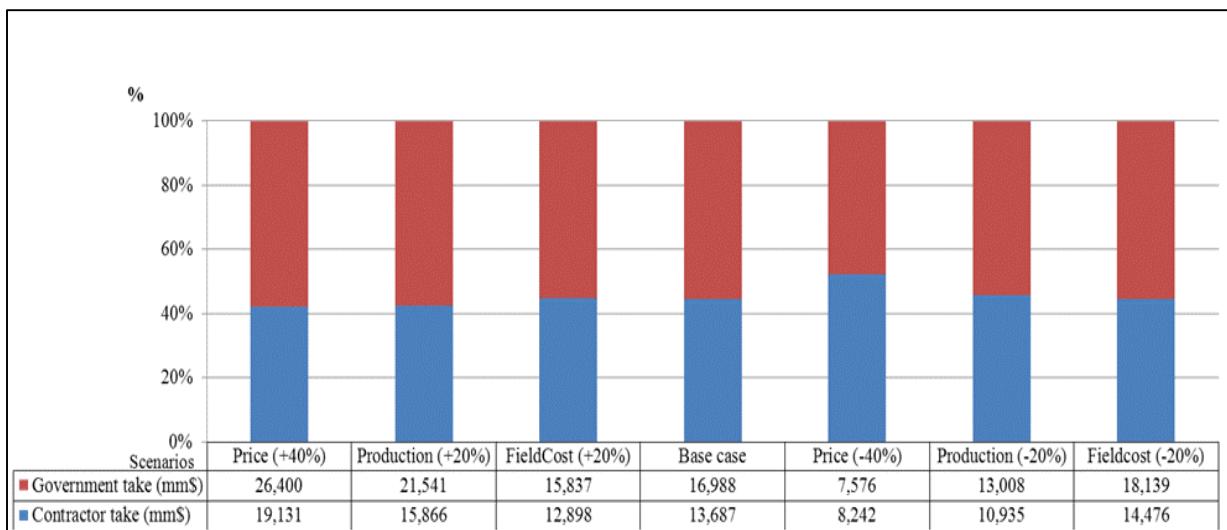


Figure 30: Response of take indicators to one variable variation at a time (EcoPetro_Oil model)

Expected monetary value for the exploration phase recorded three negative values; a (-124) mm \$ response to the reduction of the oil price, a (-57) mm \$ response to the reduction of the oil production, and a (-74) response to the increase of the field cost (Fig. 31).

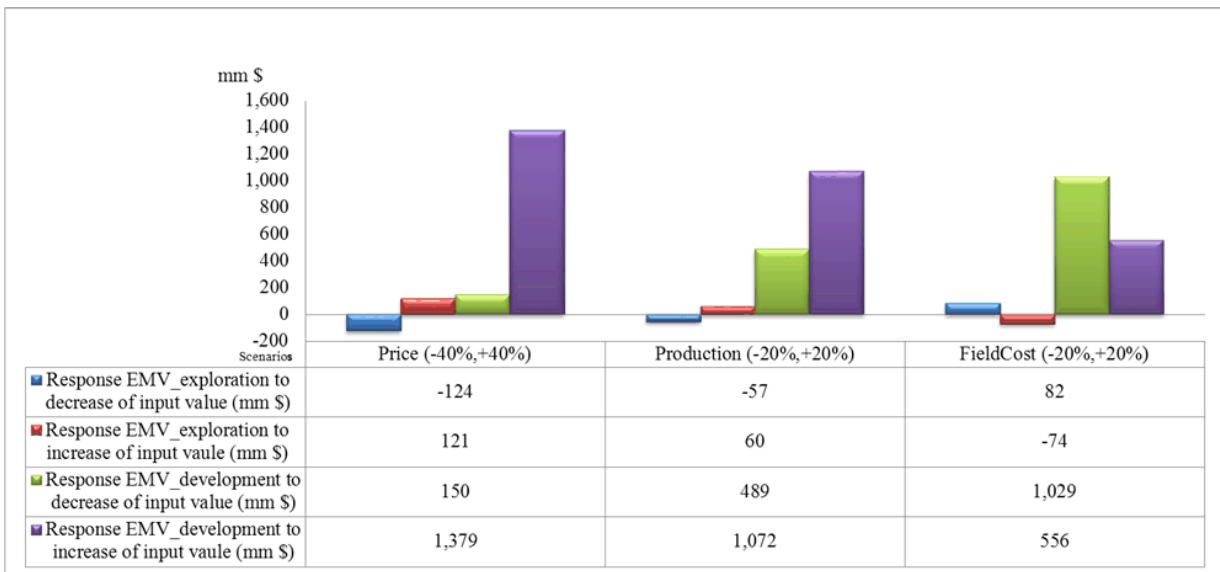


Figure 31: Response of EMVs to one variable variation at a time (EcoPetro_Oil model)

One factor at a time sensitivity analysis does not take into consideration the correlation between the key variables and the fact that variation in one or more variables could cause changes in other related variables. Therefore, the next scenarios, summarized in table 5, represent the multi-variable sensitivity analysis scenarios.

Table 5: Input scenarios of deterministic sensitivity analysis, case: multi-variable variations (EcoPetro_Oil model)

Scenario ID	Oil production bbl/d	Price \$/bbl	OPEX mm \$	CAPEX mm \$	Abandonment mm \$
BC	6	80	2,650	2,232	330
G1	+20%	+40%	+20%	+20%	+20%
G2	-20%	-40%	+20%	+20%	+20%
G3	+20%	+40%	-20%	-20%	-20%
G4	-20%	-40%	-20%	-20%	-20%
G5	-20%	-40%	+20%	+20%	+20%
G6	+20%	+40%	-20%	-20%	-20%
G7	-20%	-40%	+20%	+20%	+20%
G8	+20%	+40%	-20%	-20%	-20%

Figure 32 compares the NCF and NPV response to multi-variable sensitivity analysis. The sensitivities in all scenarios are similar. The most optimistic scenario (G3), where the price increases by 40%, production increases by 20% and the field cost decrease by 20%, results a 66% increase in the NCF from 13,687 mm \$ to 22,624 mm \$ and a 69% increase in the NPV from 2,118 mm \$ to 3,968 mm \$. While the most pessimistic scenario (G7) with a reduction in price by 40%, the reduction in production by 20% and an increase in field cost by 20% results a 56% decrease in the NCF from 13,687 mm \$ to 6,020 mm \$ and a 70% decrease in the NPV from 2,118 mm \$ to 409 mm \$.

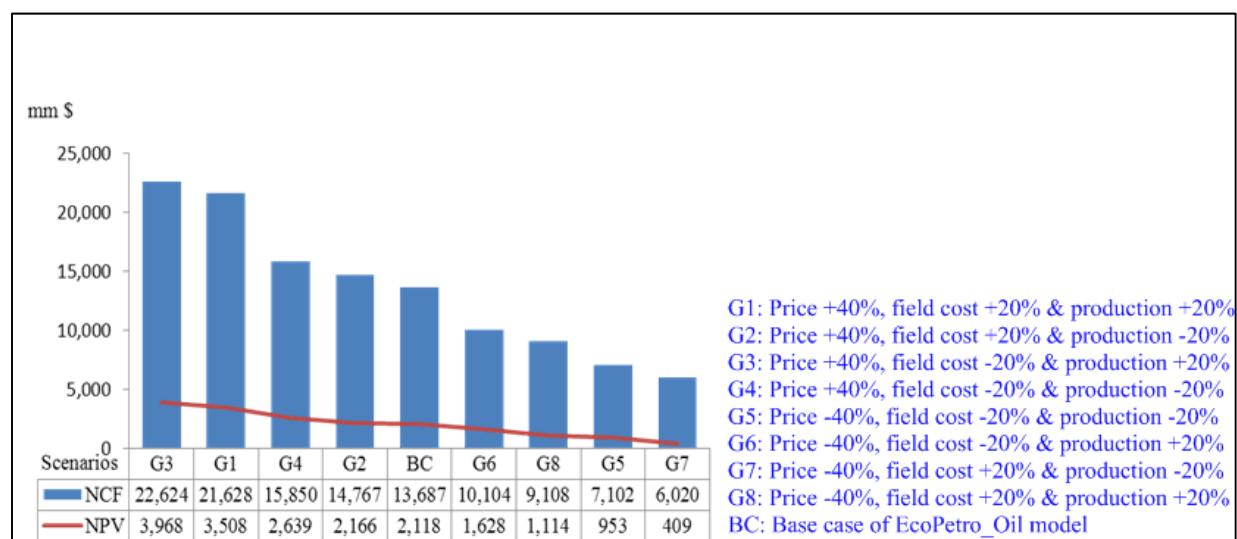


Figure 32: Response of NPV & NCF to multi-variable variations (EcoPetro_Oil model)

The contractor take and the government take resulting from the developed multi-variable sensitivity analysis are presented in figure 33 as percentages. The contractor take increases from 45% to 55% compared with the government take which reduced from 55% to 45% during the reduction of the revenue in the worst scenario (G7).

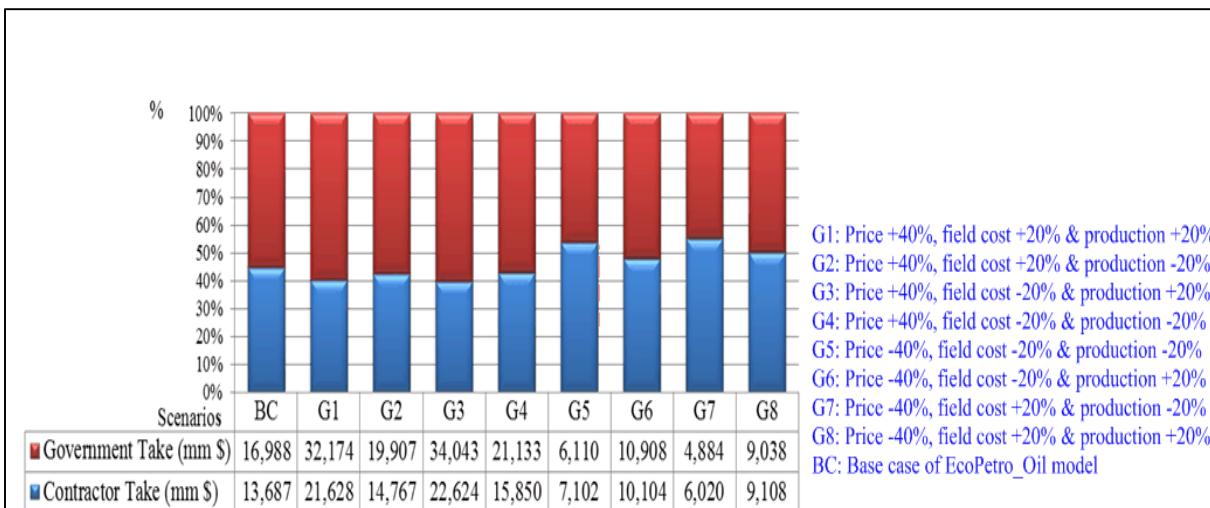


Figure 33: Response of take indicators to multi-variable variations (EcoPetro_Oil model)

The expected monetary values are very sensitive indicators to price, production, and field cost variations, obvious in the worst scenario a negative EMV_exploration equal to (-251) mm \$ and a EMV_development equal to (-329) mm \$ are resulted, as shown in figure 34. In other words, if the decision to invest in EcoPetro_Oil was made based on the EMV indicators and an expected oil price of 48 \$ per bbl, the expected daily oil production per well of 4,800 bbl per day per well with total field cost equal to 5,212 mm \$, the project would be rejected.

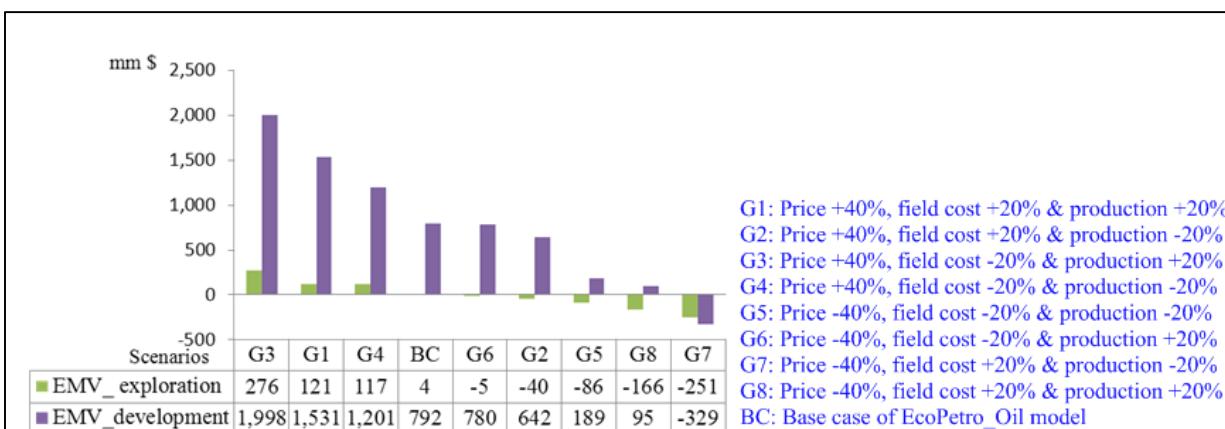


Figure 34: Response of EMVs to multi-variable variations (EcoPetro_Oil model)

Figure 35 shows that the payback period of EcoPetro_Oil model base case is not so sensitive to multi-variable variations and does not become shorter than 7 years, but it became longer; in the worst case scenario (G7) it increases from 7 to 9 years.

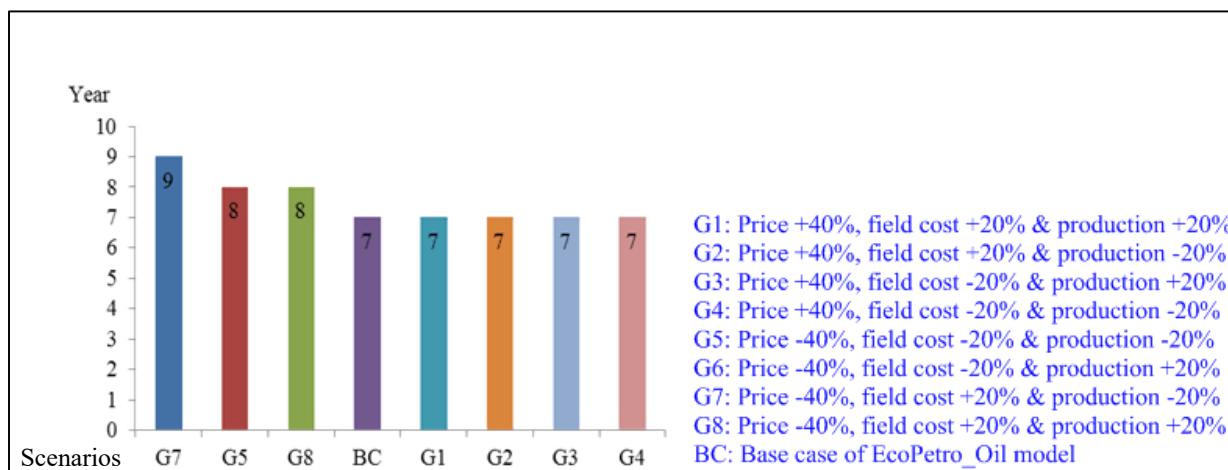


Figure 35: Response of payback period to multi-variable variations (EcoPetro_Oil model)

Figure 36 illustrates the sensitivity of the IRR to multi-variable analysis, where the IRR increased from 42% to 59% when price and production increased and the field cost decreased (G3). The lowest IRR at 21% is registered by decreases in the price by 40%, production by 20% and increased field cost by 20% (G7).

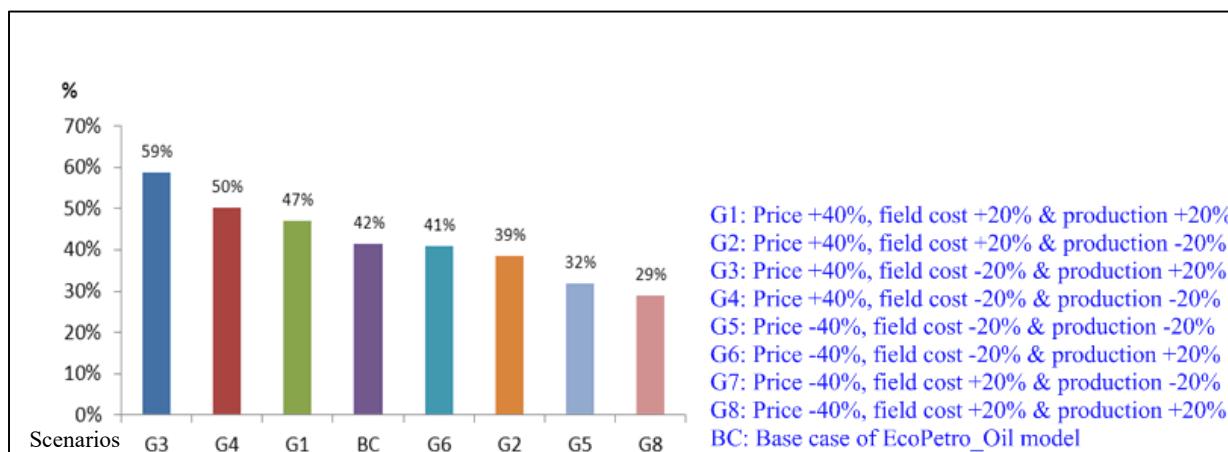


Figure 36: Response of IRR to multi-variable variations (EcoPetro_Oil model)

6.1.4.2 Possibility Sensitivity Analysis

Oil production, oil price and field cost represent the most significant uncertain variables of EcoPetro_Oil model. In order to implement a possibility sensitivity analysis, a degree of uncertainty (error rate) is identified for each uncertain input variable.

While the uncertainties of variables differ according to the petroleum project phase, two possibility analysis scenarios were built, an exploration phase scenario and a development phase scenario, based on aggregate variable values of the whole project, after taking into consideration the inflation impact.

Firstly, and in order to build the exploration phase scenario using FuzzyCalc¹⁴ a $\pm 5\%$ error rate was given for oil production, $\pm 7\%$ was given for oil price¹⁰ and $\pm 3\%$ was given for each from, CAPEX, OPEX and abandonment, to avoid inconsistencies within the model; a $\pm 1\%$ error rate was given for probability of success. Other input variables are assumed to be error free and their values are adopted from the deterministic model.

Figure 37 shows an extract from FuzzyCalc for the NPV. According to the possibility approach, the NPV is about 2,118 mm \$ with an upper bound of 2,714 mm \$ and a lower bound of 1,555 mm \$.

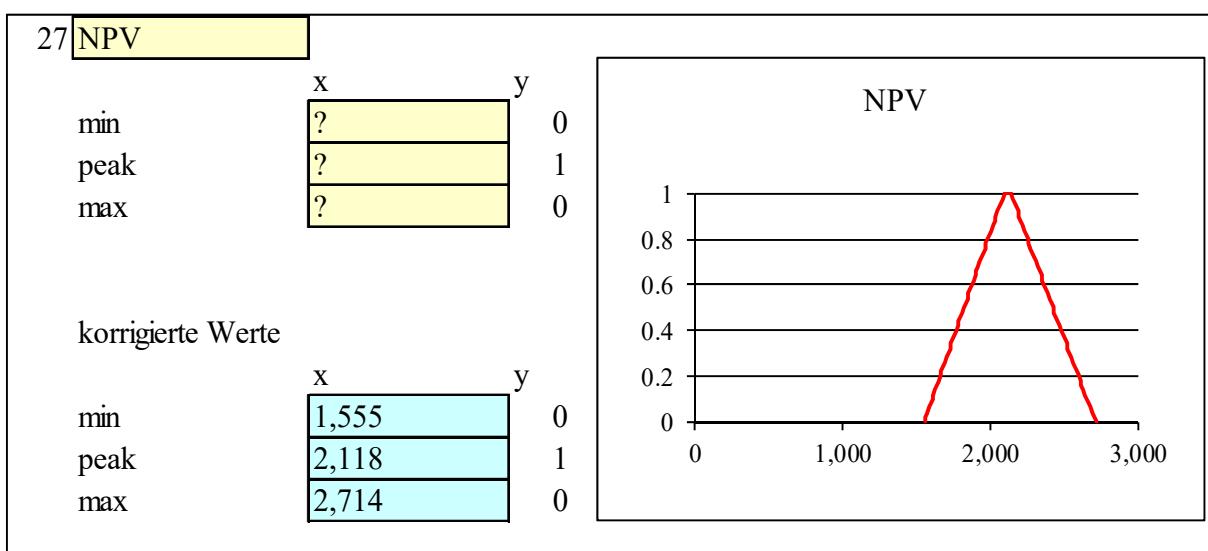


Figure 37: Fuzzy value of NCF calculated based on $\pm 7\%$ error rate of price, $\pm 5\%$ error rate of oil production and $\pm 3\%$ error rate of field cost (EcoPetro_Oil model, exploration phase scenario)

¹⁴ The error rate for the price is based on a standard deviation calculation of yearly price values along project life

The question mark in figure 37 refers to unknown input variable values, after running the FuzzyCalc; its fuzzy value calculated is based on the inserted structural equations system into FuzzyCalc. The IRR and payback period cannot be estimated using FuzzyCalc due to the non-linear character of their equations.

Table 6 collects the prior values (input values) of the EcoPetro_Oil model of the exploration phase possibility scenario and the adjusted values (output values) after running FuzzyCalc of the scenario. It is obvious that the prior and adjusted values of the known input variables are symmetric. The revenue is about of 37,140 mm \$ with error rate $\pm 12\%$, the contractor take is about of 20,153 mm \$ with upper error rate $+ 18\%$ and lower error rate $- 17\%$.

The upper error rate of the government take is $+ 6\%$ and the lower error rate is $- 5\%$ are significant smaller than other error rates output due to the assumption that the input fiscal costs (tax, royalty and bonus) are error free.

The NCF fuzzy value was calculated with a peak value of 13,687 mm \$, with an upper error rate of $+ 28\%$ and a lower error rate of $- 27\%$. The peak value of EMV_exploration is about of 4 mm \$ with too high uncertainty intervals (upper bound 81 mm \$ and lower bound 68 mm \$)¹⁵.

The IRR and payback period cannot be estimated using FuzzyCalc due to the non-linear character of their equations.

¹⁵ The calculation of EMV_exploration using FuzzyCalc appears to be not applicable for the exploration phase before drilling since the uncertainties of variables are still too high.

Table 6: Fuzzy variables before and after adjustment (EcoPetro_Oil model, exploration phase scenario)

Variable	Prior value	Adjusted value
Oil production (mm bbl)	$353 \pm 5\%$	$353 \pm 5\%$
Oil price (\$/bbl)	$105 \pm 7\%$	$105 \pm 7\%$
Revenue (mm \$)	?	$32,379 \pm 12\%$
Royalty (mm \$)	$2,590 \pm 0$	$2,590 \pm 0$
Bonus (mm \$)	4.5 ± 0	4.5 ± 0
Profit share rate contractor	$80\% \pm 0$	$80\% \pm 0$
Profit share rate government	$20\% \pm 0$	$20\% \pm 0$
Government profit oil (mm \$)	?	$5,745 (+ 16\%, - 15\%)$
Contractor profit share (mm \$)	?	$22,478 (+ 16\%, - 15\%)$
Cost oil (mm \$)	$8,265 \pm 0$	$8,265 \pm 0$
OPEX (mm \$)	$3,482 \pm 3\%$	$3,482 \pm 3\%$
CAPEX (mm \$)	$2,488 \pm 3\%$	$2,488 \pm 3\%$
Abandonment (mm \$)	$496 \pm 3\%$	$496 \pm 3\%$
Tax (mm \$)	$8,265 \pm 0$	$8,265 \pm 0$
NCF (mm \$)	?	$13,687 (+ 28\%, - 27\%)$
Contractor take ¹⁶ (mm \$)	?	$20,159 (+ 18\%, - 17\%)$
Government take (mm \$)	?	$16,986 (+ 6\%, - 5\%)$
Discount factor ¹⁷	$15\% \pm 0$	$29\% \pm 0$
NPV @ 15% (mm \$)	?	$2,118 (+ 28\%, - 27\%)$
POS_exploration	$12\% \pm 1\%$	$12\% \pm 1\%$
Discounted exploration cost @ 15%	284 ± 0	284 ± 0
EMV_exploration (mm \$)	?	$4 (+ 81/- 68)$

After a successful exploration phase the development phase starts. At that phase production and field cost variable values get more certainty; therefore a 1% error rate was given for each of the values for the development phase scenario in FuzzyCalc except the error rate of oil price; this is remaining at $\pm 7\%$ as in the exploration phase scenario, since the prediction of the future price level does not get more accurate by successful exploration.

Figure 38 shows the NPV and EMV_development resulting after running the FuzzyCalc for the scenario development phase. The peak value of NPV is 2,118 mm \$ with an upper bound at

¹⁶ The contractor take is here based on revenue; contractor take based on revenue net of field cost is equal to NCF.

¹⁷ Discount factor is calculated based on the deterministic EcoPetro_Oil model and reflects the effective discount rate at which the aggregate net cash flow discounted to get the net present value.

2,684 mm \$ and a lower bound at 1,558 mm \$. The resulting EMV_development fuzzy value is about 792 mm \$ with an upper bound at 1,153 mm \$ and a lower bound at 442 mm \$.

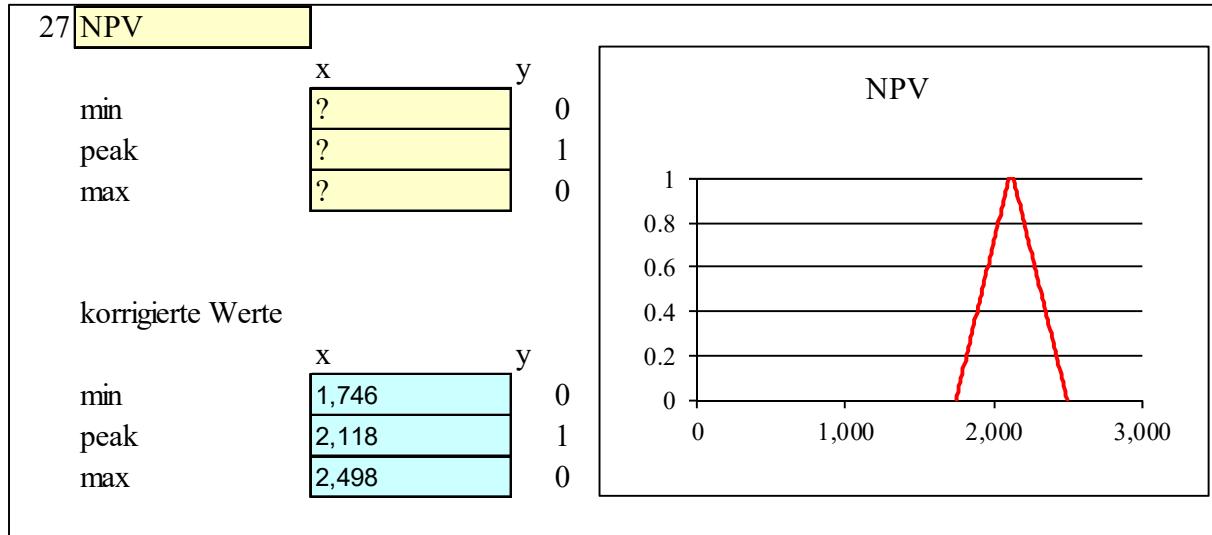


Figure 38 Fuzzy value of NCF calculated based on $\pm 7\%$ error rate of price, $\pm 1\%$ error rate for each from oil production and field cost (EcoPetro_Oil model, development phase scenario)

Table 7 shows the prior values of the EcoPetro_Oil model and the adjusted values for the development phase scenario using FuzzyCalc. The prior and adjusted values of the known input variables are symmetric. The government take is around 16,986 mm \$ with an error rate of $\pm 4\%$. The NCF and NPV have the same uncertainty intervals with different peak values, where the peak value of NCF is at around 13,687 mm \$ with an upper error rate of $+ 27\%$ and a lower error rate of $- 26\%$, the peak value of NPV is at around 3,356 with the same error rate as of the NCF. The peak value of EMV_development is at around 792 mm \$ with an upper error rate of $+ 46\%$ and a lower error rate of $- 44\%$, compared to the EMV_exploration calculations reasonable results.

Table 7: Fuzzy variables before and after adjustment (EcoPetro_Oil model, development phase scenario)

Variable	Prior value	Adjusted value
Oil production (mm bbl)	$353 \pm 1\%$	$353 \pm 1\%$
Oil price (\$/bbl)	$105 \pm 7\%$	$105 \pm 7\%$
Revenue (mm \$)	?	$37,141 \pm 8\%$
Royalty (mm \$)	$2,590 \pm 0$	$2,590 \pm 0$
Bonus (mm \$)	4.5 ± 0	4.5 ± 0
Profit share rate contractor	$80\% \pm 0$	$80\% \pm 0$
Profit share rate government	$20\% \pm 0$	$20\% \pm 0$
Government profit oil (mm \$)	?	$5,745 (+ 11\%, - 10\%)$
Contractor profit share (mm \$)	?	$22,478 (+ 11\%, - 10\%)$
Cost oil (mm \$)	$8,265 \pm 0$	$8,265 \pm 0$
OPEX (mm \$)	$3,482 \pm 1\%$	$3,482 \pm 1\%$
CAPEX (mm \$)	$2,488 \pm 1\%$	$2,488 \pm 1\%$
Abandonment (mm \$)	$496 \pm 1\%$	$496 \pm 1\%$
Tax (mm \$)	$8,265 \pm 0$	$8,265 \pm 0$
NCF (mm \$)	?	$13,687 (+ 18\%, - 17\%)$
Contractor take (mm \$)	?	$20,159 \pm 12\%$
Government take (mm \$)	?	$16,986 \pm 4\%$
Discount factor	$15\% \pm 0$	$29\% \pm 0$
NPV @ 15% (mm \$)	?	$2,118 (+ 18\%, - 17\%)$
POS_exploration	$60\% \pm 1\%$	$60\% \pm 1\%$
Discounted capital cost @ 15%	284 ± 0	792 ± 0
EMV_development	?	$792 (+ 31\%, - 30\%)$

Figure 39 represents the fuzzy values of NPV response to the developed possibility scenarios. Each bar can be interpreted as a fuzzy triangular membership function (min, peak, and max). Here, the vertical axis is the peak value of NPV. A reduction of the input error rate of production from $\pm 5\%$ to $\pm 1\%$ and the input error rate of field cost from $\pm 3\%$ to $\pm 1\%$ reduced the error rates of NPV from $+ 28\%, - 27\%$ to $+ 18\%, - 17\%$.

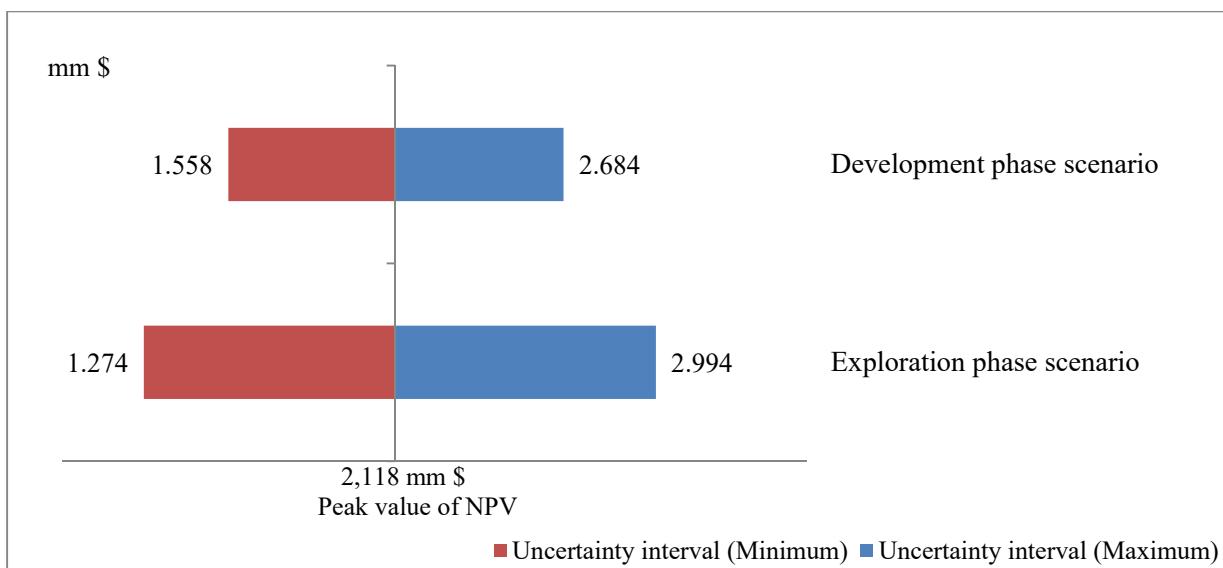


Figure 39: Response of uncertainty intervals of NPV to error rate variation (EcoPetro_Oil model)

6.1.4.3 Probability Sensitivity Analysis

The probability sensitivity analysis was developed using the Quantor application (QR). All input values (prior knowledge) are Gaussian distributed and the computed values are interpreted as mean value and symmetric confidence intervals. To implement a probability sensitivity analysis, the same scenarios and input values of the possibility sensitivity analysis used above are adopted.

The peak value of the fuzzy number represents the mean value of the Gaussian distribution and the error rate of the fuzzy number represents the standard deviation of the corresponding Gaussian distributions (confidence degree).

Figure 40 represents the input and output of the exploration phase scenario (oil price $\pm 7\%$, production $\pm 5\%$ and field cost $\pm 3\%$) using Quantor. It can be seen that the auxiliary variables (value1, value2 etc.) were used due to the restrictions of the equations in QR. The question marks refer to the computed values, and there is no graphical presentation of the output. One observes that the computed confidence intervals for the exogenous variables are of the same value as the input confidence intervals, which means the variables are model consistent. The NPV mean value is 2,118 mm \$ with a confidence degree (standard deviation) equal to $\pm 18\%$. The confidence degree of the EMV_exploration calculation by Quantor is too high, so, comparable to the Fuzzy Logic approach Quantor should not be used in EMV calculations for exploration phases of oil projects.

OilPrice 105.131 ± 7.360 105.131 ± 7.372	OilProduction 353.270 ± 17.660 353.270 ± 17.660	Royalty 2971.000 ± 0.000 2971.000 ± 0.000	Bonus 4.500 ± 0.000 4.500 ± 0.000	ContractorProfitOilShare 0.797 ± 0.000 0.797 ± 0.000	GovernmentProfitOilSha 0.204 ± 0.000 0.204 ± 0.000
CostOil 5946.000 ± 0.000 5946.000 ± 0.000	OPEX 3481.980 ± 104.460 3481.980 ± 104.460	CAPEX 2487.890 ± 74.640 2487.890 ± 74.640	Abandonment 496.210 ± 14.890 496.210 ± 14.890	Tax 8265.350 ± 0.000 8265.350 ± 0.000	
DiscountFactor 0.155 ± 0.000 0.155 ± 0.000	Revenue ? 37139.625 ± 3195.874	FieldCost ? 6466.080 ± 129.247	GovernmentProfitOil ? 5745.210 ± 650.680	ContractorProfitOil ? 22478.559 ± 2545.833	Value1 ? 28218.125 ± 3195.874
GovernmentTake ? 16986.061 ± 650.680	ContractorTake ? 20159.209 ± 2545.833	NCF ? 13693.129 ± 2549.111	NPV ? 2118.464 ± 394.373		
DiscountedExploration 284.010 ± 0.000 284.010 ± 0.043	POS_exploration 0.120 ± 0.001 0.120 ± 0.001	POF_exploration 0.880 ± 0.009 0.880 ± 0.009	Value_2 ? 254.216 ± 47.394	Value_3 ? 249.929 ± 2.499	EMV_exploration ? 4.287 ± 47.460

Figure 40: Output of probability analysis of exploration phase scenario (EcoPetro_Oil model)

The probability analysis for the development phase scenario using Quantor was implemented in similar manner to the possibility sensitivity analysis (see section 6.1.4.2), i.e., it is based on the reduction of the confidence rates (confidence intervals) of oil production and field cost; figure 41 shows the input and output variable values of this scenario.

OilPrice 105.131 ± 7.360 105.131 ± 7.360	OilProduction 353.270 ± 3.533 353.270 ± 3.533	Royalty 2971.000 ± 0.000 2971.000 ± 0.000	Bonus 4.500 ± 0.000 4.500 ± 0.000	ContractorProfitOilShare 0.797 ± 0.000 0.797 ± 0.000	GovernmentProfitOilSha 0.204 ± 0.000 0.204 ± ?
CostOil 5946.000 ± 0.000 5946.000 ± 0.000	OPEX 3481.980 ± 34.820 3481.980 ± 34.820	CAPEX 2487.890 ± 24.879 2487.890 ± 24.879	Abandonment 496.210 ± 4.962 496.210 ± 4.962	Tax 8265.350 ± 0.000 8265.350 ± 0.000	
DiscountFactor 0.155 ± 0.000 0.155 ± 0.000	Revenue ? 37139.625 ± 2626.506	FieldCost ? 6466.080 ± 43.081	GovernmentProfitOil ? 5745.210 ± 534.757	ContractorProfitOil ? 22478.559 ± 2092.275	Value1 ? 28218.125 ± 2626.506
GovernmentTake ? 16986.061 ± 534.757	ContractorTake ? 20159.209 ± 2092.275	NCF ? 13693.129 ± 2092.718	NPV ? 2118.464 ± 323.764		
DiscountedCAPEX 1195.920 ± 0.000 1195.920 ± 0.224	POS_development 0.600 ± 0.006 0.600 ± 0.006	POF_development 0.400 ± 0.004 0.400 ± 0.004	Value_4 ? 1271.078 ± 194.678	Value_5 ? 478.368 ± 4.784	EMV_development ? 792.710 ± 194.736

Figure 41: Output of probability analysis of exploration phase scenario (EcoPetro_Oil model)

At the development phase scenario of the probability analysis, the NPV mean value is 2,118 mm \$ with a confidence degree equal to ± 15%. The EMV_development mean value is 793 mm \$ with a confidence rate equal to ± 25%.

Figure 42 shows a bar diagram of NPV confidence interval response to variation of confidence degrees, where each bar can be interpreted as a symmetric confidence interval (min, medium, max). It is obvious that the confidence intervals of NPV have no negative value. A reduction of

the production confidence interval from $\pm 5\%$ to $\pm 1\%$ and the reduction of the field cost confidence interval from $\pm 3\%$ to $\pm 1\%$, the confidence interval of NPV is reduced by $\pm 4\%$.

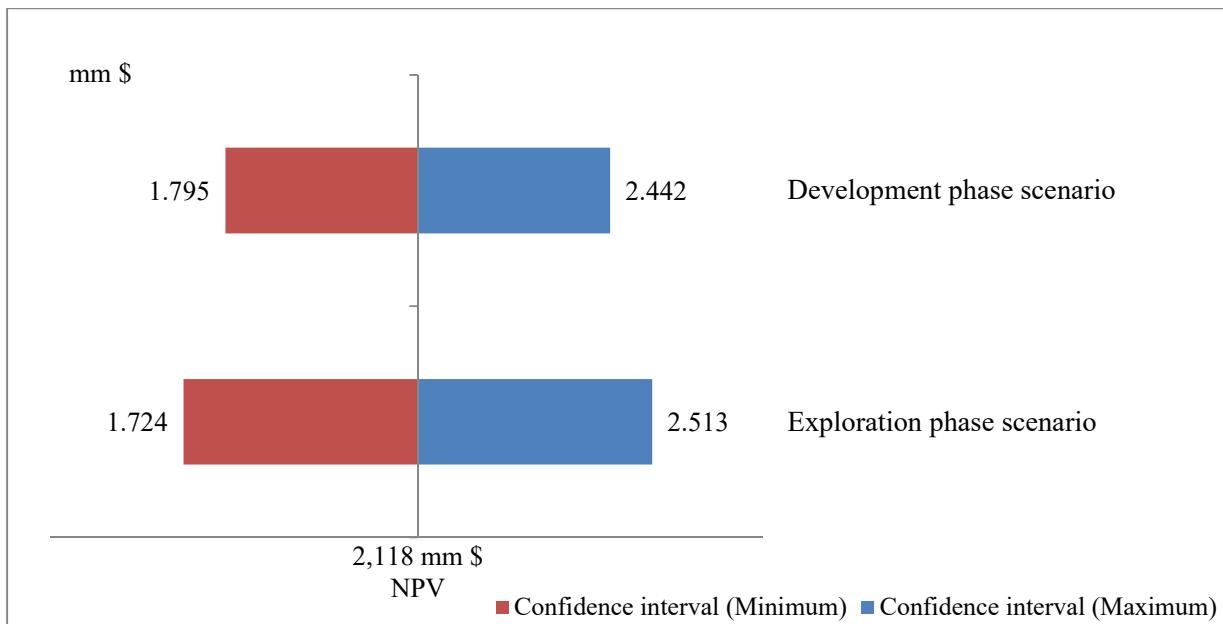


Figure 42: Response of confidence intervals of NPV to confidence degree variations (EcoPetro_Oil model)

6.1.4.4 Monte Carlo Simulation

The Monte Carlo simulation was completed using Oracle Crystal Ball. Two cornerstones were defined before starting the simulation: firstly, the number of iterations, which was set at 20,000 trials; secondly, the type of input probability distributions for uncertainty variables which are called assumption variables. For comparison purposes of the Monte Carlo simulation results with the results of the probability and possibility approaches, it is assumed that all input uncertainty variables follow the triangle distribution with (min, med, max) values. The input variable values in the scenario of the exploration phase are shown in table 8, and given in real value after considering the inflation rate.

Table 8: Input values to Monte Carlo simulation (exploration phase scenario, EcoPetro_Oil model)

Uncertainty Variables	Unit	Min	Mean	Max
Oil production	mm bbl	336	353	371
Oil price	\$/bbl	98	105	112
CAPEX	mm \$	2,413	2,488	2,562
OPEX	mm \$	3,378	3,482	3,586
Abandonment	mm \$	481	496	511

The most important output values¹⁸ after running the simulation of the above scenario are collected in table 9. It can be seen that the mean¹⁹ of estimated distribution differs slightly from the base case value. For example, the NCF base case value is 13,687 mm \$ and the mean value of the NCF probability distribution is equal to 13,691 mm \$; also the median²⁰ of the output distribution of NCF is equal to 13,685 mm \$. Also the NCF varies by 161 mm \$ (the standard deviation) to the mean value of 2,118 mm \$, i.e. the NCF is around 2,118 mm \$ with an error rate of $\pm 7.6\%$.

The EMV_exploration using Monte Carlo simulation has the same base case, mean and median value of 4 mm \$ with standard deviation equal to 19 mm \$ which consider also a too high error rate comparable with FuzzyCalc and Quantor.

Table 9: Relevant statistical output of Monte Carlo simulation (exploration phase scenario, EcoPetro_Oil model)

Item	Contractor take mm \$	Government take mm \$	NCF mm \$	NPV mm \$	EMV_exploration mm \$
Trials	20,000	20,000	20,000	20,000	20,000
Base Case	20,153	16,988	13,687	2,118	4
Mean	20,154	16,989	13,691	2,118	4
Median	20,151	16,987	13,685	2,117	4
Standard Deviation ²¹	856	219	1,041	161	19
Minimum	17,914	16,184	10,501	1,625	-55
Maximum	22,421	17,838	16,941	2,621	67

¹⁸ The simulation was made on 06/04/2015 at 09:11 PM. When the simulation was reset and restarted without any changes in the model, different results were achieved but the differences can be considered to be insignificant..

¹⁹ The Mean is the arithmetic average of the deterministic value.

²⁰ The median is found by ordering the values from the smallest to the largest and then selecting the middle value.

²¹ The Standard Deviation is a measure of dispersion of a distribution or the average distance of each value from the mean. It is usually used in conjunction with normal distributions.

Figure 43 indicates the wide range of possible NPVs of the EcoPetro_Oil model using Monte Carlo simulation for the exploration phase scenario. The produced distribution of the NPV reflects the probability to obtain a certain value. The NPV calculated is on average 2,118 mm \$, with an 80% certainty of being between 1,908 mm \$ and 2,331 mm \$.

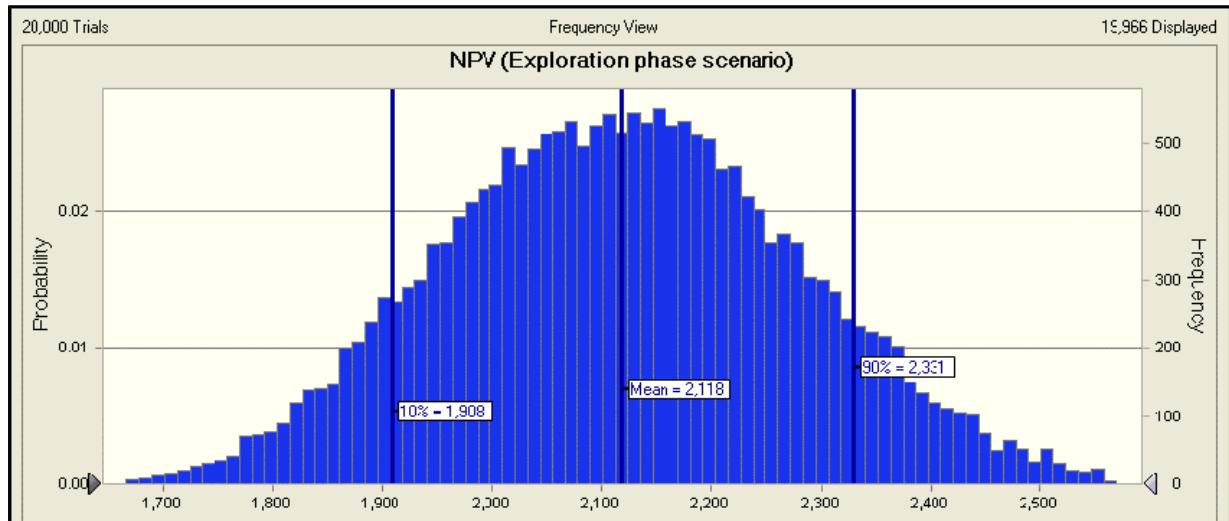


Figure 43: Probability distribution of NPV resulting from Monte Carlo simulation (EcoPetro_Oil model, exploration phase scenario)

The probability distribution of EMV_exploration is shown in figure 44. The mean value of the EMV_exploration distribution is 4 mm \$ with an 80% certainty of being between (-21) mm \$ and 29 mm \$ and 58% certainty of being a positive value.

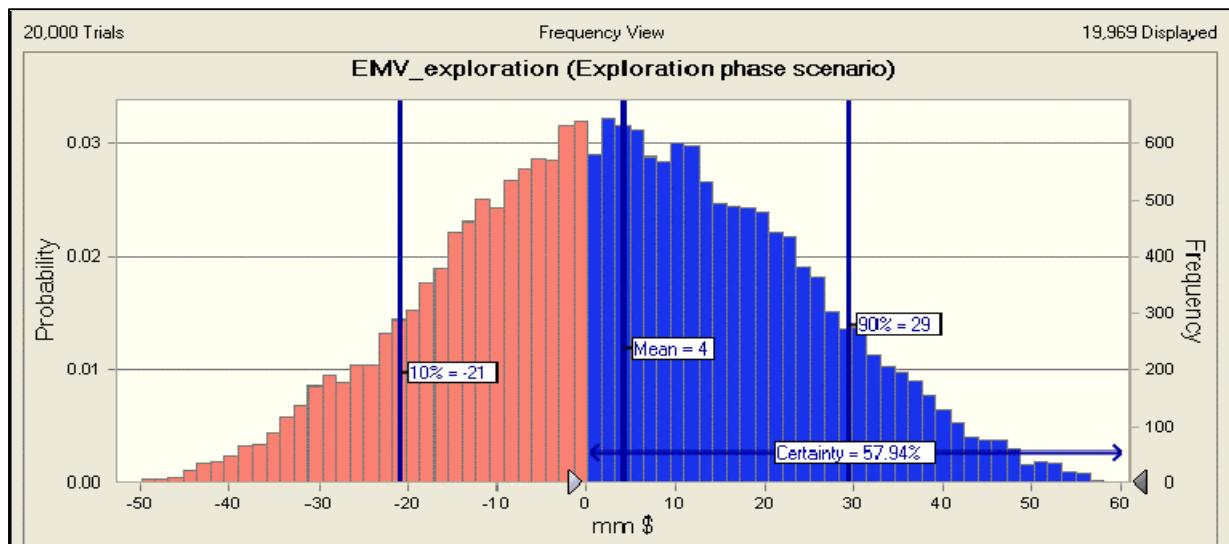


Figure 44: Probability distribution of EMV_exploration resulting from Monte Carlo simulation (EcoPetro_Oil model, exploration phase scenario)

In order to build the development phase scenario using Crystal Ball is assumed that the mean value remains constant and the uncertainty intervals (min, max) become smaller for each the oil production and field cost variables (see Tab. 10)

Table 10: Input values to Monte Carlo simulation (development phase scenario, EcoPetro_Oil model)

Uncertainty Variables	Unit	Min	Mean	Max
Oil production	mm bbl	350	353	357
Oil price	\$/bbl	98	105	112
CAPEX	mm \$	2,463	2,488	2,513
OPEX	mm \$	3,447	3,482	3,517
Abandonment	mm \$	491	496	501

After running the simulation using Crystal Ball and based on 20,000 trials, the most important statistic output is summarized in table 11. The NCF base case value remains at 13,687 mm \$, the mean value of the NCF is equal to 13,688 mm \$ and slightly differs from the NCF mean value of the exploration scenario; the median of the output distribution of NCF is equal to 13,683 mm \$.

The NCF varies by 856 mm \$ to the mean value; that means the NCF is around 13,683 mm \$ with an error rate of $\pm 6.3\%$.

Table 11: Relevant statistical output of Monte Carlo simulation (development phase scenario, EcoPetro_Oil model)

Item	Contractor take mm \$	Government take mm \$	NCF mm \$	NPV mm \$	EMV_development mm \$
Trials	20,000	20,000	20,000	20,000	20,000
Base Case	20,153	16,988	13,687	2,118	792
Mean	20,154	16,988	13,688	2,118	792
Median	20,151	16,987	13,683	2,117	792
Standard Deviation	856	219	856	132	80
Minimum	17,914	16,416	11,453	1,772	580
Maximum	22,421	17,568	15,951	2,468	1,000

Figure 45 shows NPVs of the EcoPetro_Oil model using Monte Carlo simulation for the development phase scenario. The generated distribution of NPV reflects that the NPV is on average at 2,118 mm \$, with an 80% certainty of being between 1,939 mm \$ and 2,295 mm \$.

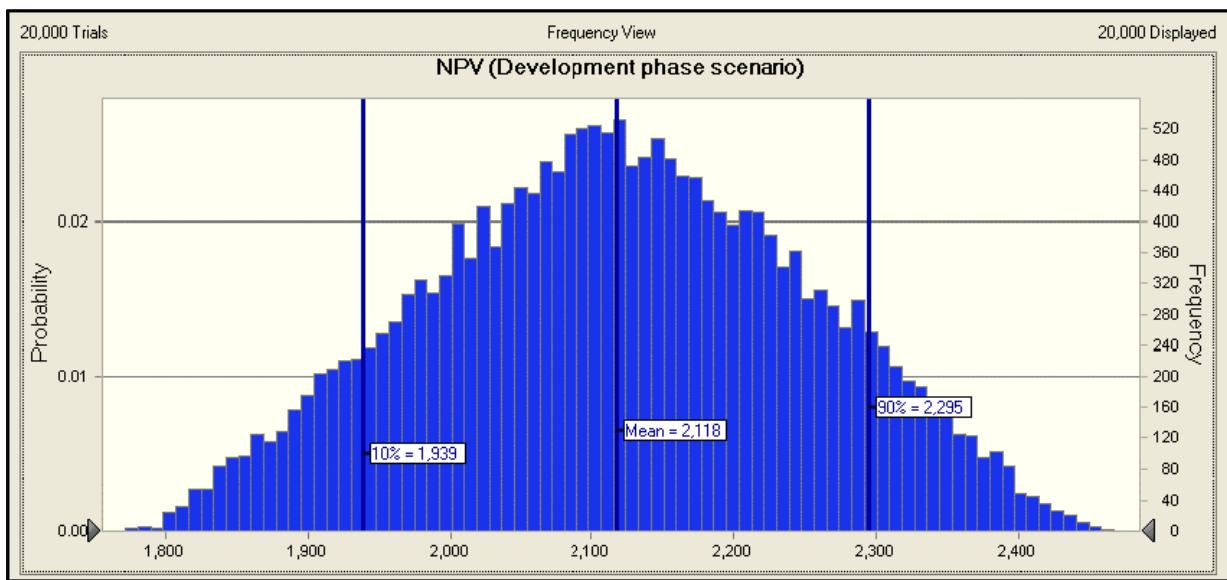


Figure 45: Probability distribution of NPV resulting from Monte Carlo simulation (EcoPetro_Oil model, development phase scenario)

The probability distribution of EMV_development is shown in figure 46. The mean value of the EMV_development distribution is 792 mm \$ with an 80% certainty of being between 685 mm \$ and 899 mm \$.

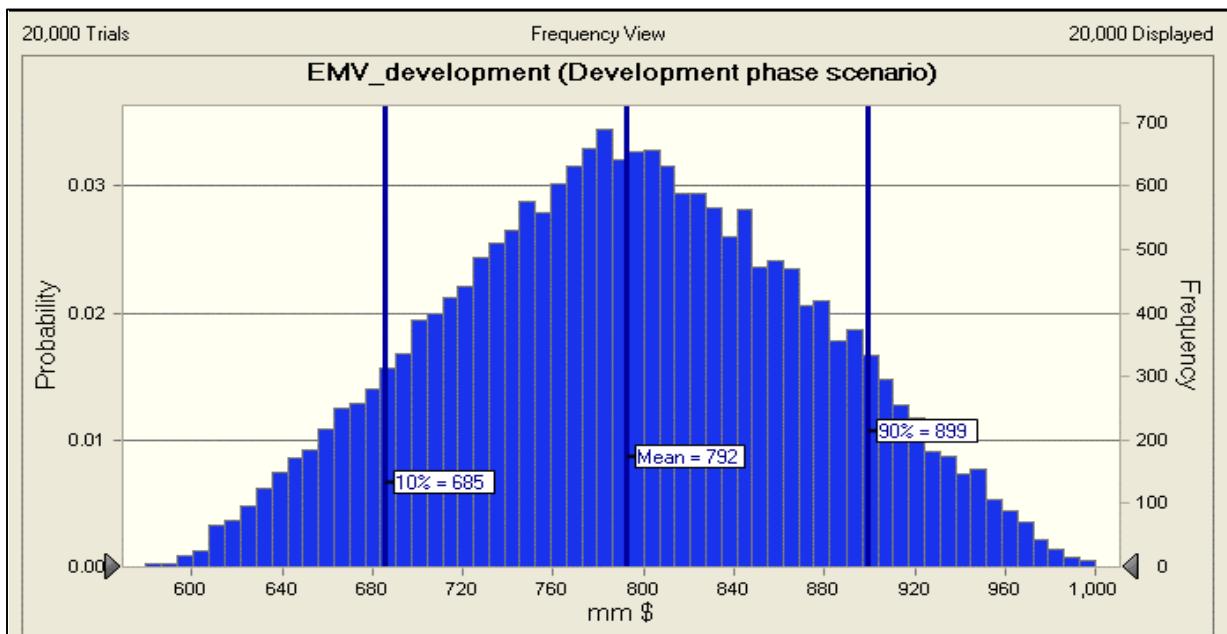


Figure 46: Probability distribution of EMV_development resulting from Monte Carlo simulation (EcoPetro_Oil model, exploration phase scenario)

An overlay chart using Oracle Crystal Ball is generated, in order to compare the probability distributions of NPV for the exploration phase with the development phase scenario (Fig. 47). It is obvious that the mean value of NPV does not change between the scenarios. The distributions reflect²² that the standard deviation of the NPV of the exploration phase scenario in the order of 161 mm \$ is greater than the standard deviation of the development phase scenario at 132 mm \$, or the error rate of NPV is reduced by the reduction of the input uncertainty intervals of production from $\pm 7\%$ to $\pm 1\%$ and field cost from $\pm 3\%$ to $\pm 1\%$.

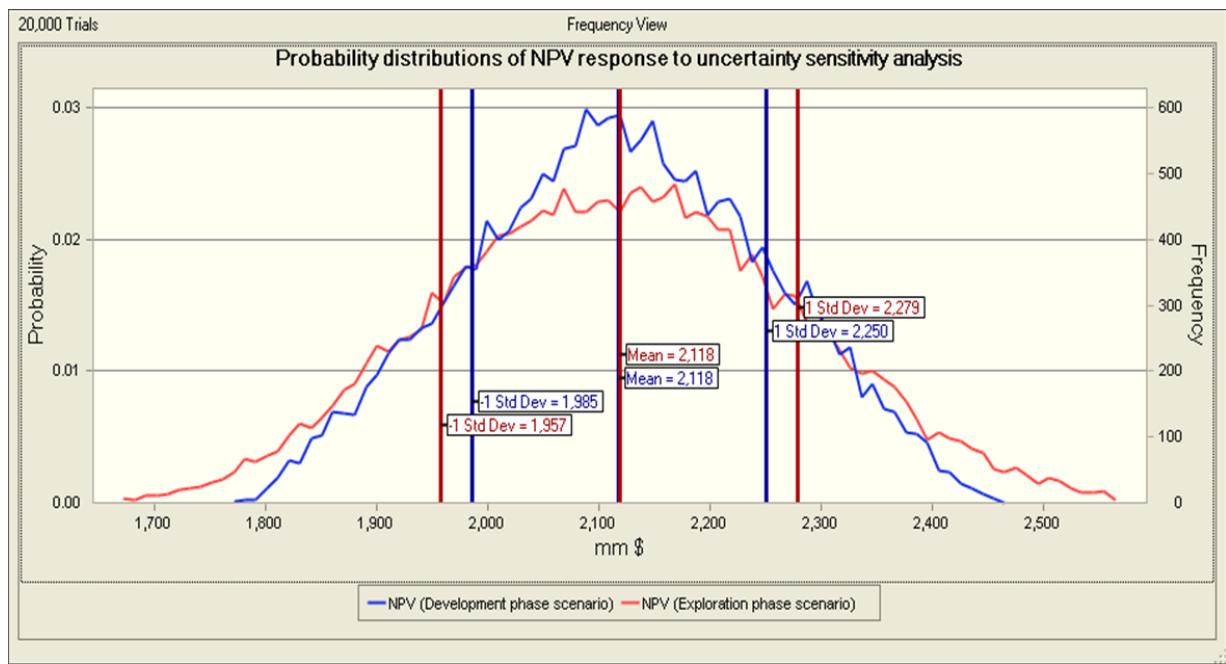


Figure 47: Response of probability distributions of NPV to the sensitivity analysis based on Monte Carlo simulation (EcoPetro_Oil model)

²² Based on the figure 47, the standard division is calculated as $(2,118 - 1,957 = 132 \text{ mm } \$)$

Figure 48 compares the probability distributions of EMV_exploration and EMV_development phases according to the relevant scenarios.

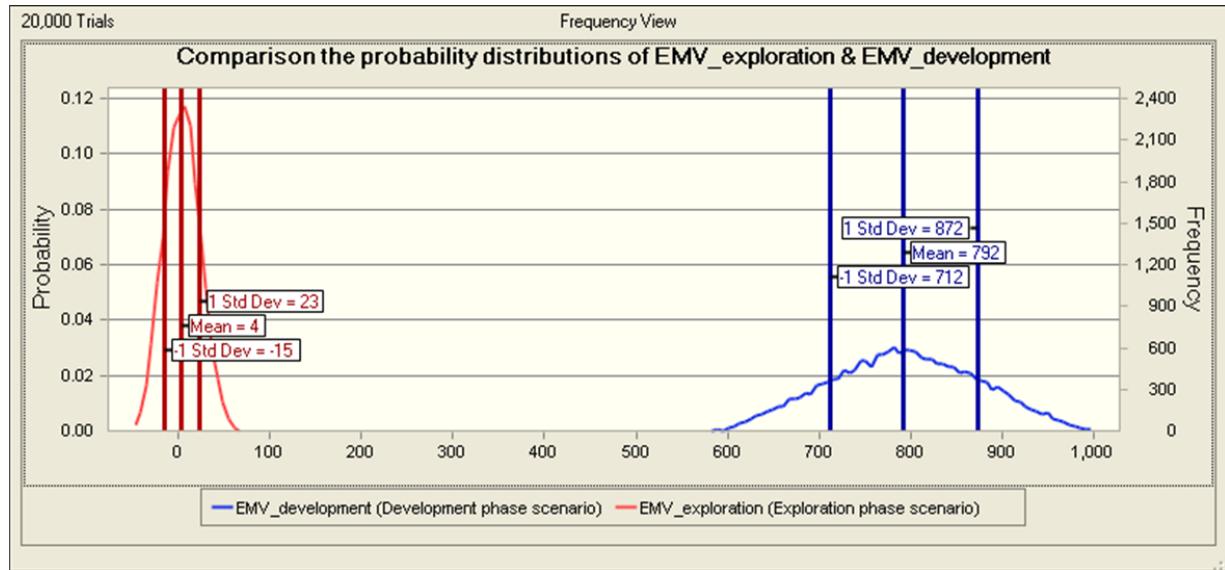


Figure 48: Response of probability distributions of NPV to the sensitivity analysis based on Monte Carlo simulation (EcoPetro_Oil model)

6.2 Gas Economics Model (EcoPetro_Gas model)

In order to implement the gas economics model (EcoPetro_Gas model) the offshore Atlantic region Nova Scotia of Canada was chosen as exemplary. There, the first offshore exploration started in 1959, and until now around 2.5% of the total Canadian gas supply is produced in Nova Scotia offshore projects. Currently the largest gas project in Nova Scotia is the Sable project, which produces 450 MMCF per day (Ballem, 2008).

6.2.1 Nova Scotia Canada Concession Contract

The fiscal regime which organizes the petroleum investments in Canada consists of a combination of royalties and income tax (concession contract type), and the contractor is required to make royalty payments to the Nova Scotia government based on the Offshore Petroleum Royalty Act.

The computation of royalties is fairly complex and is based on cumulative profitability and petroleum prices. Three break-even points (called Payout) are identified in the project; these are the points at which project revenues first reach or exceed the sum of allowed exploration costs,

capital costs, operating costs and royalties paid. The royalty rate of small fields is calculated as follows (Mintz & Chaen, 2010):

1. 2% of revenue pre Payout.
2. 5% of revenue once the Payout is achieved.
3. 20% of net revenues after Payout, where net revenue is calculated as revenue minus operating cost for the same period (year).

In addition to the royalty, the contractor must pay federal tax (19% from taxable income) to the Canadian government and provincial tax (16% from taxable income) which is paid to the provincial government (Clancy, 2011). To determine the taxable income, several compensatory deductions from revenues are granted to the taxpayer. In addition to the annual operating costs and royalties, the following deductions are in use (Toselli et al., 2008):

1. Investment tax credits (ITCs). This is a tax reward for capital investment and calculated as 10% of the capital cost of a qualified property.
2. Capital cost allowance (CCA). The capital cost allowance includes the costs of tangible equipment that facilitate the production of petroleum, such as wellhead equipment, gathering systems, batteries, etc. These costs are summed up in the capital allowance cost, to be deducted from the income on a declining balance basis and different rates. These rates represent the maximum amount of deduction (Tab.12).

Table 12: Capital cost allowance rates of Nova Scotia Canada

Item	Expenditures	Allowance rate
1	Oil and gas well equipment	25%
2	Other tangible equipment	20%
3	Computer hardware & system software	30%
4	Pipelines not part of a gathering system	8%

(adopted from Toselli et al., 2008)

3. Canadian exploration expense (CEE). This expense includes the geological, geophysical, and geochemical costs, and, additionally, the dry hole cost. It is deducted by 100% from the income compiled for tax purpose.
4. Canadian development expense (CDE). It includes intangible drilling and fulfilment costs that are not otherwise comprised as a Canadian exploration expense. It is deducted up to a maximum rate of 30% per year on decline balance for tax purposes.

6.2.2 Structural Equations System

The EcoPetro_Gas structural equations system is also an extract from the structural equations system of standard economics model (EcoPetro_Model). Prices of oil and gas, in addition to the field cost are expressed in nominal values after taking into account the inflation effects in the correlated equations.

- Oil production and revenue equations are defined as:

$$GP_{wa} = \begin{cases} CFPD_w.DGP_{w_a}(100\% - GPd\%_w) & \text{if } a = Gdy_w \\ DGP_{w_{a-1}}(100\% - GPd\%_w) & \text{if } a > Gdy_w \\ CFPD_w.DGP_{w_a} & \text{else} \end{cases} \quad (6.25)$$

$$OP_{wa} = \begin{cases} BOPD_w.DOP_{w_a}(100\% - OPd\%_w) & \text{if } a = Ody_w \\ DOP_{w_{a-1}}(100\% - OPd\%_w) & \text{if } a > Ody_w \\ BOPD_w.DOP_{w_a} & \text{else} \end{cases} \quad (6.26)$$

$$P_a = \sum_{w=1}^W OP_{wa} + \sum_{w=1}^W GP_{BOE_{wa}} \quad (6.27)$$

$$Rev_a = PO_a \cdot \sum_{w=1}^W OP_{wa} + PG_a \cdot \sum_{w=1}^W GP_{wa} \quad (6.28)$$

- Field cost and its components are defined as:

$$FieldCost_a = CAPEX_a + OPEX_a + Abandon_a \quad (6.29)$$

$$CAPEX_{ra} = Explor_a + Develop_a \quad (6.30)$$

$$Explor_a = G&G_Ser_a + ExplorDrill_Ser_a \quad (6.31)$$

$$Develop_a = Develop_Drill_a + Develop_Surface_a + Develop_Trans_a + Develop_other_a \quad (6.32)$$

$$OPEX_a = OPEX_{perUnit} \cdot P_a \quad (6.33)$$

$$Abandon_a = Remove_a + Plug_a + Treat_a \quad (6.34)$$

- Fiscal cost and its components are defined as²³:

$$Roy_a = Roy_{ra} \cdot Rev_a \quad (6.35)$$

$$TAX_a = \sum_{y=0}^Y TAXin_{ya} TAXrate_{ya} \quad (6.36)$$

- Key business indicators and the expected monetary values (EMV) are defined as:

$$NCF_a = Rev_a - (OPEX_a + CAPEX_a + Aband_a TAX_a + Roy_a) \quad (6.37)$$

$$DCF_a = NCF_{a\varphi} / (1 + i)^{a+0,5} \quad (6.38)$$

$$NPV = \sum_{a=0}^{a=A} DCF_a \quad (6.39)$$

$$EMV_exploration = NPV \cdot POS_exploration - Explor_{discounted} (1 - POS_exploration) \quad (6.32)$$

$$EMV_development = \\ NPV \cdot POS_development - CAPEX_{discounted} (1 - POS_development) \quad (6.33)$$

- The Take indicators are defined as:

$$CT_a = Rev_a - Roy_a - TAX_a \quad (6.40)$$

$$GT_a = Roy_a + TAX_a \quad (6.41)$$

To better understand the structure and the dependency of the main variables of EcoPetro_Gas, the model graph in figure 49 represents the relationship between the variables.

²³ The royalty equation of EcoGas_Model represents a simplification of the Canadian royalty rules, where in the excel model three royalty tiers are taken into account to calculate the Payout point, and the royalty amount for each tier is calculated thereafter. The royalty rate in this equation represents the effective royalty rate , $Roy_{ra} = Roy/Rev_a$

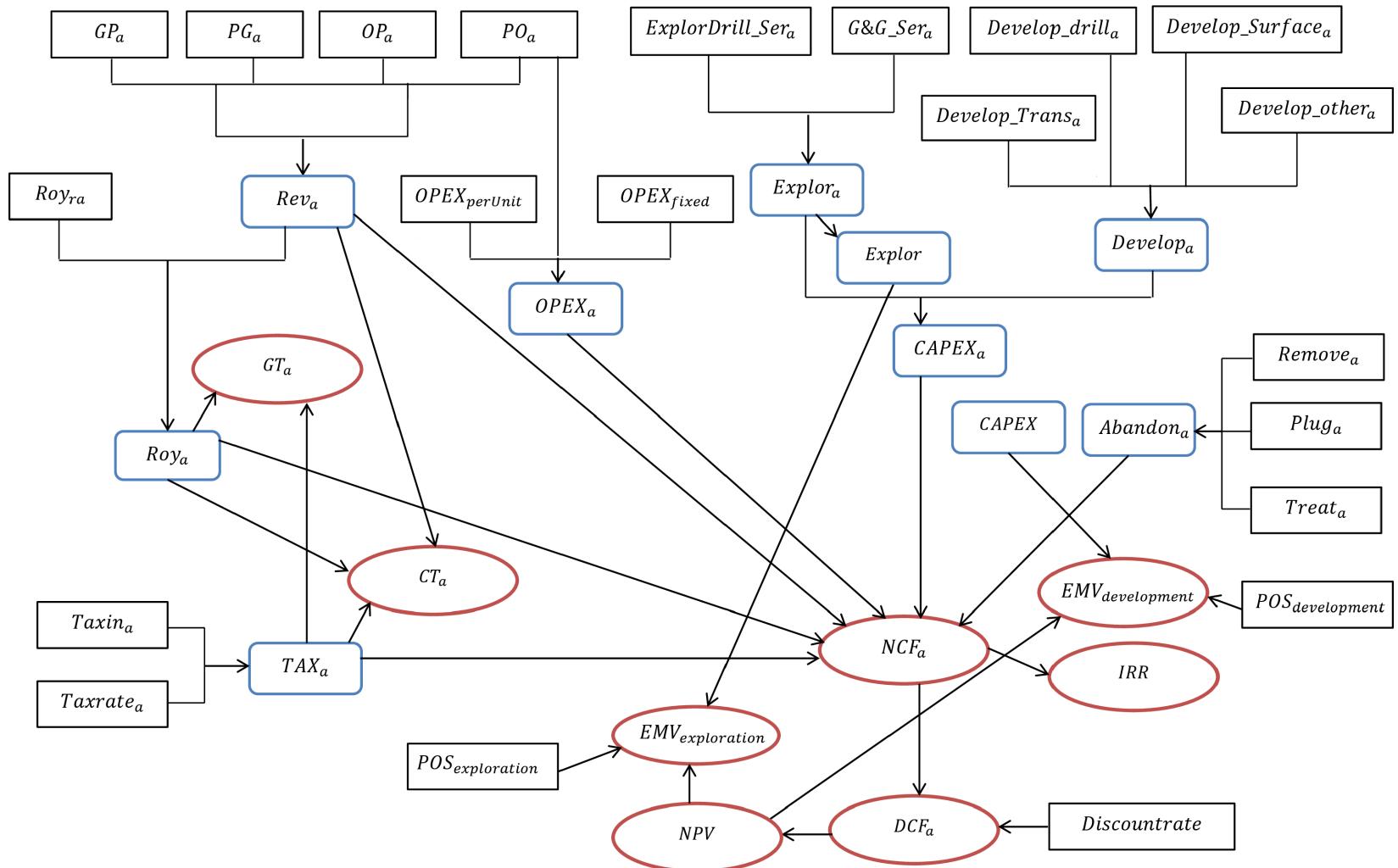


Figure 49: Model graph of the EcoPetro_Gas

6.2.3 Input & Output of EcoPetro_Gas model (Base Case)

The EcoPetro_Gas field is located offshore from Nova Scotia, and its estimated reserves are 471 mm BOE (305 mm bbl oil and 997 BCF gas), with an estimated probability of success for the exploration phase equal to 15% and an estimated probability of success for the development phase equal to 60%.

The exploration phase will start in 2016 and last for three years. The development cost will be incurred over 5 years and first production starts in 2022, with extraction of oil and gas from 3 wells till the following year, where additional 9 production wells will be achieved as is shown in figure 50.

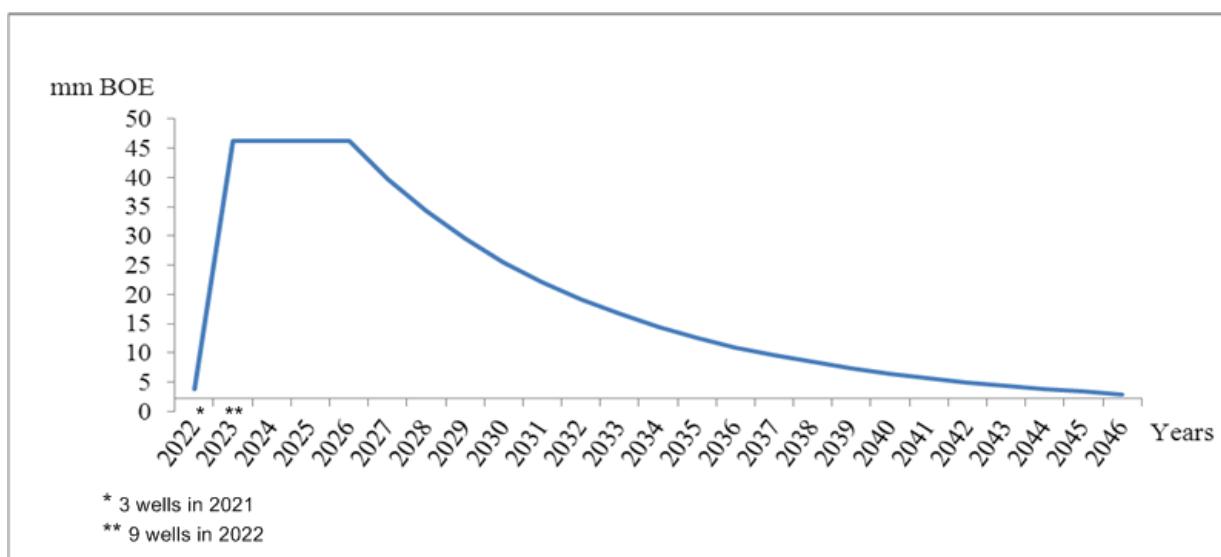


Figure 50: Production curve of EcoPetro_Gas model base case

The production build-up period lasts for 2 years, followed by a plateau period which continues for 4 years. Production will then start to decline in 2027 with a decline rate equal 10% until the year 2046 (production end year). In the following year all wells will be abandoned. An abandonment payment will be made in the abandonment year.

The real oil price input is represented as a flat rate equal to 80 \$ per barrel, the gas price is equal to 5.4 \$ per MCF and the inflation rate is estimated to be 2%. The net cash flow of EcoPetro_Gas model is discounted at a rate of 10%. The real OPEX is estimated based on a yearly fixed OPEX equal to 30 mm \$ in addition to a variable OPEX per barrel equal to 5 \$ per barrel oil equivalent. CAPEX is estimated to be 3,350 mm \$ including an amount of 305 mm \$

exploration cost. The results from the previous deterministic input are called base case of EcoPetro_Gas (BC).

Figure 51 shows the components of NPV of EcoPetro_Gas in nominal values, where the contractor gets the total revenue resulting from oil and gas, and then pays the royalty and tax for the government, in addition to the field cost payments to achieve the government cash flow. It is also obvious that the amount of tax and royalty is significantly greater than the fiscal cost payments.

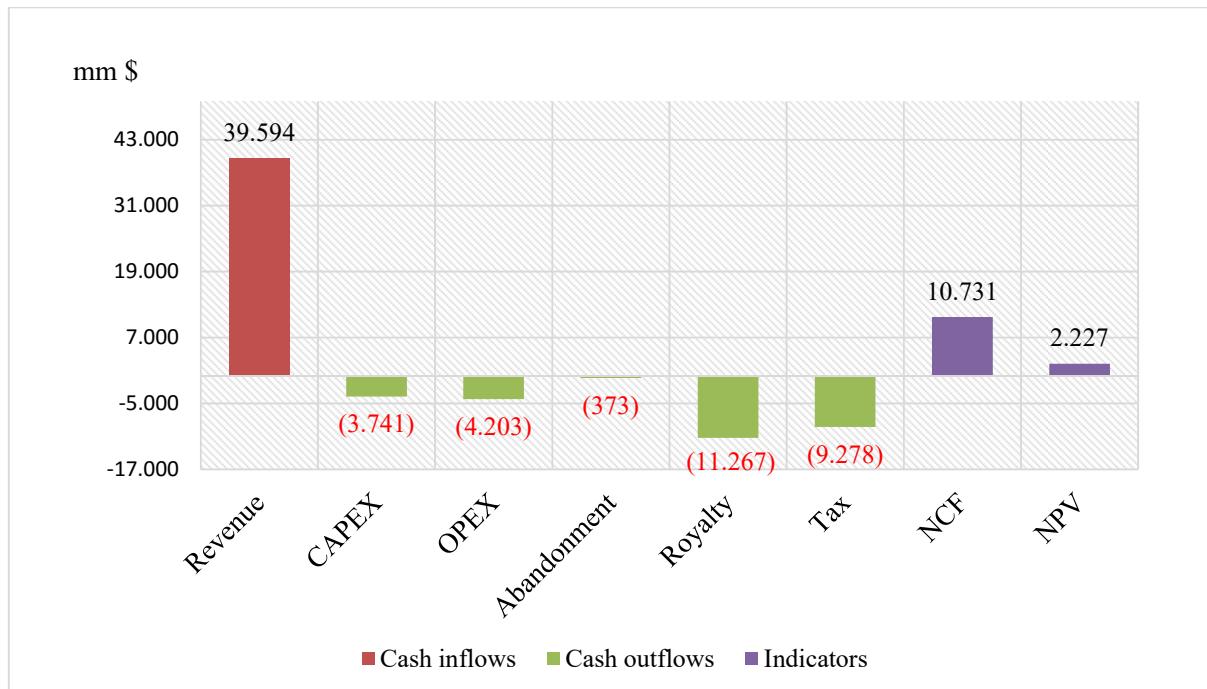


Figure 51: NPV of EcoPetro_Gas model (base case)

The percentage of the contractor take from the revenue after field cost payment (34%) is almost constant during the project life (Fig. 52) and the contractor recovers exploration cost in the first year through capital allowances, other capital cost is recovered by decline rate over the life of the project of the EcoPetro_Gas model.

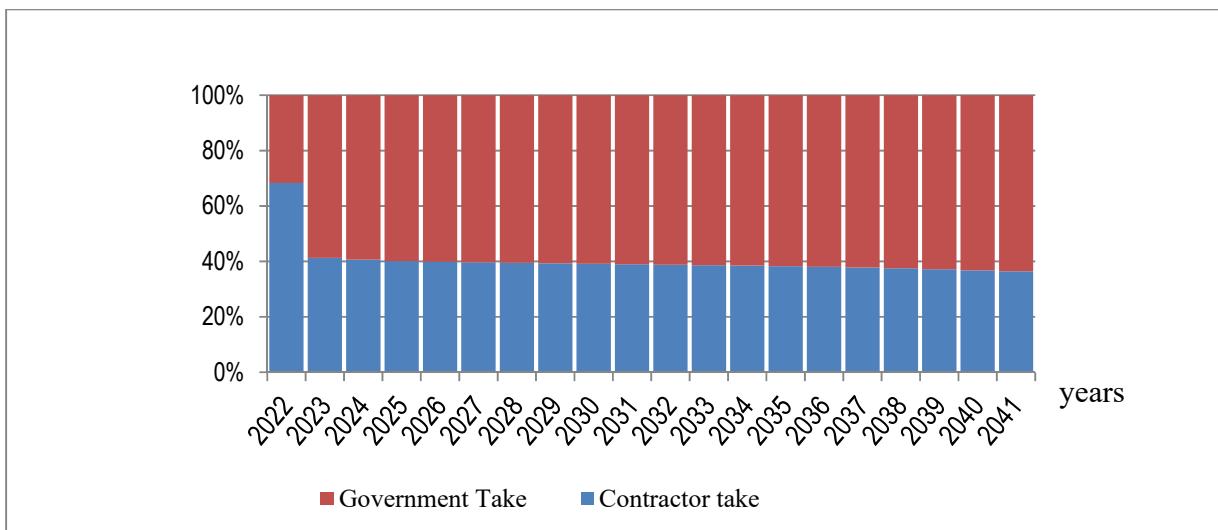


Figure 52: Government and contractor take of EcoPetro_Gas model as percentage of revenue after field cost (base case)

The cumulative NCF of EcoPetro_Gas model base case is presented in figure 53; it becomes positive from the year 2025 on. Payback period is the period from the beginning of the project until achievement of positive cumulative NCF, and that is for the EcoPetro_Gas (base case) equal to 9 years.

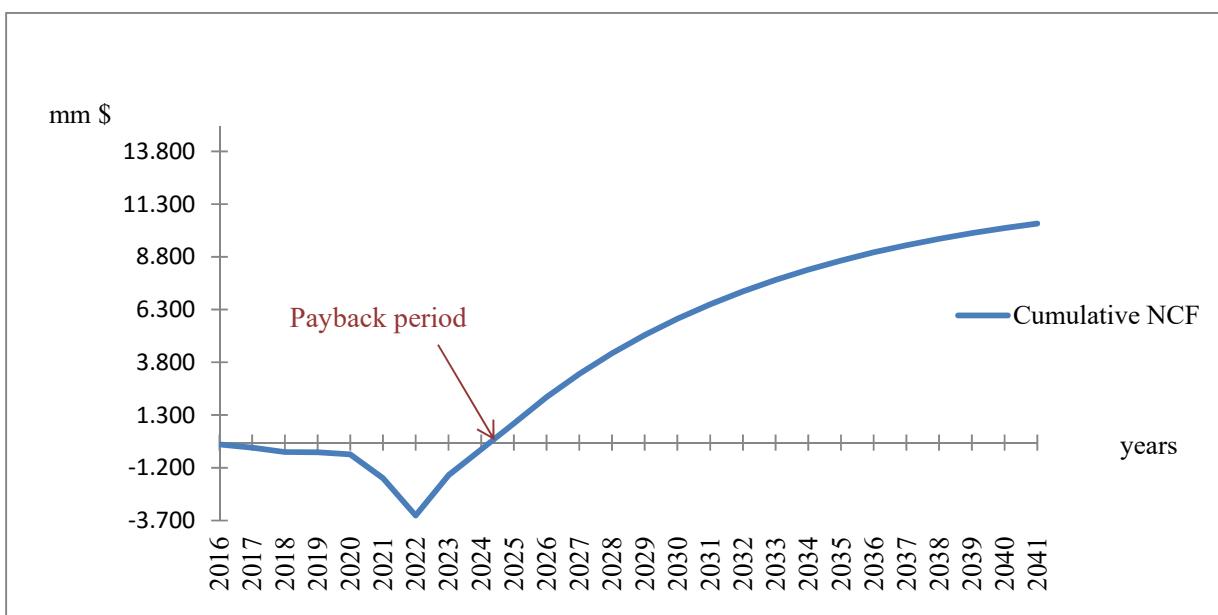


Figure 53: Cumulative NCF/Payback period of EcoPetro_Gas (base case)

A decision tree for the EcoPetro_Gas model is shown in figure 54, where positive EMVs are achieved by both the exploration and the development phases. We can state from this viewpoint that the base case of EcoPetro_Gas model is profitable and the decision to invest can be taken.

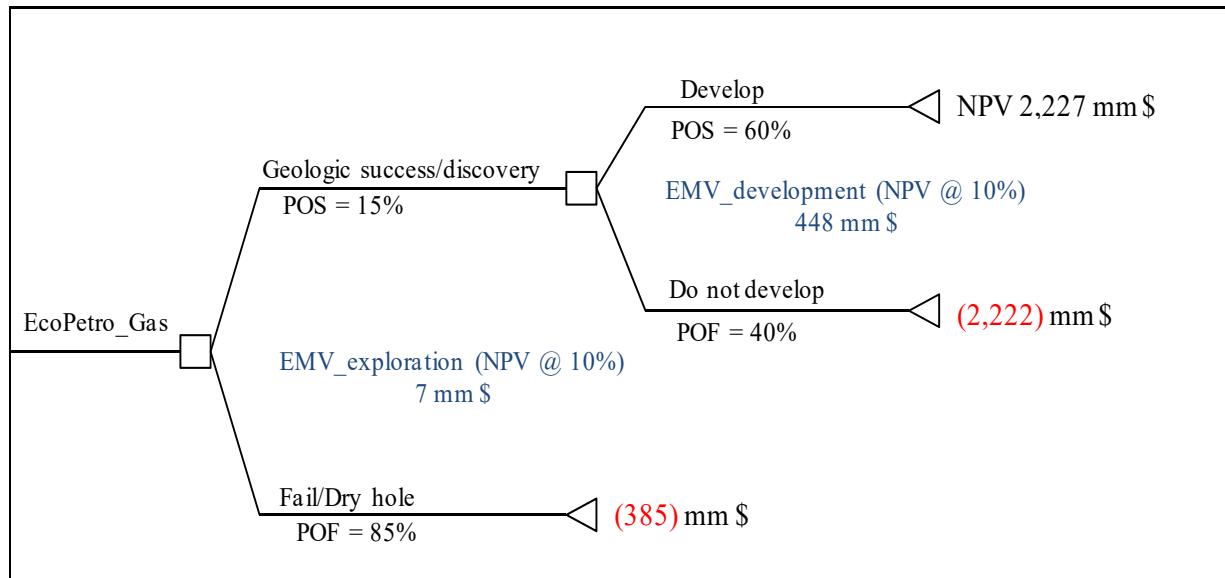


Figure 54: Decision tree of EcoPetro_Gas model (base case)

Figure 55 shows an extract from the Excel sheet (Summary) of the EcoPetro_Gas model. The base case of EcoPetro_Gas indicates a positive NPV equal to 2,227 mm \$. The Payback period is equal to 9 years and the internal rate of return is 25%. The government take of 66% as percentage from revenue net of field cost is higher than the government take of EcoPetro_Oil base case (55%) due to the ineffective design of the petroleum fiscal regime in Nigeria (Tordo, 2010).

By using the net present value discounted at 10%, the EMV_exploration is equal to 7 mm \$, and the EMV_development is equal to 448 mm \$.

Summary of EcoPetro_Gas model output (base case)			
Net Cash Flow (NCF) mm \$		Discounted Cash Flow (DCF) mm \$	
Item	mm \$	Item	mm \$
Revenue	39,594	Revenue	11,165
Contractor profit share	0	Contractor profit share	0
Cost Oil	0	Cost Oil	0
Subtotal	39,594	Subtotal	11,165
CAPEX	(3,741)	CAPEX	(2,222)
OPEX	(4,203)	OPEX	(1,115)
Abandonment	(373)	Abandonment	(19)
Field cost	(8,318)	Field cost	(3,356)
Royalty	(11,267)	Royalty	(3,000)
Bonus	0	Bonus	0
SurfaceFee	0	SurfaceFee	0
Tax	(9,278)	Tax	(2,582)
Fiscal cost	(20,545)	Fiscal cost	(5,582)
Contractor NCF (NPV@ 0%)	10,731	Contractor NPV @ 10%	2,227
IRR	25%		-
Payback period (year)	9		
EMV exploration (NPV @ 10%) mm \$	7		
EMV development (NPV @ 10%) mm \$	448		
Contractor Take as percenatge of project NCF (mm \$)	10,731	34%	
Government Take as percenatge of project NCF (mm \$)	20,545	66%	
Contractor Take as percenatge of revenue (mm \$)	19,048	48%	
Government Take as percenatge of revenue (mm \$)	20,545	52%	

Figure 55: Summary of EcoPetro_Gas model output (base case)

6.2.4 Sensitivity Analysis

6.2.4.1 Deterministic Sensitivity Analysis

As previously mentioned, the first step in performing the deterministic sensitivity analysis is the identification of the key variables of the analysis. The EcoPetro_Gas model has two main products, oil and gas, and both play a major role in the determination of the profitability of the EcoPetro_Gas model base case; in addition to the third key variable, the field costs.

The one variable at a time scenarios are collected in table 13, where the input values are in real terms using a similar approach to the deterministic sensitivity analysis of EcoPetro_Oil.

**Table 13: Input scenarios of deterministic sensitivity analysis, case: one variable variation at a time
(EcoPetro_Gas)**

Key variables	Unit	Input value (Medium)	Increase rate	Increase value (maximum)	Decrease rate	Decrease value (minimum)
Gas production	MMCF/d/we ll	27	+ 20%	32	- 20%	22
Gas price	\$/ MCF	5.4	+ 40%	8	- 40%	3
Oil production	BOPD/well	6,000	+ 20%	7,200	- 20%	4,800
Oil price	\$/bbl	80	+ 40%	112	- 40%	48
OPEX	mm \$	3,106	+ 20%	3,727	- 20%	2,485
CAPEX	mm \$	3,731	+ 20%	4,477	- 20%	2,985
Abandonment	mm \$	200	+ 20%	240	- 20%	160

Figure 56 shows the NCF values from the one factor sensitivity analysis; it can be seen that a fall of prices by 40% decreased the NCF by 62% (from 10,731 mm \$ to 4,039 mm \$), while a rise of field cost by 20% decreased the NCF by 14% (from 10,731 mm \$ to 9,260 mm \$). A rise in production by 20% increased the NCF by 27% (from 10,731 mm \$ to 13,620 mm \$).

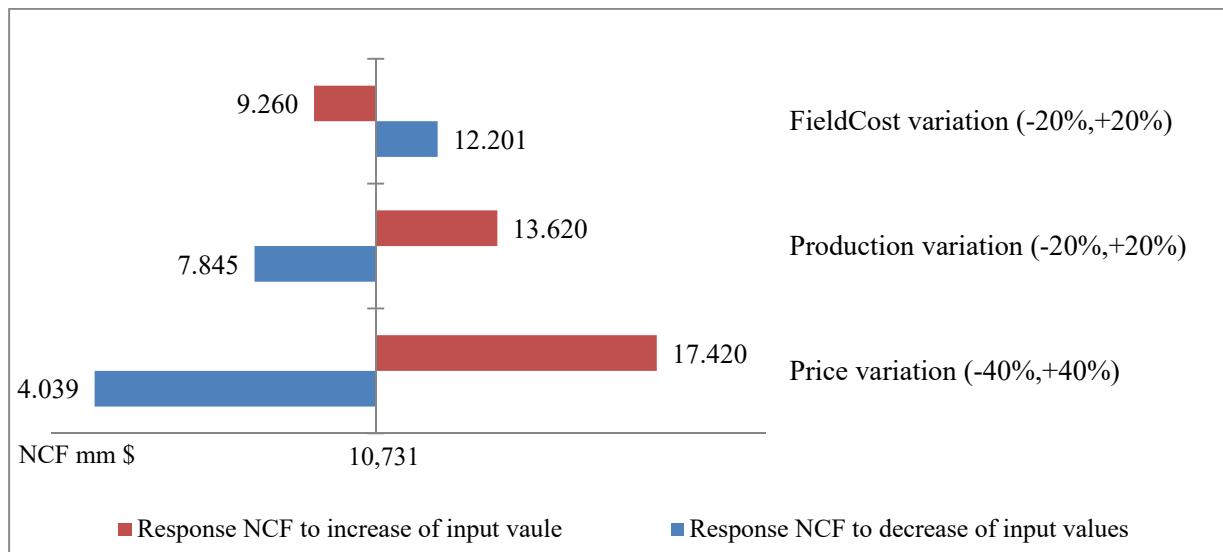


Figure 56: Response of NCF to the one variable variation at a time (EcoPetro_Gas model)

It can be seen in figure 57 that the decrease of production by 20% decreased the NPV by 37% (from 2,227 mm \$ to 1,410 mm \$), while the decrease of field cost by 20% increased the NPV by 28%, (from 2,227 mm \$ to 2,851 mm \$).

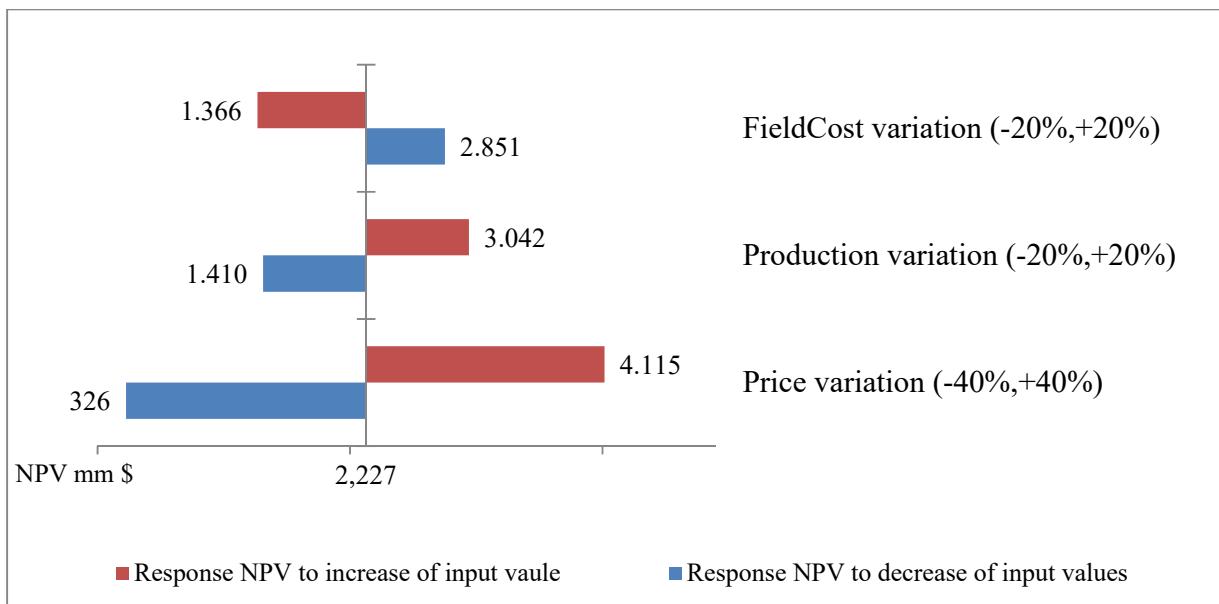


Figure 57: Response of NPV to the one variable variation at a time (EcoPetro_Gas model)

The IRR recorded several sensitivities to change one variable at a time; the best value of IRR is 36%, achieved when the field cost decreased by 20%, while the worst value of IRR is equal to 13% (decrease of price by 40%) as shown in figure 58.

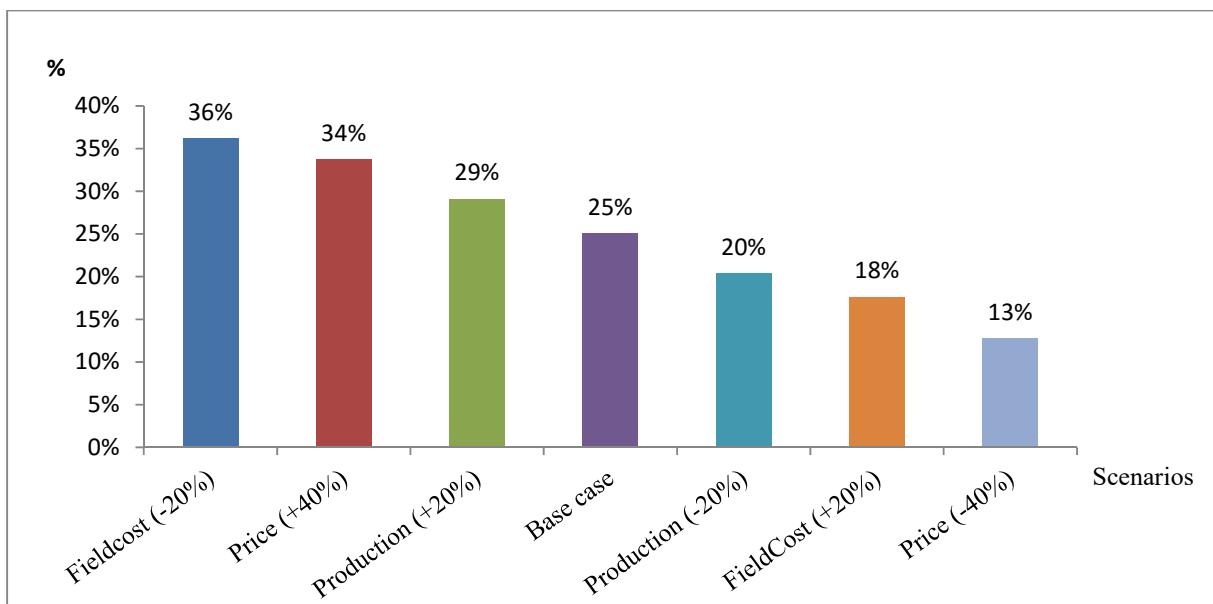


Figure 58: Response of IRR to one variable variation at a time (EcoPetro_Gas model)

Figure 59 shows the impact of the one variable variation at a time on the payback period of EcoGas_Canada model base case. The decrease of prices by 40% increased the payback period

from 9 to 11 years, while the Payback period is reduced one year from 9 to 8 by the scenarios, increase of price by 40%, increase of production by 20% and by decrease of field cost by 20%.

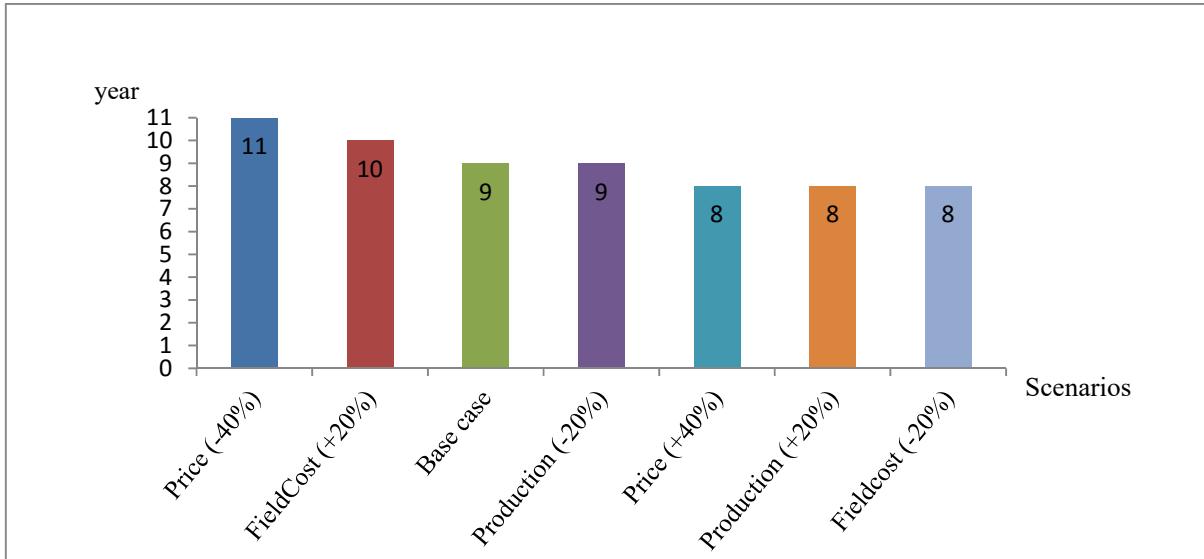


Figure 59: Response of payback period to the one variable variation at a time (EcoPetro_Gas model)

A reduction in oil and gas prices by 40% decreased the EMV_exploration significantly from 7 mm \$ to (-278) mm \$, and the EMV_development from 448 mm \$ to (-693). A rise in field cost by 20% caused a decrease in EMV_exploration from 7 mm \$ to (-156) mm \$ and the EMV_development from 448 mm \$ to (-104), also a reduction in production by 20% caused a decrease in EMV_exploration from 7 mm \$ to (-115) mm \$ and the EMV_development from 448 mm \$ to (-42)

Therefore; the EcoPetro_Gas model base case is considered to be classified as a very high risk project because it might not stand up in the face of falling prices or production or rising in the field cost, as is shown in figure 60.

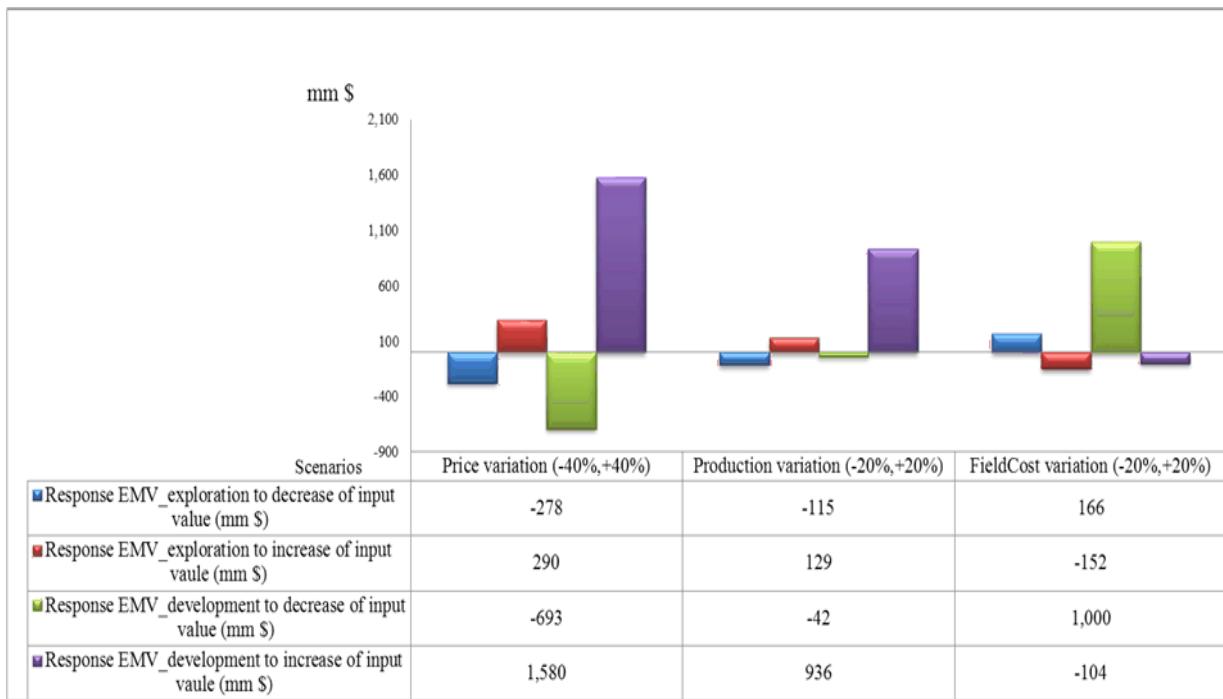


Figure 60: Response of EMVs to one variable variation at a time (EcoPetro_Gas model)

Contractor take and government take values of EcoPetro_Gas model do not show large change in response to the one variable at a time scenarios. But it is clear that the division of net cash flow is in favour of the government, and the government take increased by decreasing of the price, see figure 61.

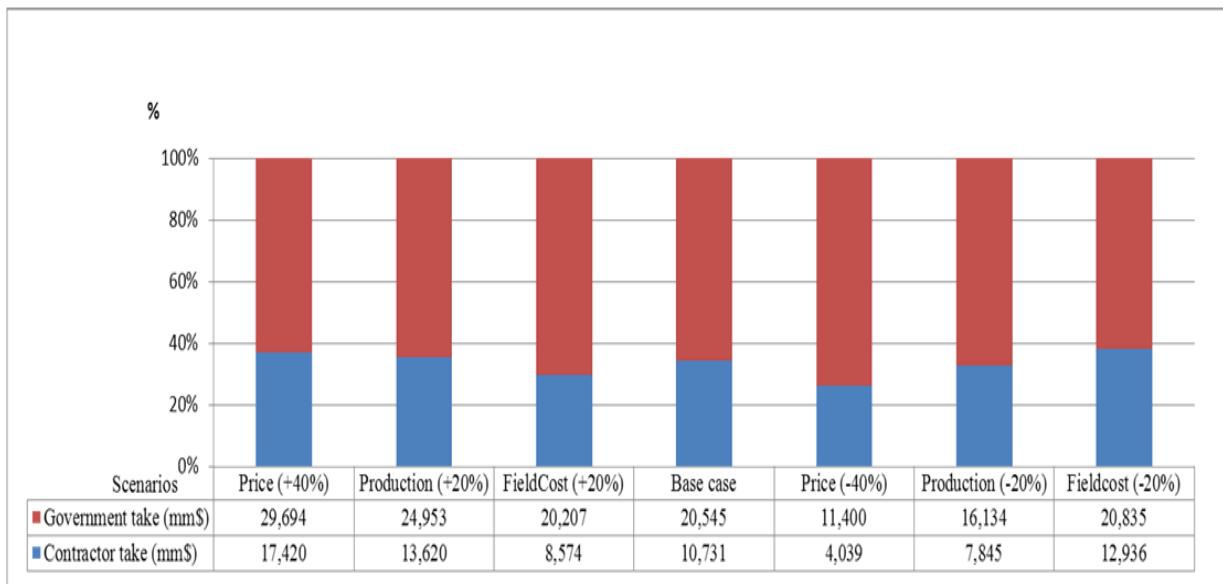


Figure 61: Response of take indicators to the one variable variation at a time (EcoPetro_Gas model)

From here on, the correlation between the key variables is taken into account. The correlation between the oil and gas prices is positive, which means that they decrease or increase together, and the correlation between oil production and gas production also shows a positive correlation. The scenarios of multi sensitivity analysis of EcoPetro_Gas are shown in table 14.

Table 14: Input scenarios of deterministic sensitivity analysis, case: multi-variable variations (EcoPetro_Gas model)

Scenario ID	Gas production MMCF/d	Oil production Bbl/d	Gas price \$/ MCF	Oil price \$/bbl	OPEX mm \$	CAPEX mm \$	Abandonment mm \$
BC	27	6	5.4	80	3,106	3,741	200
G1	+20%	+20%	+40%	+40%	+20%	+20%	+20%
G2	-20%	-20%	+40%	+40%	+20%	+20%	+20%
G3	+20%	+20%	+40%	+40%	-20%	-20%	-20%
G4	-20%	-20%	+40%	+40%	-20%	-20%	-20%
G5	- 20%	- 20%	-40%	-40%	+20%	+20%	+20%
G6	+ 20%	+ 20%	-40%	-40%	-20%	-20%	-20%
G7	- 20%	- 20%	-40%	-40%	+20%	+20%	+20%
G8	+20%	+20%	-40%	-40%	-20%	-20%	-20%

The NCF remained positive, even for the worst case scenario G7 as shown in figure 62. In the best scenario G3 (prices increase by 40%, oil and gas production increase by 20% and field cost decrease by 20%) the NCF increased by 87% from 10,731 mm \$ to 20,118 mm \$, while the NPV recorded a negative value (-801) mm \$ the worst scenario G7 (prices decrease by 30%, oil and gas production decrease by 25% and field cost increase by 20%).

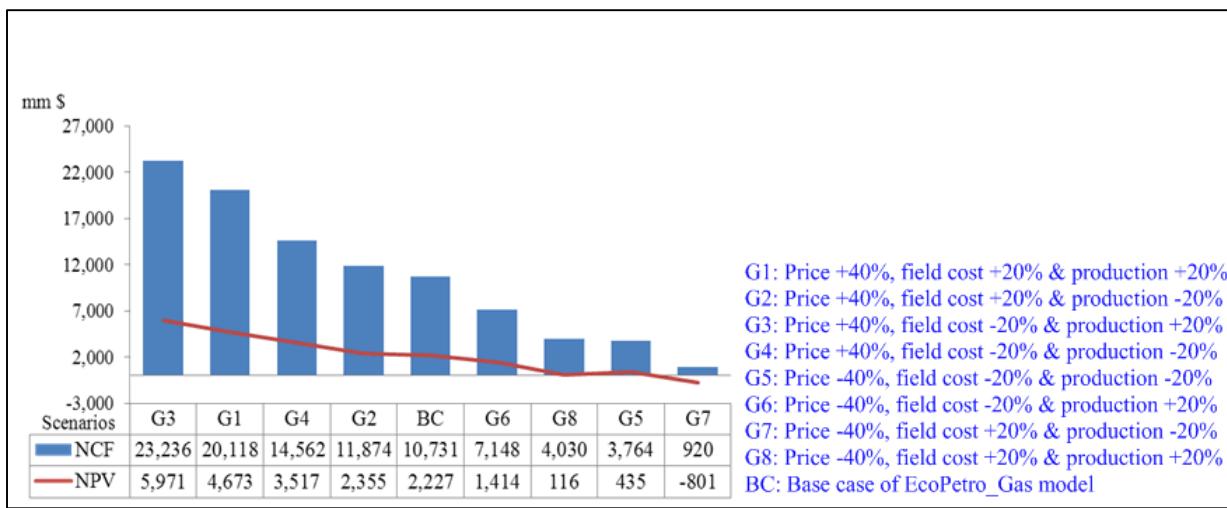


Figure 62: Response of NCF and NPV to multi-variable variations (EcoPetro_Gas model)

Figure 63 addresses the impact of the worst scenario (G7) on the payback period, where the payback period increased from 9 to 16 years through decreased prices, production and increased field cost. The best scenario (G3) decreases the payback period by only one year.

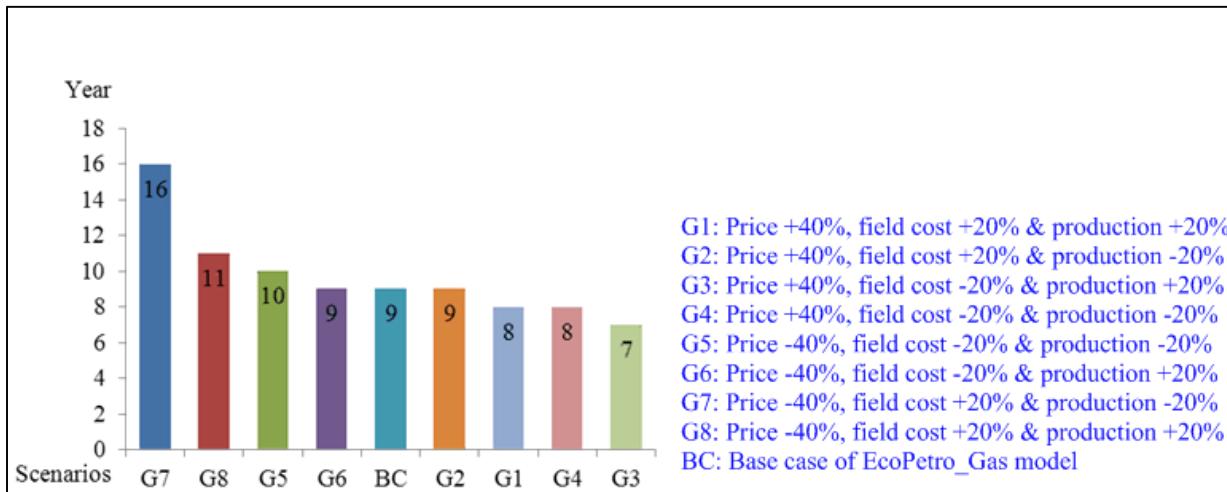


Figure 63: Response of Payback period to multi-variable variations (EcoPetro_Gas model)

The take indicators of EcoPetro_Gas model are shown in figure 64, and it is obvious that the contractor take percentage from revenue after field cost is reduced dramatically by 74% at the worst case scenario (G7), from 34% to 9%, while by the best case scenario (G3) the contractor take increased by 15%, from 34% to 39%.

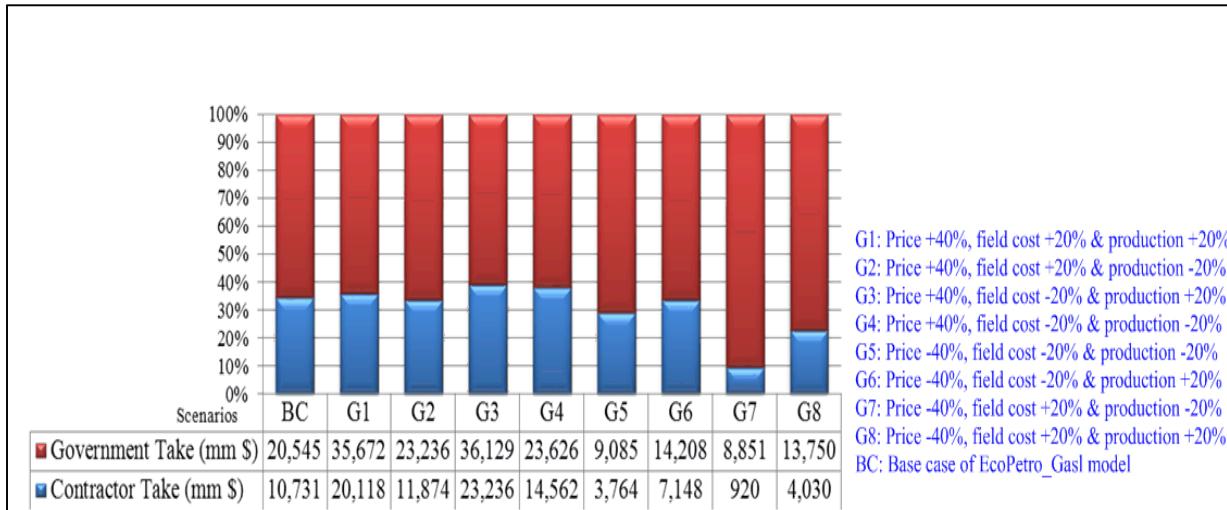


Figure 64: Response of take indicators to multi-variable variations (EcoPetro_Gas model)

The IRR of EcoPetro_Gas model showed a lot of sensitivity to multi-variable variations as shown in figure 65, where the IRR increased by from 25% to 46% in the best case scenario (G3) and decreased from 25% to 3% in the worst case scenario (G7).

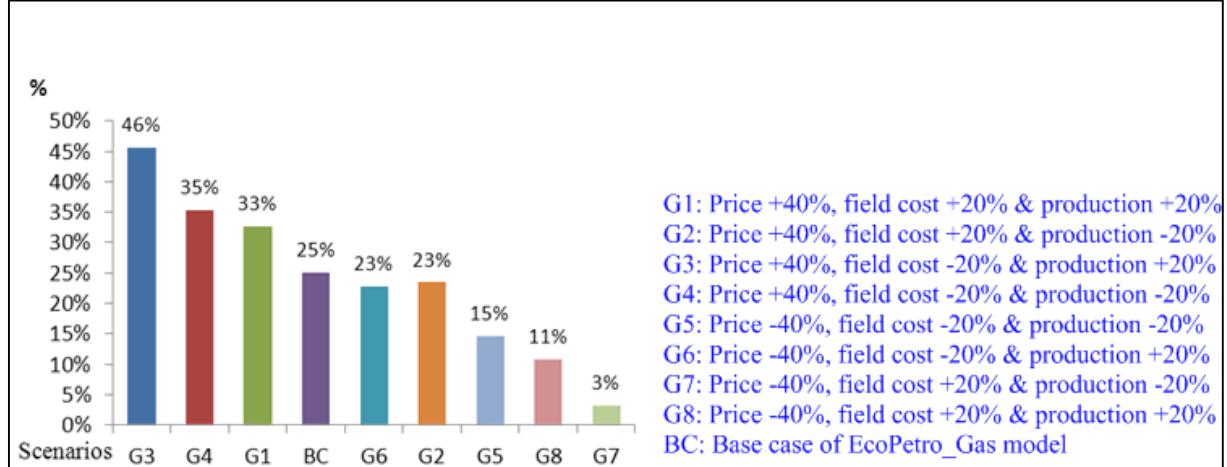


Figure 65: Response of IRR to multi-variable variations (EcoPetro_Gas model)

The high risk character of the EcoPetro_Gas model base case is indicated once again by the EMV's response to multi-variable variations, as shown in figure 66. Three scenarios caused negative values of EMV_exploration and EMV_development, so the decision makers should be careful in choosing to invest in this project or must have a plan to face a probable loss.

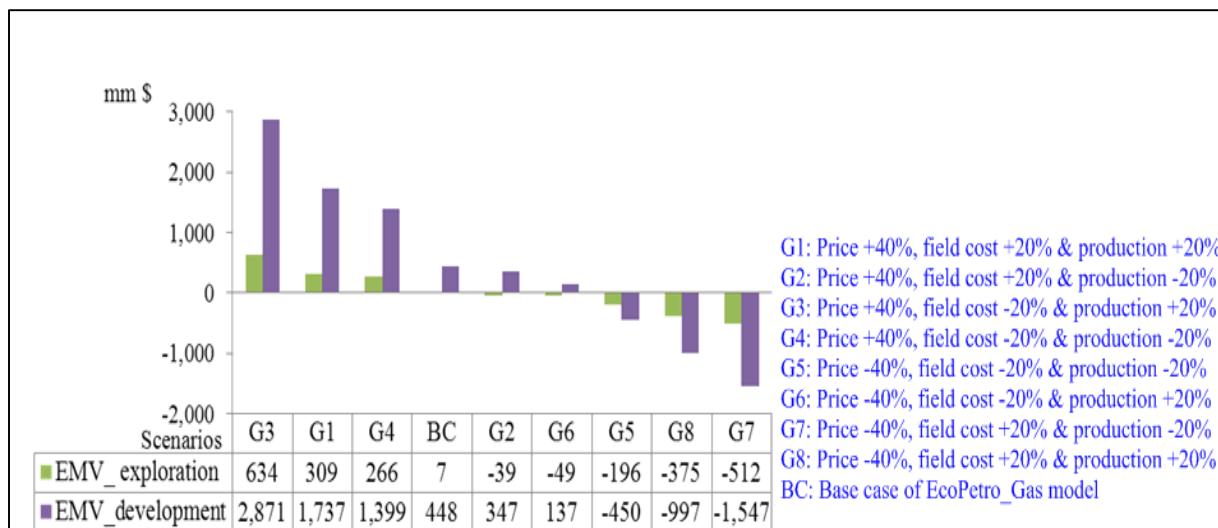


Figure 66: Response of EMVs to multi-variable variations (EcoPetro_Gas model)

6.2.4.2 Possibility Sensitivity Analysis

The possibility analysis of EcoPetro_Gas model is constructed in similar manner to that of EcoPetro_Oil model. Therefore, in order to build a scenario for the exploration phase, 5% error rate was given to oil and gas production, 7% error rate to oil, gas and prices, and a 3% error rate to CAPEX, OPEX and abandonment cost. To avoid the inconsistencies of the model a 1% error rate was given to probability of success.

Other input variables are assumed to be error free and their deterministic values from the main deterministic EcoPetro_Gas model were adopted. Figure 67 shows an extract from FuzzyCalc for the NPV of the exploration phase scenario. The NPV fuzzy value is about of 2,987 mm \$, with an upper bound of 4,074 mm \$ and a lower bound of 1,977 mm \$.

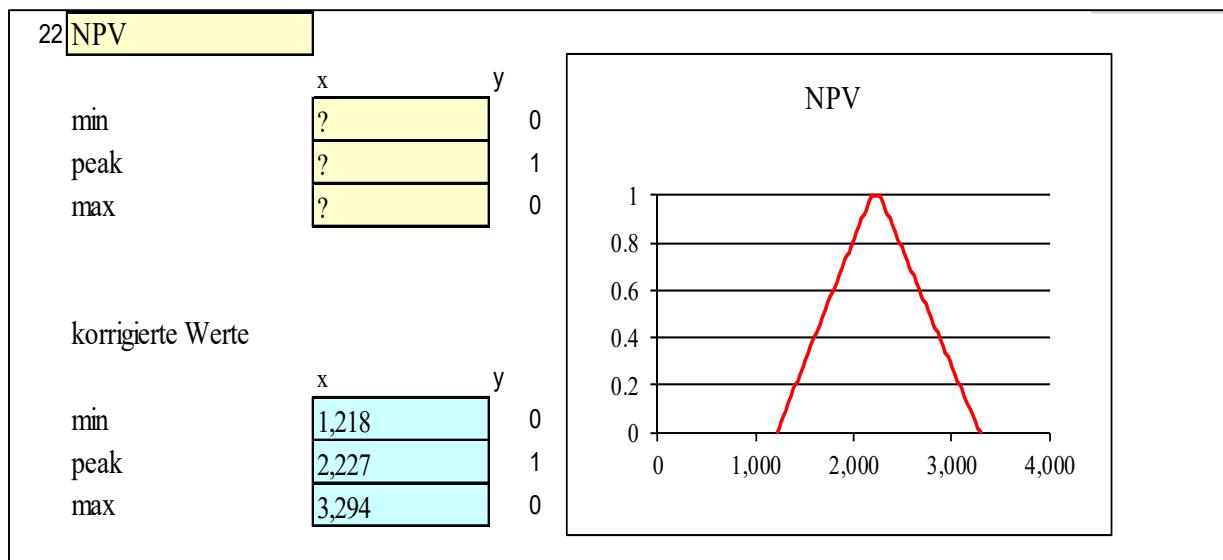


Figure 67: Fuzzy value of NPV calculated based on $\pm 7\%$ error rates of price, $\pm 5\%$ error rates for each from production and $\pm 3\%$ error rate of field cost (EcoPetro_Gas model, exploration phase scenario)

Table 15 collects the prior values of EcoPetro_Gas model and the adjusted values after running FuzzyCalc. Prior and adjusted values of the input variables are symmetric with the model. The revenue as fuzzy value is about of 39,593 mm \$ with error rates ± 12 , the contractor take is about of 19,048 mm \$ with upper error rate + 22% and lower error rate - 21%, while the government take resulted from the above possibility analysis scenario is error free due to the assumption that the input fiscal costs (tax, royalty) are also error free.

The NCF fuzzy value is around 10,731 mm \$ with upper error rate equal to +36% and a lower error rate equal to -34%, also the NPV peak value is at 2,227 mm \$ with an upper error rate equal to +36% and a lower error rate equal to -34%.

The peak value of EMV_exploration is at 7 mm \$ with too high uncertainty intervals (upper bound 187 mm \$ and lower bound 152 mm \$).

Table 15: Prior fuzzy values and adjusted value (EcoPetro_Gas model, exploration phase scenario)

Variable	Prior value	Adjusted value
Gas production (BCF)	998 ± 5%	998 ± 5%
Gas price (\$ / MCF)	7 ± 7%	7 ± 7%
Oil production (mm bbl)	305 ± 5%	305 ± 5%
Oil price (\$/ bbl)	107 ± 7%	107 ± 7%
Revenue (mm \$)	?	39,593 ± 12%
OPEX (mm \$)	4,203 ± 3%	2,692 ± 3%
CAPEX (mm \$)	3,741 ± 3%	3,299 ± 3%
Abandonment (mm \$)	373 ± 3%	479 ± 3%
Royalty (mm \$)	11,267 ± 0	5,761 ± 0
Tax (mm \$)	9,278 ± 0	9,400 ± 0
Discount factor	21% ± 0	21% ± 0
Contractor take (mm \$)	?	19,048 (+22%, -21%)
Government Take (mm \$)	?	20,545 ± 0
NCF (mm \$)	?	10,731(+36%, -34%)
NPV @ 10% (mm \$)	?	2,227 (+36%, -34%)
Discounted exploration cost @ 10% (mm \$)	271 ± 0	271 ± 0
POS_exploration	11% ± 1%	11% ± 1%
EMV_exploration ²⁴ (mm \$)	?	7 (+187/-152)

In order to implement the development phase scenario using FuzzyCalc for the EcoPetro_Gas model an ± 1% error rate was given to each, oil production, gas production and field cost, while the error rates of oil and gas prices remain at ± 7%. The NPV and EMV_exploration resulting from the above scenario are shown in figure 68. The NPV as fuzzy value is about 2,227 mm \$ with an upper bound of 2,908 mm \$ and a lower bound of 1,558 mm \$.

²⁴ The calculation of EMV_exploration using FuzzyCalc appears to be not applicable for the exploration phase before drilling since the uncertainties of variables are still too high.

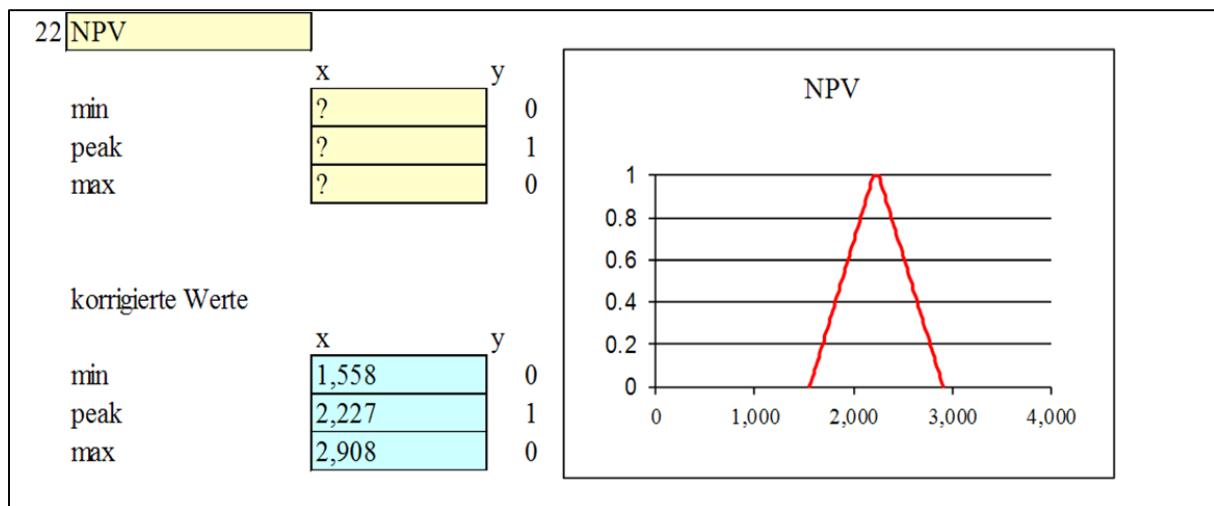


Figure 68: Fuzzy value of NPV calculated based on $\pm 7\%$ error rates of price, $\pm 1\%$ error rates for each, production and field cost (EcoPetro_Gas model, development phase scenario)

Table 16 collects the prior values of the EcoPetro_Gas model and the adjusted values after running FuzzyCalc for the development phase scenario.

A reduction of the input error rates of production from $\pm 5\%$ to $\pm 1\%$ and the input error rates of field cost from $\pm 3\%$ to $\pm 1\%$ reduced the error rates of revenue from $\pm 12\%$ to $\pm 8\%$, and reduced the upper error rate of the contractor take peak value from $+ 22\%$ to $+ 17\%$; the lower error rate from $- 21\%$ to $- 16\%$.

The government take remains an error free output variable, The NCF as fuzzy value is around 10,731 mm \$ with an upper error rate of $+ 31\%$ and lower error rate of $- 30\%$. The peak value of NPV is 2,227 mm \$ with the same error rates of the NCF. The EMV_development as fuzzy value has a positive peak value of 448 mm \$, an upper error rate of $+ 97\%$, and a lower error rate of $- 94\%$.

Table 16: Prior fuzzy values and adjusted value (EcoPetro_Gas model, development phase scenario)

Variable	Prior value	Adjusted value
Gas production (BCF)	998 ± 5%	998 ± 1%
Gas price (\$ / MCF)	7 ± 7%	7 ± 7%
Oil production (mm bbl)	305 ± 5%	305 ± 1%
Oil price (\$/ bbl)	107 ± 7%	107 ± 7%
Revenue (mm \$)	?	39,593 ± 8%
OPEX (mm \$)	4,203 ± 3%	2,692 ± 1%
CAPEX (mm \$)	3,741 ± 3%	3,299 ± 1%
Abandonment (mm \$)	373 ± 3%	479 ± 1%
Royalty (mm \$)	11,267 ± 0	5,761 ± 0
Tax (mm \$)	9,278 ± 0	9,400 ± 0
Discount factor	21% ± 0	21% ± 0
Contractor take (mm \$)	?	19,048 (+17%, -16%)
Government Take (mm \$)	?	20,545 ± 0
NCF (mm \$)	?	10,731(+31%, -30%)
NPV @ 10% (mm \$)	?	2,227 (+31%, -30%)
Discounted capital cost @ 10% (mm \$)	2,222 ± 0	2,222 ± 0
POS_development	60% ± 1%	60% ± 1%
EMV_development (mm \$)	?	448 (+97%, -94%)

Figure 69 shows the fuzzy values of NPV response to error rate variations, where each bar can be interpreted as a fuzzy value (min/peak/max) in a similar way to the EcoPetro_Oil model. The vertical axis represents the peak value of NPV. A reduction of the input error rates of production from ± 5% to ± 1% and the input error rates of field cost from ± 3% to ± 1% reduced the error rates of NPV from + 36% and -34% to ± + 31% and -30%.

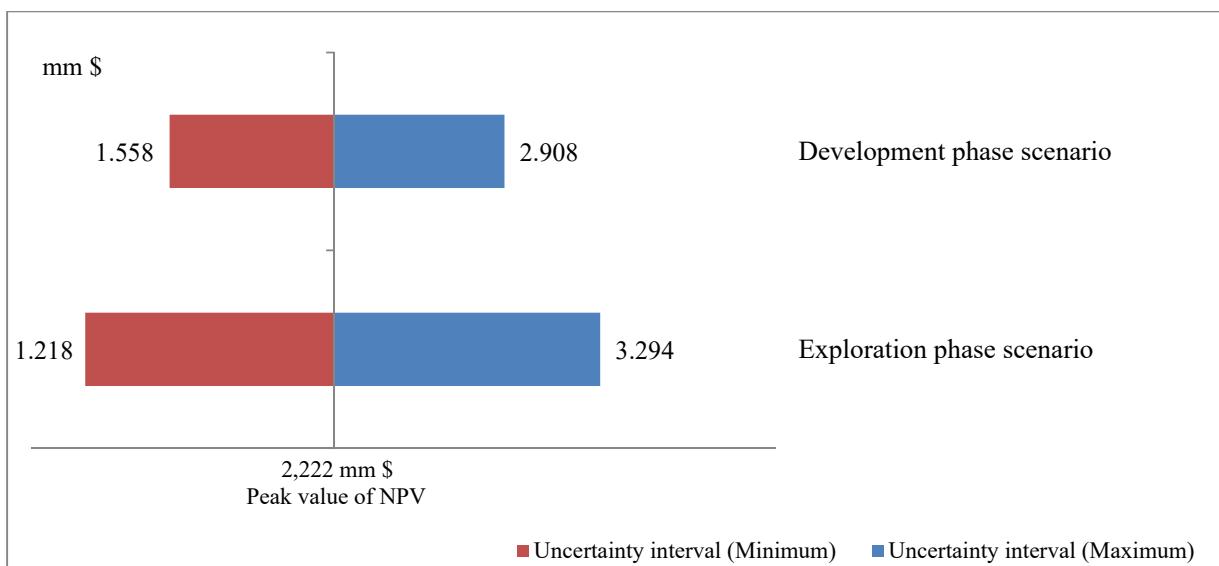


Figure 69: Response of uncertainty interval of NPV to error rate variations (EcoPetro_Gas model)

6.2.4.3 Probability Sensitivity Analysis

The probability sensitivity analysis of the EcoPetro_Gas model has the same scenarios as the possibility sensitivity analysis. The peak value of the fuzzy number represents the mean value of Gaussian distribution. Upper or lower boundaries of the fuzzy number represent the standard deviation of the corresponding Gaussian distribution (confidence degrees) as previously stated (section 6.1.4.3).

The output of the exploration phase scenario (oil production $\pm 5\%$, oil price $\pm 7\%$, gas production $\pm 5\%$, gas price $\pm 7\%$ and field cost $\pm 1\%$) are shown in figure 70. The exogenous variables are consistent with the model, because the computed confidence intervals of the exogenous variables are of the same values as of the input confidence intervals.

The NCF mean value is 10,730 mm \$ with a confidence rate equal to $\pm 25\%$ and the NPV mean value is 2,227 mm \$ with a confidence rate (standard deviation) equal also to $\pm 25\%$. The EMV_exploration²⁵ mean value is 7 mm \$ with a confidence intervals equal to ± 82 mm \$.

²⁵ The calculation of EMV_exploration of EcoPetro_Gas using Quantor is comparable to FuzzyCalc not applicable for the exploration phase before drilling.

GasProduction	GasPrice	OilProduction	OilPrice	Value1	Value2
997.600 ± 49.880	6.940 ± 0.490	305.004 ± 15.250	107.110 ± 6.470	?	?
997.600 ± 50.048	6.940 ± 0.490	305.004 ± 15.288	107.110 ± 6.470	6923.344 ± 599.167	32668.979 ± 2562.400
Revenue	Royalty	OPEX	CAPEX	Abandonment	Tax
?	11267.000 ± 0.000	4203.000 ± 126.090	3741.000 ± 112.230	373.000 ± 11.190	9278.000 ± 0.000
39592.324 ± 2631.520	11267.000 ± 0.000	4203.000 ± 126.090	3741.000 ± 112.230	373.000 ± 11.190	9278.000 ± 0.000
DiscountFactor	NCF	NPV			
0.208 ± 0.000	?	?			
0.208 ± 0.000	10730.324 ± 2636.952	2227.257 ± 547.343			
FieldCost	ContractorTake	GovernmentTake			
?	?	?			
8317.000 ± 169.173	19047.324 ± 2631.520	20545.000 ± 0.000			
DiscountedExploration	POS_exploration	POF_exploration	Value_2	Value_3	EMV_exploration
384.500 ± 0.000	0.150 ± 0.002	0.850 ± 0.009	?	?	?
384.500 ± 0.000	0.150 ± 0.002	0.850 ± 0.009	334.089 ± 82.171	326.825 ± 3.268	7.264 ± 82.236

Figure 70: Output of probability analysis of the exploration phase scenario (EcoPetro_Gas model)

The probability analysis using the Quantor for the development phase scenario, was implemented in similar manner to the possibility sensitivity analysis, so the confidence rates of oil production, gas production are reduced from ± 5% to ± 1% and field cost from ± 3% to ± 1% (see Fig. 71). The NPV mean value is 2,227 mm \$ with a confidence rate equal to ± 19%. The EMV_development mean value is 448 mm \$ with a confidence rate equal to ± 57%.

The discounted CAPEX is shown in yellow, and that means the dispersion of the output value of discounted CAPEX is significantly greater than the dispersion of the input value.

GasProduction	GasPrice	OilProduction	OilPrice	Value1	Value2
997.600 ± 9.976	6.940 ± 0.490	305.004 ± 3.050	107.110 ± 6.470	?	?
997.600 ± 10.013	6.940 ± 0.490	305.004 ± 3.056	107.110 ± 6.470	6923.344 ± 493.711	32668.979 ± 2000.271
Revenue	Royalty	OPEX	CAPEX	Abandonment	Tax
?	11267.000 ± 0.000	4203.000 ± 42.030	3741.000 ± 37.410	373.000 ± 3.730	9278.000 ± 0.000
39592.324 ± 2060.299	11267.000 ± 0.000	4203.000 ± 42.030	3741.000 ± 37.410	373.000 ± 3.730	9278.000 ± 0.000
DiscountFactor	NCF	NPV			
0.208 ± 0.000	?	?			
0.208 ± 0.000	10730.324 ± 2061.071	2227.257 ± 427.810			
FieldCost	ContractorTake	GovernmentTake			
?	?	?			
8317.000 ± 56.391	19047.324 ± 2060.299	20545.000 ± 0.000			
DiscountedCAPEX	POS_Development	POF_Development	Value_4	Value_5	EMV_Development
2221.800 ± 0.000	0.600 ± 0.006	0.400 ± 0.004	?	?	?
2221.800 ± 0.779	0.600 ± 0.006	0.400 ± 0.004	1336.354 ± 257.038	888.720 ± 8.887	447.634 ± 257.192

Figure 71: Output of probability analysis of the exploration phase scenario (EcoPetro_Gas model)

A reduction of the production confidence intervals from $\pm 5\%$ to $\pm 1\%$ and the field cost confidence intervals from $\pm 3\%$ to $\pm 1\%$; reduced the confidence intervals of NPV by 24%, from $\pm 25\%$ to $\pm 19\%$. Figure 72 compares the confidence intervals of NPV response to variation of input confidence rates, where each bar can be interpreted as a symmetric confidence interval (min, medium, max). It is obvious that the confidence intervals of NPV have no negative value.

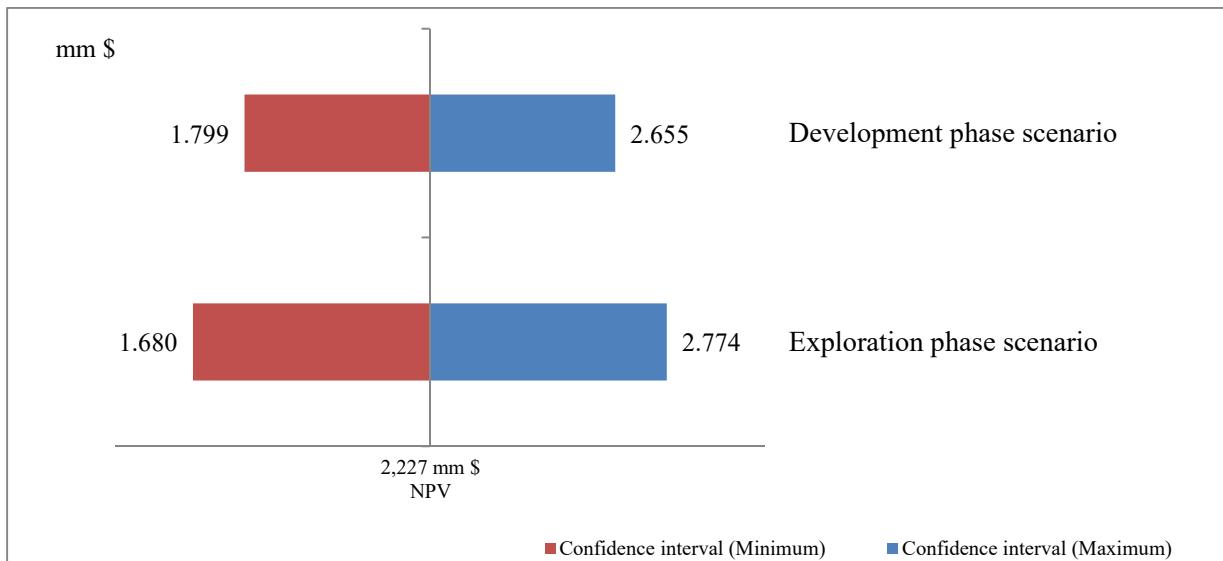


Figure 72: Response of confidence intervals of NPV to confidence degree variations (EcoPetro_Gas model)

6.2.4.4 Monte Carlo Simulation

In order to design the Monte Carlo simulation of the EcoPetro_Gas model in a structure comparable with the Monte Carlo simulation of the EcoPetro_Oil model, the number of iterations are again set at 20,000 trials, and the type of the input probability distributions for uncertainty variables are assumed to have triangular distribution with (min/med/max) values (Tab. 17).

Table 17: Input values to Monte Carlo simulation (exploration phase scenario, EcoPetro_Oil model)

Uncertainty Variables	Unit	Min	Mean	Max
Gas production	B cf	948	998	1,047
Gas price	\$/ MCF	7.43	7	6.46
Oil production	mm bbl	290	305	320
Oil price	\$/bbl	115	107	100
CAPEX	mm \$	3,853	3,741	3,629
OPEX	mm \$	4,329	4,203	4,077
Abandonment	mm \$	464	384	362

The most important statistical output values²⁶ after running the simulation of the above scenario are collected in table 18. The NCF base case value is 10,678 mm \$ and the mean value of the NCF probability distribution is equal to 10,723 mm \$. The median of the output distribution of NCF is equal to 10,709 mm \$. The error rate of the NCF mean value is equal to \pm 11%. The contractor take mean value is 19,047 mm \$ and differs slightly from the base case value, with error rates equal to \pm 6%. The EMV_exploration mean value is 7 mm \$ with a too high standard deviation of 37 mm \$.

Table 18: Relevant statistical output of Monte Carlo simulation (exploration phase scenario, EcoPetro_Gas model)

Item	Contractor take mm \$	Government take mm \$	NCF mm \$	NPV mm \$	EMV_exploration mm \$
Trials	20,000	20,000	20,000	20,000	20,000
Base Case	19,047	20,545	10,730	2,227	7
Mean	19,041	20,545	10,723	2,225	7
Median	19,030	20,545	10,709	2,223	7
Standard Deviation	1,174	0	1,175	244	37
Minimum	15,334	20,545	7,045	1,462	-108
Maximum	22,826	20,545	14,432	2,995	123

The mean of NPV 2,225 mm \$ differs also slightly from the NPV base case value with a standard deviation equal to 244 mm \$ or error rates equal to \pm 11%. Figure 73 indicates the possible NPVs of the EcoPetro_Gas model using Monte Carlo simulation response for the development phase scenario. The generated distribution of the NPV reflects the probability to obtain a certain value. The NPV calculated to be on average 2,225 mm \$ has an 80% certainty of being between 1,906 mm \$ and 2,542 mm \$.

²⁶ The simulation was made on 06/04/2015 at 10:12 a.m. When the simulation was reset and restarted without any changes in the model, different results were achieved but the differences can be considered to be insignificant.

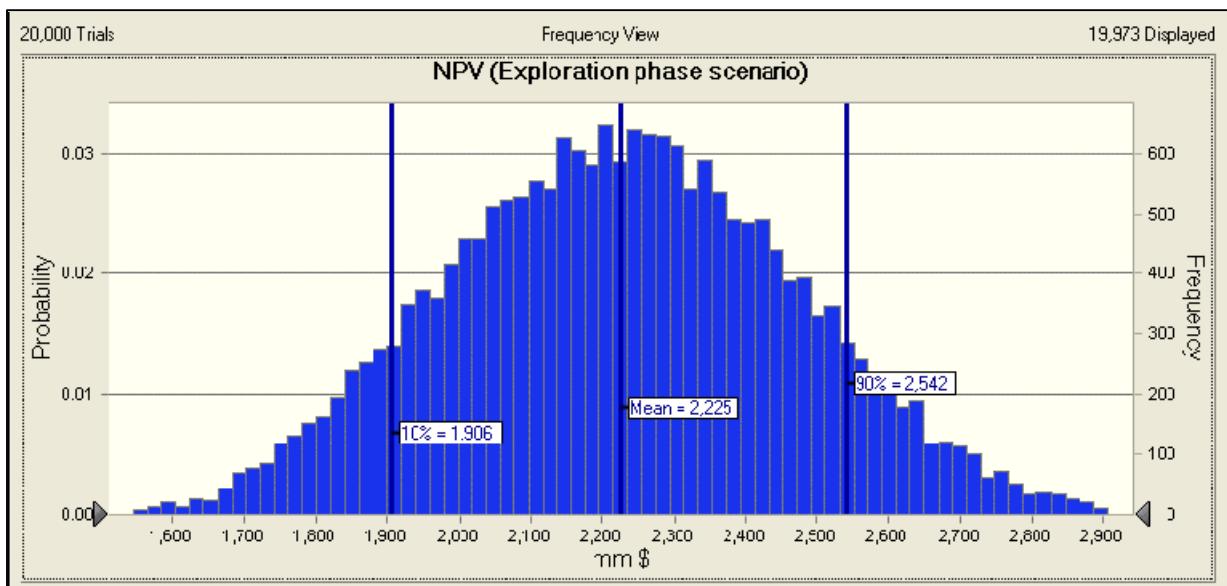


Figure 73: Probability distribution of NPV resulting from Monte Carlo simulation (EcoPetro_Gas model, exploration phase scenario)

The probability distribution of EMV_exploration is shown in figure 74. The mean value of the EMV_exploration distribution is 7 mm \$ with an 80% certainty of being between (-41) mm \$ and 54 mm and 58% certainty of being a positive value.

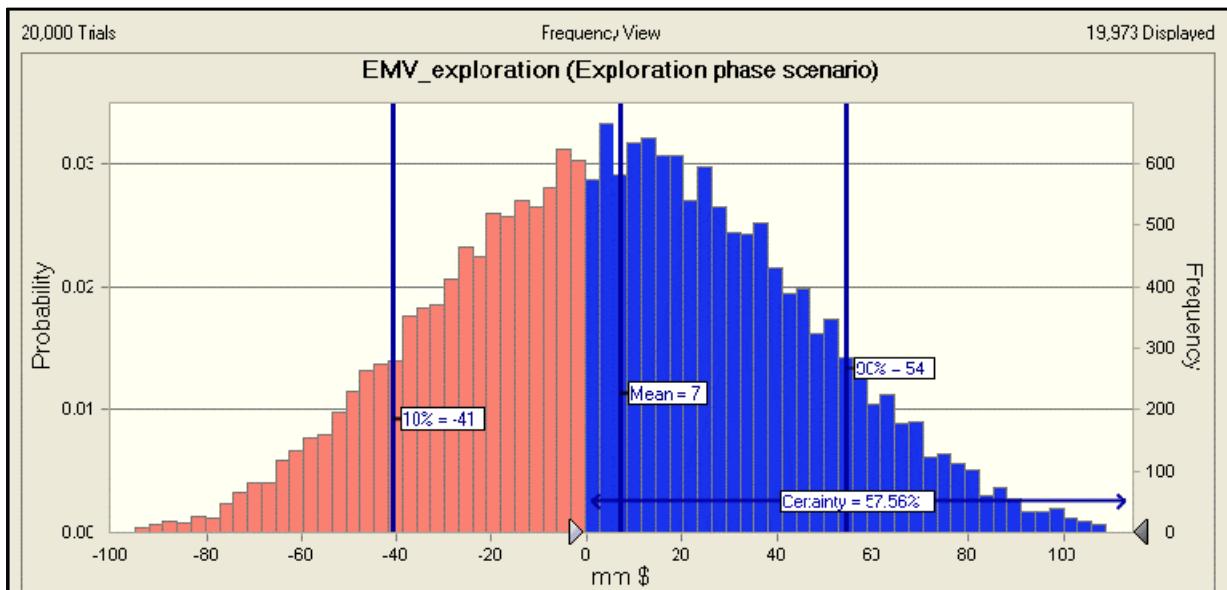


Figure 74: Probability distribution of EMV_exploration resulting from Monte Carlo simulation (EcoPetro_Gas model, exploration phase scenario)

It is assumed that the likeliest input values remain constant in order to implement the development phase scenario using Crystal Ball and the uncertainty intervals (min, max) are

reduced for each, oil production and field cost variables. Table 19 shows the input values of uncertain variables of this scenario.

Table 19: Input values to Monte Carlo simulation (development phase scenario, EcoPetro_Gas model)

Uncertainty Variables	Unit	Min	Mean	Max
Gas production	B cf	988	998	1,007
Gas price	\$/ MCF	5.6	7	6.5
Oil production	mm bbl	302	305	308
Oil price	\$/bbl	86	107	90
CAPEX	mm \$	3,266	3,741	3,332
OPEX	mm \$	2,665	4,203	2,719
Abandonment	mm \$	474	384	484

The simulation using Crystal Ball was implemented based on 20,000 trials; table 20 collects the most important statistic output. The mean value of the NCF is equal to 10,734 mm \$ which slightly differs from the NCF mean value of the exploration scenario. The median of the output distribution of NCF is equal to 10,740 mm \$. The NCF varies by 968 mm \$ to the mean value, with an error rate of $\pm 9\%$. The mean value of contractor take is 19,052 mm \$ with an error rate equal to $\pm 5\%$ and the mean value of EMV_development is 448 with an error rate equal to $\pm 27\%$.

Table 20: Relevant statistical output of Monte Carlo simulation (development phase scenario, EcoPetro_Oil model)

Item	Contractor take mm \$	Government take mm \$	NCF mm \$	NPV mm \$	EMV_development mm \$
Trials	20,000	20,000	20,000	20,000	20,000
Base Case	19,047	20,545	10,730	2,227	448
Mean	19,052	20,545	10,734	2,228	448
Median	19,058	20,545	10,740	2,229	449
Standard Deviation	968	0	968	201	122
Minimum	16,365	20,545	8,061	1,673	96
Maximum	21,804	20,545	13,532	2,809	804

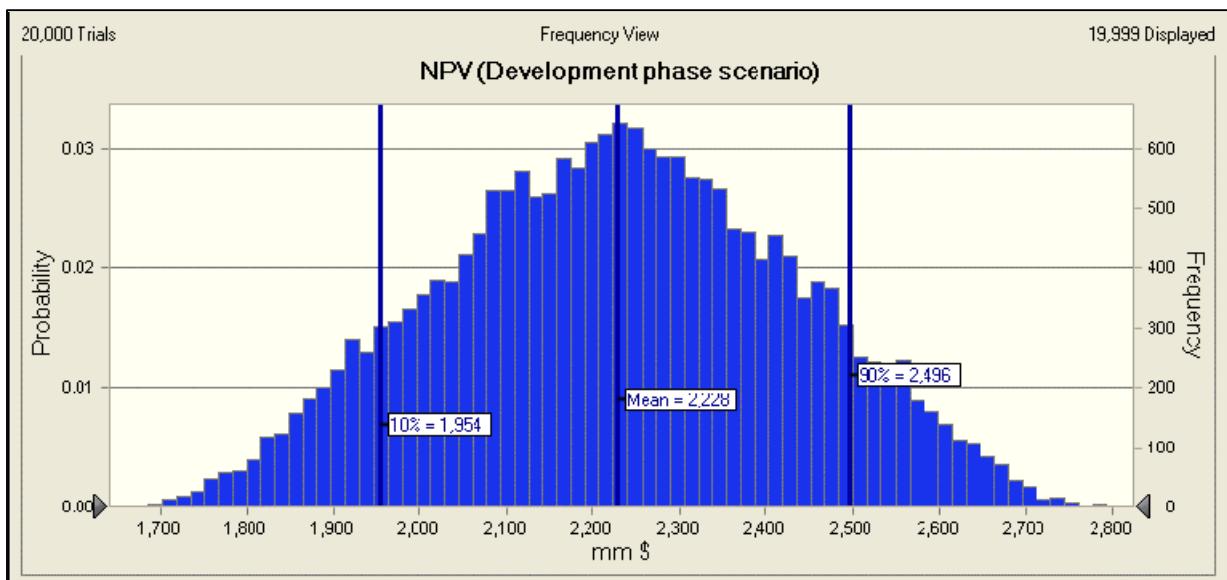


Figure 75: Probability distribution of NPV resulting from Monte Carlo simulation (EcoPetro_Gas model, development phase scenario)

Figure 75 shows NPVs of EcoPetro_Gas model using Monte Carlo simulation for the development phase scenario. The generated distribution of NPV reflects that the average of NPV at 2,228 mm \$, with an 80% certainty of being between 2,496 mm \$ and 1,954 mm \$.

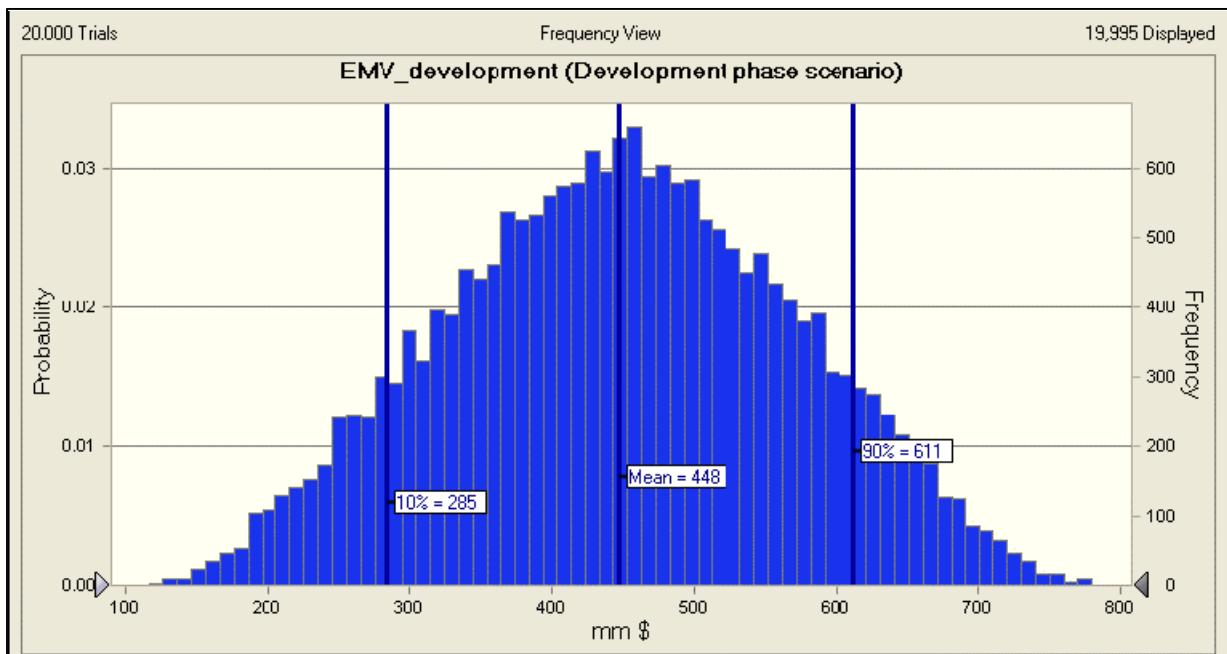


Figure 76: Probability distribution of EMV_development resulting from Monte Carlo simulation (EcoPetro_Gas model, development phase scenario)

Figure 76 shows the distribution of EMV_development with the mean value of 44 mm \$ and an 80% certainty of being between 285 mm \$ and 611 mm \$.

The overlay Chart in figure 77 compares the probability NPV distributions of the exploration and development phase scenarios. The mean value of NPV changed slightly from 2,228 mm \$ to 2,226 mm \$. The standard deviation of the NPV of the exploration phase scenario of 244 mm \$ is greater than the standard deviation of the development scenario of 244 mm \$; i.e., the error rates of NPV decreased from $\pm 11\%$ to $\pm 9\%$, by the decrease of the input uncertainty intervals of the oil and gas production from $\pm 5\%$ to $\pm 1\%$ and of the field cost from $\pm 3\%$ to $\pm 1\%$.

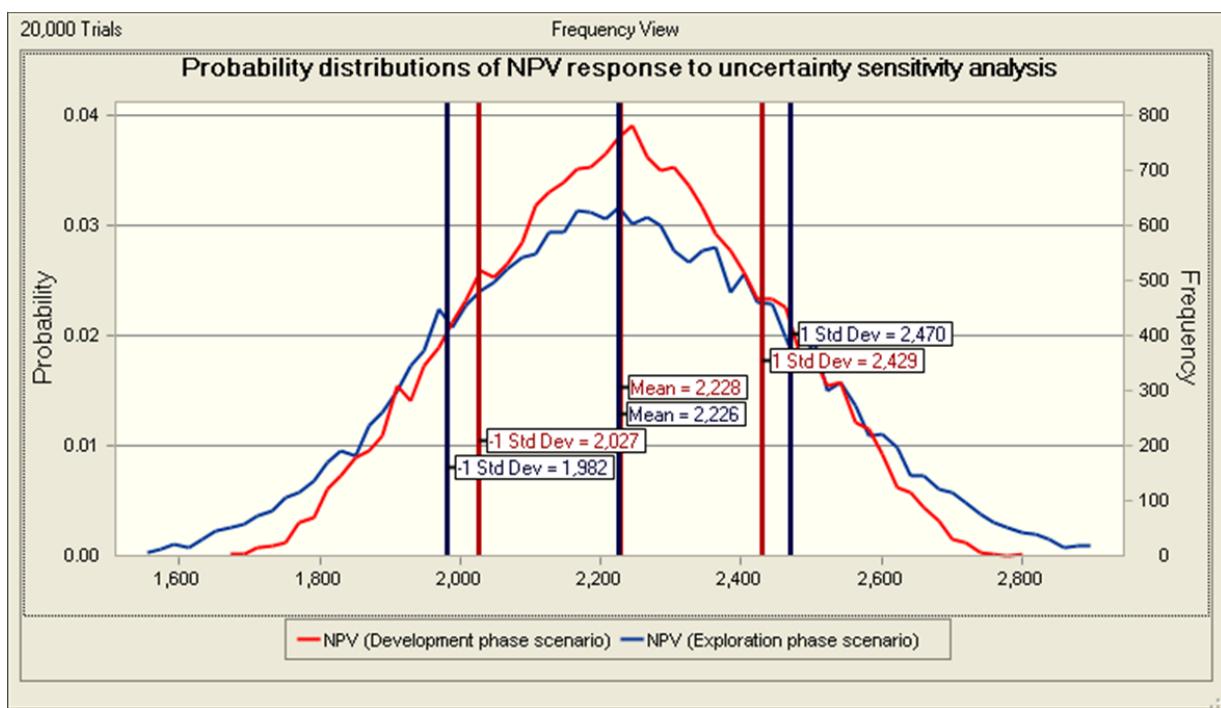


Figure 77: Response of probability distributions of NPV to sensitivity analysis based on Monte Carlo simulation (EcoPetro_Gas model)

Figure 78 compares the probability distributions of EMV_exploration and EMV_development resulting from the developed scenarios.

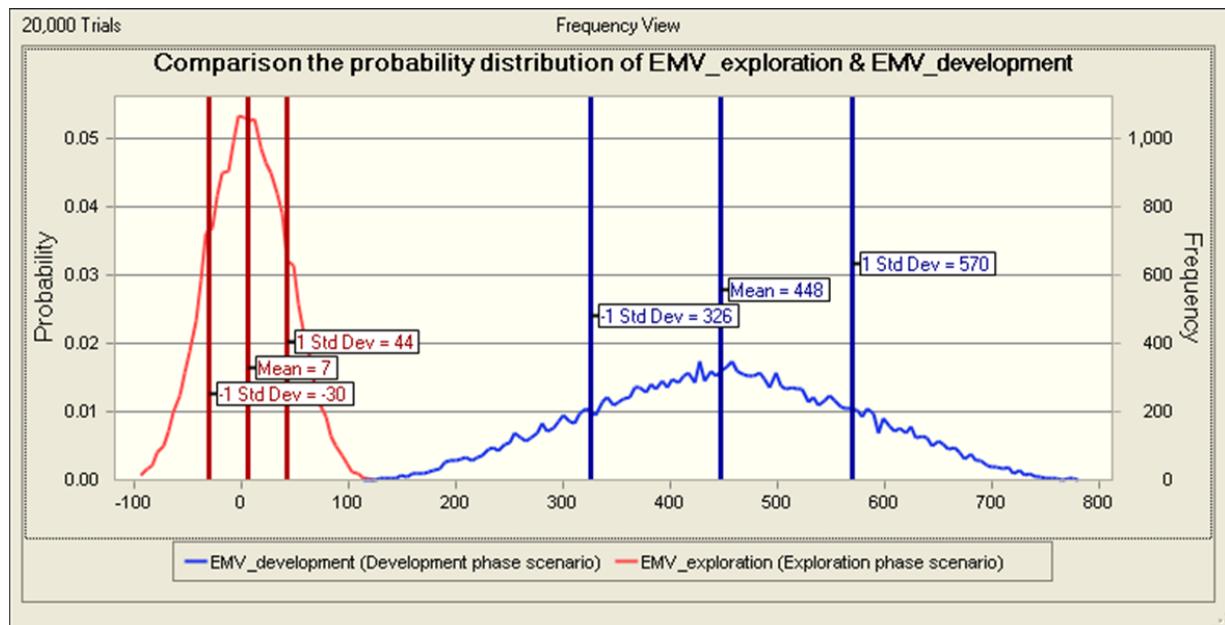


Figure 78: Response of probability distributions of NPV to sensitivity analysis based on Monte Carlo simulation (EcoPetro_Gas model)

Chapter 7: Conclusion

7.1 Models Evaluation

After a description of the basic framework of a petroleum exploration and production economics model, the standard model (EcoPetro_Model) based on Excel 2010 was defined and designed in order to benefit from its results in further economic analysis under risk and imprecise data.

The EcoPetro_Model provides a clear definition of input variables and a wide flexibility in calculation of cost and choice of fiscal regimes, in addition to a clear graphical presentation for base case results and deterministic sensitivity analyses (one variable and multi-variable sensitivity analysis). The key business indicators to evaluate a project using EcoPetro_Model are NCF, NPV, IRR, Payback period and take indicators (government take, contractor take), and in addition the expected monetary values (EMV). All variable values can be inserted into EcoPetro_Model in real and/or inflated value.

EcoPetro_Model is constructed based on simplifications of reality and deterministic input values; therefore the output requires additional analysis to cover the uncertainty in the input data.

In order to verify the efficiency of EcoPetro_Model, two different models (EcoPetro_Oil, EcoPetro_Gas) were performed, where the EcoPetro_Oil model applies a production sharing contract and the EcoPetro_Gas model applies a concession contract. The EcoPetro_Model is complicated but well-defined. The cases and data used for the tests of the petroleum models (EcoPetro_Oil and EcoPetro_Gas) were well-chosen and draw a clear picture of the profitability of the oil and gas projects. However, it can be stated that the Nigerian fiscal regime can be optimally assessed using the EcoPetro_Model, whereas in the Nova Scotia fiscal regime some simplifications related to royalty calculations needed to be implemented.

By comparing the key business indicators of EcoPetro_Oil and EcoPetro_Gas models (base case), it is noted that the revenue of the EcoPetro_Gas model in the order of 39,594 mm \$ is greater than the revenue of EcoPetro_Oil model at 37,141 mm \$, but the NCF of the EcoPetro_Gas model of 10,731 mm \$ is less than the NCF of the EcoPetro_Oil model at 13,687 mm \$, caused by the high capital cost of North Atlantic offshore projects where the geologic nature is difficult to explore and the modern production technology is expensive.

The NPV of the base case of the EcoPetro_Oil and EcoPetro_Gas model are in order of 2,118 and 2,227 mm \$ respectively. And the EMV_exploration of EcoPetro_Oil is of 4 mm \$ and The EMV_development is at 792 mm \$, whereas the EMV_exploration of EcoPetro_Gas is at 7 mm \$; the EMV_development is 448 mm \$.

Under the assumption that the projects are independent it can be invested in both, otherwise, in case of mutually exclusive projects the EcoPetro_Gas project must be chosen based on the largest positive NPV and EMV.

The deterministic sensitivity analysis on the EcoPetro_Oil model recorded positive NPVs in all scenarios (one variable at a time and multi-variable), e.g. 409 mm \$ even in the worst-case scenario, whereas the EcoPetro_Gas model recorded a negative NPV (-801) mm \$ for the worst-case scenario of decreased prices (by 40%), decreased oil and gas production (by 20%) and increased field cost (by 20%). The EMVs of EcoPetro_Gas and EcoPetro_Oil models recorded several negative value responses to the sensitive analysis. The payback period of EcoPetro_Oil model base case (7 years) is less than the EcoPetro_Gas model base case of 9 years and for the worst-case scenario the payback period increased to 9 years for the EcoPetro_Oil and to 16 years for the EcoPetro_Gas models.

So, the EcoGas_Model base case is more sensitive to variable variations indicating the high risk character of the project due to the tax regime functions which work better in favor of the contractor in the EcoOil_Model in times of significant fluctuations in prices and high capital cost in worst-case scenarios.

After the deterministic economics analysis, the models were further developed to decision analysis and risk assessment of projects by the possibility and the probability approach as well as by Monte Carlo simulation.

The NPVs of EcoPetro_Oil model using the risk assessment approaches for the exploration phase by FuzzyCalc 2,118 (+ 28%, - 26%) mm \$, by Quantor 2,118 (\pm 18%) mm \$ and Oracle Crystal Ball 2,118 (\pm 8%). For the development phase, FuzzyCalc 2,118 (+ 27%, - 26%) mm \$, by Quantor 2,118 (\pm 15%) mm \$ and by Oracle Crystal Ball 2,118 (\pm 6%).

The NPVs of the EcoPetro_Gas model using the risk assessment approaches for the exploration phase resulted to FuzzyCalc 2,227 (+ 36%, - 34%) mm \$, Quantor 2,227 (\pm 25%) mm \$ and Oracle Crystal Ball 2,225 (\pm 10%); for the development phase; FuzzyCalc 2,227 (+ 31%, -

30%) mm \$, Quantor 2,227 (\pm 19%) mm \$ and Oracle Crystal Ball 2,227 (\pm 9%). The high risk character of EcoPetro_Gas model becomes more obvious using the risk assessment approaches²⁷.

7.2 Comparison of Approaches

The three approaches presented, the possibility approach, the probability approach and the Monte Carlo simulation, were tested in order to assess the uncertainty in the economics of petroleum projects due to the impact of risk factors in data and variables. The results of the approaches are restricted by the application used, FuzzyCalc, Quantor, and Oracle Crystal Ball).

The peak values of the possibility approach are almost the same as the mean values of the probability analysis and of the Monte Carlo simulation, but the uncertainty intervals of output fuzzy values are greater than the confidence intervals of output values using Quantor and the standard deviations (error rates) of the output values using Monte Carlo simulation.

The results of the approaches are similar and provide better quality for risk assessment, in addition to supporting the decision makers to improve their decisions. Each of the approaches has its own advantages and disadvantage, which depend on the application used.

FuzzyCalc presents the equations of the model in clear mathematical form, where the equations are stated as a block. Two of the most commonly used membership functions are available with FuzzyCalc: triangular and trapezoid. However, it does not include the multivariate membership function; it performs only basic arithmetic operations and each equation consists of only one of the four operators.

Quantor also performs only linear correlations between the input variables (+, -, / and \times) and allows only one arithmetic operation per cell, which produces several sub-equations per forecast variable in a similar way to FuzzyCalc. Additionally, this application has no graphical presentation for the uncertainty modelling.

Oracle Crystal ball does not have the linear restrictions and provides the ability to choose between several alternative input distributions, but its results depend on and are restricted to the number of iterations and give the user small differences in the results of each simulation without making any changes in the input variables. Too many output formats of one variable (statistics, probability distributions, cumulative distributions, percentiles, etc.) sometimes lead to confusion

²⁷ Oil and gas prices used as independent variables in the EcoGas_Model caused higher uncertainty intervals compared to the EcoOil_Model results.

of the analyst and the interpretation of the results, an often heard criticism on the Oracle Crystal ball application.

All available approaches to risk assessment do not reduce the risk or do not make a decision, but help to identify possible future problems in the course of project implementation and support the project management to take corrective action to the benefit of the project. To make optimal investment decisions regarding an evaluated project under risk and to control the project realization requires good judgment and intuition from the analyst and decision maker.

7.3 Contribution

EcoPetro _Model represents a deterministic model to evaluate the economics of potential petroleum projects, or the reevaluation of petroleum projects after a successful exploration project prior to the development or production phases. In addition it supports the preparation of strategies, the decision analysis at various times before the project starts and later at any time of the project's life cycle helps to optimize the risk management and the company's finance and investment policies.

Further efforts are suggested to improve the EcoPetro _Model in order to add other features such as portfolio optimization by integrated EMV calculation and detailed POS- (Probability of Success) evaluation and project management in order to establish a stand-alone risk assessment tool, covering the total of geological, business and political risks of petroleum projects.

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Appendix I

FuzzyCalc® Tool

FuzzyCalc is a user-friendly software application which is used as an Excel add-on; it was developed by Lenz & Müller (2000) as a method for planning, forecasting, controlling and analyzing fuzzy data. The program runs under Windows and uses the MS office package. Macros must be activated within Excel in order to display the FuzzyCalc toolbar (see figure A.1).



Figure A.1: FuzzyCalc toolbar

The FuzzyCalc toolbar consists of ten buttons; the first button is used to create a new empty worksheet. The triangle and trapezium buttons allow 3 or 4 new dot membership functions, and the question mark represents a new unknown fuzzy set. The first “=” symbol opens a new equation, while the second “=...” symbol allows a formula to be created. The next two buttons (“red – sign”, “green + sign”) hide and show the model details. The exclamation mark begins the calculation and the last symbol resets all values. Each variable has three values of fuzzy-sets with 3 points: Min; the lower bound of a variable, Peak; the mean value of a variable and Max; the upper bound of a variable.

Each equation in FuzzyCalc must be written in one of the following forms:

$$A + B = C, A - B = C, A * B = C \text{ and } A/B = C$$

Design of a model using FuzzyCalc

In order to explain how a model should be designed using FuzzyCalc, the Syrian oil contract model was implemented using this application.

The first step is to determine the variables of the model, and which of these variables are exogenous and which are endogenous. In addition to identify the decision variables, the deterministic value of each variable and their confidence interval (upper bound, lower bound) are identified by the analyst based on the information available from different sources, such as market forecast prices. All variables can be summarized in a (Data Repository) table, as is shown table A.1.

Table A.1 Data repository for the Syrian oil contract model

Variable name	Code	Type	Value	Confidence interval	Unit
Oil production	P_o	Exogenous	5	$\pm 2\%$	bbl
Oil price	OP	Exogenous	100	$\pm 2\%$	\$/bbl
Cost oil	$CostOil$	Exogenous	40	$\pm 2\%$	\$
Royalty rate	Roy_r	Exogenous	12.5%	-	%
Tax rate	Tax_r	Exogenous	10%	-	%
Revenue	Rev	Endogenous	?	?	\$
Royalty	Roy	Endogenous	?	?	\$
Revenue after royalty	$RevAfterRoy$	Endogenous	?	?	\$
Profit oil	$ProfitOil$	Endogenous	?	?	\$
Contractor profit oil share rate	$CPOSr$	Exogenous	35%	-	%
Government profit oil share rate	$GPOSr$	Exogenous	65%	-	%
Contractor profit oil share	$CPOS$	Endogenous	?	?	\$
Government profit oil share	$GPOS$	Endogenous	?	?	\$
Income Tax	Tax	Endogenous	?	?	\$
Government Take	GT	Decision variable	?	?	\$
Contractor Take	CT	Decision variable	?	?	\$

The second step is building the structural equation system of the model based on deterministic values (crisp values).

$$Rev = P_o \cdot OP$$

$$Roy = Rev \cdot Roy_r$$

$$RevAfterRoy = Rev - Roy$$

$$ProfitOil = RevAfterRo - CostOil$$

$$CPOS = CPOSr \cdot ProfitOil$$

$$GPOS = GPOSr \cdot ProfitOil$$

$$Tax = CPOS \cdot Tax_r$$

$$GT = Tax + Roy + GPOS$$

$$CT = CPOS + CostOil$$

The third step is defining the variables as fuzzy sets in FuzzyCalc and inserting the value of each endogenous variable. The structural equation system then is defined in FuzzyCalc. All equations of the model appear clearly in the top of the Excel sheet as is shown in figure A.2.

Gleichungen					
Gleichung1	Production	*	Oil price	=	Revenue
Gleichung2	Revenue	*	Royalty rate	=	Royalty
Gleichung3	Revenue	-	Royalty	=	Revenue after royalty
Gleichung4	Revenue after royalty	-	Cost oil	=	Profit oil
Gleichung5	Profit oil	*	Contractor profit oil share rate	=	Contractor profit oil
Gleichung6	Profit oil	*	Government profit oil share rate	=	Government profit oil
Gleichung7	Contractor profit oil	*	Tax rate	=	Income Tax
Gleichung8	Royalty	+	Government profit oil	=	Constant1
Gleichung9	Constant1	+	Income Tax	=	Government Take
Gleichung10	Cost oil	-	Income Tax	=	Constant2
Gleichung11	Constant2	+	Contractor profit oil	=	Contractor Take

Figure A.2: Structural equation system of Syrian oil contract model using FuzzyCalc

It can be seen from the above figure that auxiliary variables (constant variables) are used because FuzzyCalc performs mathematical operations on only two variables in one equation. The final step is to run FuzzyCalc, which shows the resulting membership function for each output variable. In order to better understand the results of FuzzyCalc, the input values (which are called prior values) and the output values (which are called adjusted values) are summarized in table A.2.

Table A.2: Variables of Syrian oil contract model before and after adjustment with FuzzyCalc

Variable	Prior Value	Adjusted value
Oil production	5 ± 0.1	$5 (+0.1/-0.99)$
Oil price	100 ± 2	$100 (+1/-0.99)$
Cost oil	40 ± 0.8	40 ± 0.79
Royalty rate	$12.5\% \pm 0$	$12.5\% \pm 0$
Tax rate	$10\% \pm 0$	$10\% \pm 0$
Revenue	?	500.05 ± 20
Royalty	?	62.5 ± 2.5
Revenue after royalty	?	437.5 ± 23
Profit oil	?	397.5 ± 23
Contractor profit oil share rate	$35\% \pm 0$	$35\% \pm 0$
Government profit oil share rate	$65\% \pm 0$	$65\% \pm 0$
Contractor profit oil share	?	139 ± 8
Government profit oil share	?	258.3 ± 15
Income tax	?	13.9 ± 0.8
Government take	?	334 ± 19
Contractor take	?	165 ± 10

According to Köppen (2008) in the case of conflicting data results two scenarios are possible:

- Strong model inconsistency of the data
- Weak model inconsistency, where an adjustment of data is possible to solve the conflict

Single Equation Analysis

The FuzzyCalc allows us to manipulate a single equation as a special case (Müller & Lenz, 2003), such as CAPEX in a petroleum project, i.e. CAPEX=Exploration cost + Development cost as balance equation. It is assumed that economists and engineers predicted development costs of around 22 mm \$ (-0.1/+0.1) in one year, and the exploration cost is around 7 mm \$ (-0.1/+0.1). At the same time, the management of the project expects total CAPEX of about 20 mm \$ (-0.1, +0.1). When these predicted values are entered into FuzzyCalc, a message then appears stating that “the values of the variables are inconsistent”. Therefore, the predicted value for at least one variable should be changed in order to resolve model inconsistency. For example, when the development costs are reduced to 14 mm \$ (-0.1/+0.1), consistent values for the three variables was achieved, this can be seen in figure A.3.

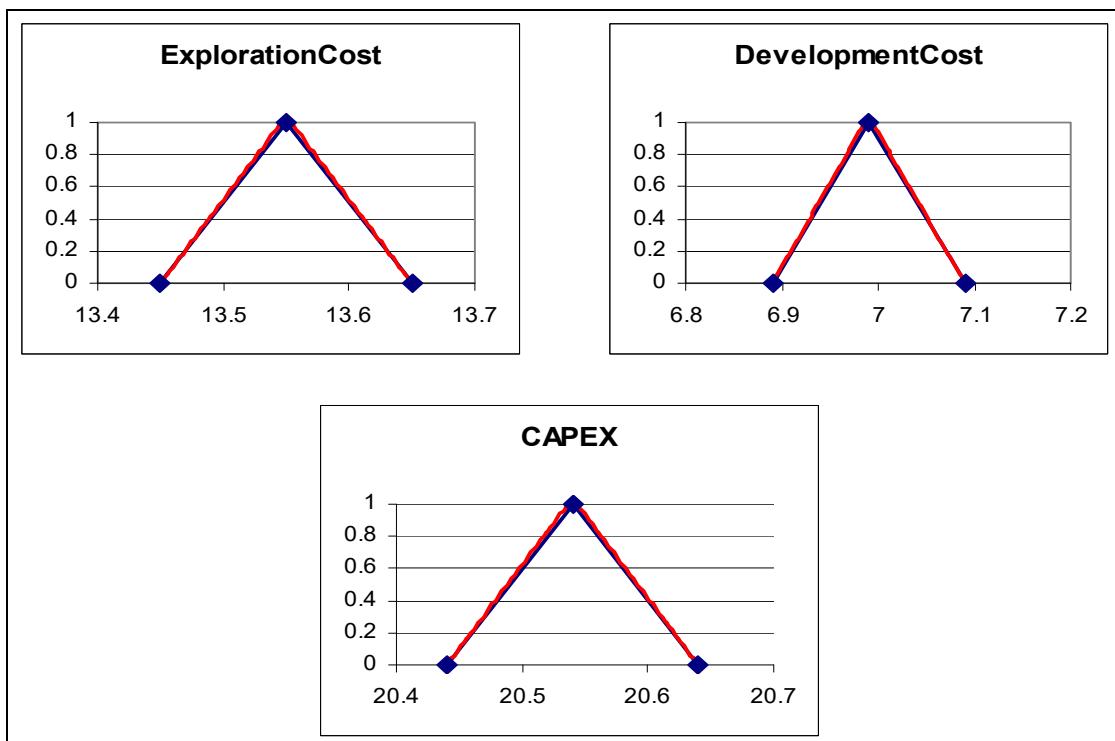


Figure A.3: Consistent charts for a single equation example by using FuzzyCalc®

In order to better understand the results of FuzzyCalc, the input values (prior values) and the output values (adjusted values) are summarized in table A.3.

Table A.3: Variables before and after adjustment with FuzzyCalc (single equation example)

Variable ID	Prior Value	Adjusted Value
Exploration cost	7 ± 0.1	$7 (-0.08,+0.13)$
Development cost	14 ± 0.1	$14 (-0.07,+0.13)$
CAPEX	20 ± 0.1	$20 (-0.13,+0.07)$

It can be seen that the prior values are not constant after adjustment; in other words, the variables are not strongly semantically consistent.

Quantor

The software tool QR (Quantitative Reasoning) or Quantor, which was developed by Schmid (1988), is an implementation of the probabilistic approach. QR version 2.03 from 1993 is used in this dissertation. Quantor deals with random variables related to imperfect data. It checks the consistency of information obtained from different sources, in order to locate errors and correct the data. The inference of QR is based on two steps

- The variables are represented in a structural equation form
- It is assumed that the random variables follow a Gaussian distribution

Model design using Quantor

QR offers a graphical user interface GUI. It consists of several spreadsheets for building a model. A spreadsheet contains a number of cells. In these cells variable values of the model are stored or newly computed. By double clicking the left mouse button on a cell all necessary variable information appears as follows:

- Name (German: Name) shows the name of the variable
- Sign (German: Kürzel) is a symbol used to describe the variables
- Operation (German: Verknüpfung) used for the definition of the cell appellation inside a spreadsheet and to refer to the cell in the joining process
- Input value (German: Eingabewert) consists of a mean value and statistical dispersion, if the input data is unknown, one can use the question mark symbol to indicate a missing value.

- Output value (Ausgabewert): represents the result of the calculation process by delivering the mean distribution. Unfortunately, QR does not supply standard deviations of the estimation.

The Syrian oil contract model was interpreted using Quantor, step 1 and 2 is completed in the same way as when using FuzzyCalc, and then the exogenous variables (e.g. oil production) are fixed in addition to their error rate as shown in figure A.4.

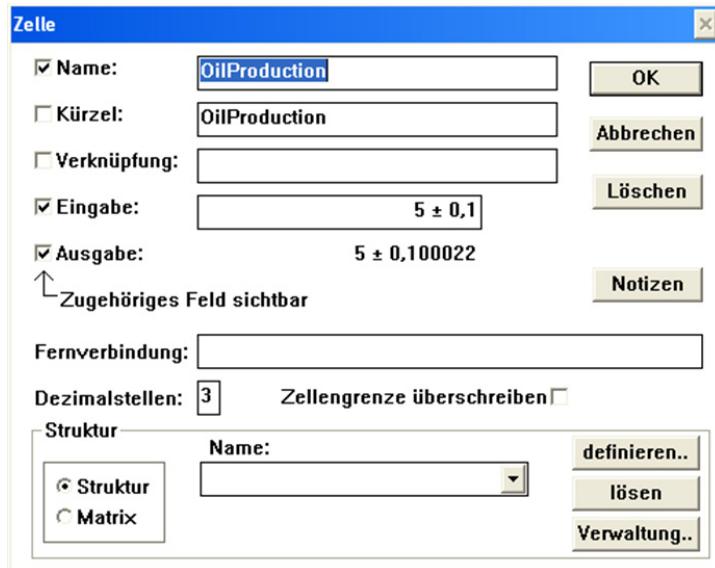


Figure A.4: Example of QR input cell of Syrian oil contract model (an exogenous variable)

The relationships between the variables are then defined using Quantor, and by clicking on the run button the resulting spread sheet of QR is produced as shown in figure A.5 where the question mark in the Quantor spread sheet refers to endogenous variables

c:\qr\modele\modele\modele\modell- 2\syrien.sht			
OilProduction 5,000 ± 0,100 5,000 ± 0,100	OilPrice 100,000 ± 2,000 100,000 ± 2,000	Revenue ? 500,000 ± 14,143	CostOil 40,000 ± 0,800 40,000 ± 0,800
RoyaltyRate 0,125 ± 0,000 0,125 ± 0,000	TaxRate 0,100 ± 0,000 0,100 ± ?	ContractorProfitOilShare 0,350 ± 0,000 0,350 ± ?	GovernmentProfitOilSha 0,650 ± 0,000 0,650 ± 0,000
Royalty ? 62,500 ± 1,768	RevenueAfterRoyalty ? 437,500 ± 12,375	ProfitOil ? 397,500 ± 12,401	ContractorProfitOilShare ? 139,125 ± 4,340
GovernmentProfitOilSha ? 258,375 ± 8,060	IncomeTax ? 13,913 ± 0,434	ContractorTake ? 165,212 ± 3,936	GovernmentTake ? 334,788 ± 10,259

Figure A.5: QR Spreadsheet of Syrian oil contract model

- . In the case of data inconsistencies two scenarios are possible:
- The expected mean values of the output values are located significantly outside the interval of the input values.
- The dispersion of the output value of a cell is significantly greater than the dispersion of the input value for the same cell.

Crystal Ball

Crystal Ball is a simulation program that works on the base of Microsoft Excel as an analysis tool for business and technical situations under risk assumption. Crystal Ball uses the technique of Monte Carlo simulation for risk analysis, so this program allows the developer to create probability distributions that describe the uncertainty surrounding specific input variables.

The Syrian oil contract model was used again to explain how to build a model using Crystal Ball. The first step is to build a deterministic model using Excel as shown in figure A.6.

	A	B
Model Inputs		
2	Production (bbl)	5
3	Oil Price (\$/bbl)	100
4	Royr (%)	12.5%
5	CostOil (\$)	40
6	CPOSr (%)	35%
7	GPOSr (%)	65%
8	Taxr (%)	10%
Model Outputs		
10	Revenue	500.0
11	Royalty	62.5
12	RevenueAfterRoyalty	437.5
13	ContractorProfitOil	139.1
14	GovernmentProfitOil	258.375
15	Tax	13.9125
16	Government Take	334.8
17	Contractor Take	179.1

Figure A.6: The Syrian oil contract model using Oracle Crystal Ball

The second step is to identify the uncertain variables in the model, where not all input values are uncertain values. So in the above example was assumed that the uncertain variables are oil production, oil price, cost oil, and other input variables are fixed or error free.

The third step is defining the assumptions (probability distribution) for each uncertain variable. Crystal Ball gives the user the option to select from 21 different distribution types. Assumptions for uncertain variables were defined by activating the cell and pressing the crystal Ball ‘define assumption’ button. Each assumption cell (colored green) is marked by an Excel note, and the production is defined to be triangularly distributed with a ‘minimum of’ a ‘likeliest of’ and a ‘maximum of’ as shown in figure A.7.

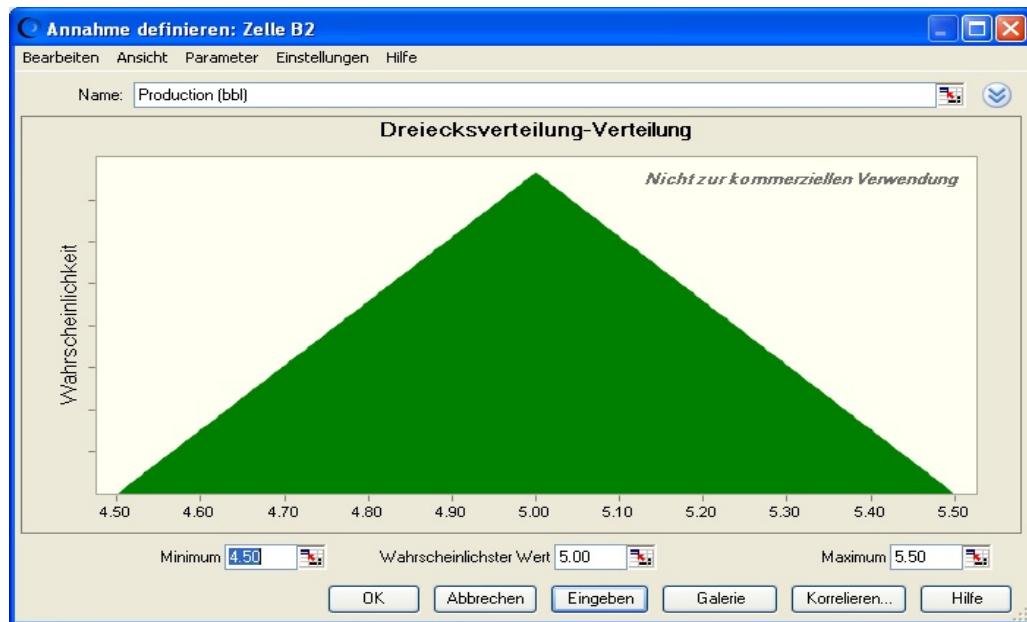


Figure A.7: Define assumption for production variable in the Syrian oil contract model

In the same manner, a distribution for each uncertain variable should be defined in the Crystal Ball sheet. The forecast variables are then defined; the forecasts are the line variables which need to be analysed after simulation. There is no limit to the number of forecasts that can be defined using Crystal Ball; in the example model one forecast variable is defined, the contractor take.

The next step is setting the run preferences. These settings control the number of trials to run and the sampling method (Monte Carlo or Latin Hypercube), and in addition there is an option to increase the speed of simulation as well as other simulation controls. 500 trials were chosen to run with a confidence level of 95%. After running the simulation, Crystal Ball saves the values in the forecast cells and displays them in a forecast chart, a histogram of the simulated values.

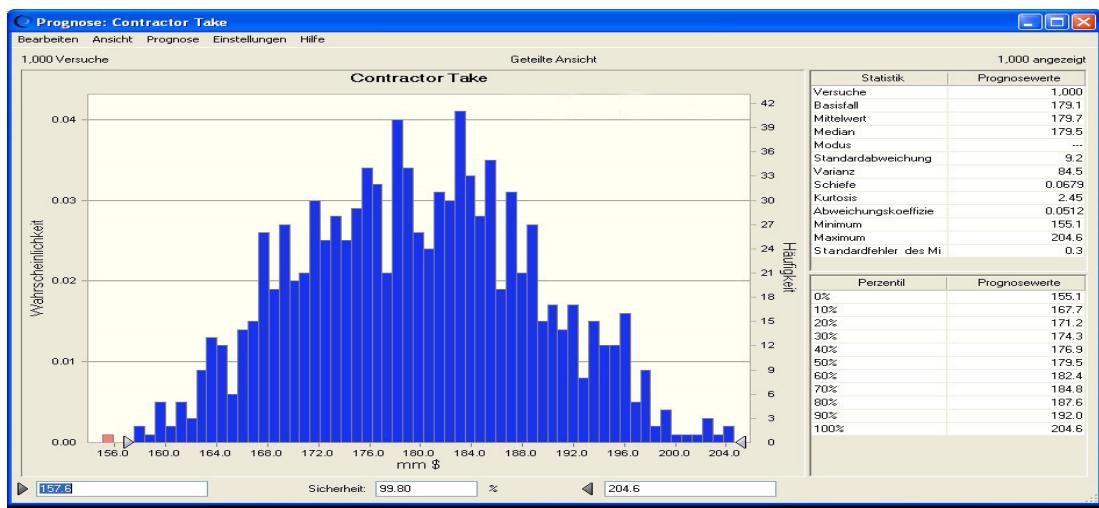


Figure A.8: Probability distribution of the contractor take, the Syrian oil contract model

Figure A.8 shows the possible values of contractor take ranging from 156 mm \$ to 204 mm \$. The height of each bar indicates how many simulation trials resulted in contractor take values fell in the corresponding interval. The right side of the histogram displays the frequency scale and the left side of the histogram displays the probability scale. Mean value of the contractor take is 179 mm \$, the maximum contractor take is 204.6 mm \$ and the minimum is 155.1 mm \$.

Appendix II

Data repository of the EcoPetro Model

The exogenous variables are colored in yellow, and the endogenous variables in silver, and the decision variables in rot.

Code	Description	Unit
a	Index of the year, where $a = 1,2..A$	number
$Abandon_a$	Abandonment per year a	mm \$
$Abandon_{ra}$	Real abandonment cost per year a	mm \$
$Area$	Size of the project area	hectare
$Area.Surfacefee_I_a$	Pre-production surface fee rate per hectare	\$/hectare
Ben_{ae}	Wages benefits rate per employee per group per year a	%
BOE_{factor}	Convert factor from cubic feet to barrel of oil equivalent (≈ 6000 cubic feet of gas)	-
$Bonus1_a$	Commercial bonus per year a	mm \$
$Bonus2_a$	Bonus at first commercial production per year a	mm \$
$Bonus3_a$	Bonus based on cumulative production (as amount) per year a	mm \$
$Bonus4_a$	Bonus based on cumulative production (as percentage) per year a	mm \$
$Bonus5_a$	Bonus based on production rate for specified period per year a	mm \$
$Bonus6_a$	Signature bonus per year a	mm \$
$Bonus_a$	Bonus per year a	mm \$
$BOPD_w$	Oil production per day per well	bbl
bv	Book value of the depreciable assets	mm \$
$CAPEX_{discounted}$	Discounted capital cost	mm \$
$CAPEX_{ra}$	Real capital cost per year a	mm \$
$CFPD_w$	Gas production per day per well	MCF
$Costpetroleum_a$	Cost recovery per year a	mm \$
CPS_a	Contractor profit share per year a	mm \$
CPS_{rate}	Contractor profit share rate in year a	%
$CT\%_{\pi a}$	Contractor take as percentage	%
$CT_{\pi a}$	Contractor take per year a	mm \$
$Cuml.DBDA-1$	Cumulative declining balance depreciation per year $a-1$	mm \$
DCF_a	Discounted cash flow per year a	mm \$
De_a	Depreciation charge per year a	mm \$
$DepRate$	Yearly depreciation rate	%

$Develop_a$	Development cost per year a	mm \$
$DevelopDrill_a$	Development well drilling cost per year a	mm \$
$DevelopOther_a$	Other development cost per year a	mm \$
$DevelopSurface_a$	Surface installation cost per year a	mm \$
$DevelopTrans_a$	Transportation equipment cost per year a	mm \$
DGP_w_a	Index of days of gas production per well per year a	number
DOP_w_a	Index of days of oil production per well per year a	number
e	Index of employees per year a , where $e = 1,2,..E$	number
$EMV_development$	Expected monetary value of the project at development phase	mm \$
$EMV_exploration$	Expected monetary value of the project at exploration phase	mm \$
$Explora_a$	Exploration cost per year a	mm \$
$Explor_{discounted}$	Discounted exploration cost	mm \$
$ExplorDrill_Log_a$	Exploration drilling logistic cost per year a	mm \$
$ExplorDrill_Rig_a$	Exploration drilling rig cost per year a	mm \$
$ExplorDrill_Ser_a$	Exploration drilling service contract cost per year a	mm \$
$ExplorDrill_staff_a$	Exploration drilling staff cost per year a	mm \$
$ExplorDrill_Supp_a$	Exploration drilling supplies cost per year a	mm \$
$ExplorDrill_a$	Exploration drilling cost per year a	mm \$
$FiscalCost_a$	Fiscal cost per year a	mm \$
$G\&G_Ser_a$	Geology & geophysics service contract cost per year a	mm \$
$G\&G_a$	Geology & geophysics cost per year a	mm \$
$G_Studies_a$	Geological studies cost per year a	mm \$
Gdy_w	Start year of gas production decline per well	-
Geo_a	Geophysics cost per year a	mm \$
GP_{BOE_wa}	Gas production measured by barrel oil equivalent per year a	mm BOE
$GPd\%_w$	Gas production decline rate per well	%
GPS_a	Government profit share per year a	mm \$
GPS_{rate}	Government profit share rate per year a	%
GP_wa	Gas production per well per year a	MMCF
$GT\%\pi_a$	Government take in percentage per year a	%
$GT_{\pi a}$	Government take per year a	mm \$
$Hour_{ae}$	Working hours per employee e per year a	Hour/a
i	Discount rate	%
Inf_r	Inflation rate	%
$IntanCAPEX_a$	Intangible CAPEX per year a	mm \$
IRR	Internal rate of return	%
LC_a	Labor cost per year a	mm \$
M	Index of materials consumed per year a , $m=0,1,..M$	number

MC_a	Materials cost per year a	mm \$
$NCF_{a\varphi}$	Net cash flow per year a per method φ	mm \$
NCF	Net cash flow of total project life	mm \$
NPV	Net present value	mm \$
OC_a	Overhead cost per year a	mm \$
Ody_w	Start year of oil production decline per well	-
$OPd\%_w$	Oil production decline rate per well	%
$OPEX_{at}$	Operating cost per year a per method τ	mm \$
$OPEX_{direct}$	Direct operating cost per year a	mm \$
$OPEX_{fixed}$	Fixed operating cost per year a	mm \$
$OPEX_{indirect}$	Indirect operating cost per year a	mm \$
$OPEX_{perUnit}$	Operating cost per unit of production	\$
$OPEX_{ra}$	Operating cost per year a in real value	mm \$
$OPEX_{variable}$	Variable operating cost per unit of production per year a	\$
OP_{wa}	Oil production per well per year a	m bbl
or_a	Overhead factor per year a	%
OSC_{as}	Cost of operating service contract per contract s per year a	mm \$
$Others_a$	Other cost which can be recovered per year a	mm \$
P_a	Total production per year a	mm BOE
PG_a	Nominal gas price per thousand cubic feet per year a	\$ /MCF
PG_{ra}	Real gas price per thousand cubic feet per year a	\$ /MCF
$Plug_a$	Well plugging cost per year a	mm \$
pm_{ma}	Price of the unit material m	\$ / unit m
PO_a	Nominal oil price per barrel per year a	\$/bbl
PO_{ra}	Real oil price per barrel per year a	\$/bbl
$POS_development$	Probability of success at development phase	%
$POS_exploration$	Probability of success at exploration phase	%
qm_{ma}	Quantity of material m required per year a	unit
$Remove_a$	Removal of equipment cost per year a	mm \$
$ResRemStart_a$	Reserves remaining at the begin of the year a	mm BOE
Rev_a	Revenue per year a	mm \$
ROY_{ao}	Royalty per year a	mm \$
Roy_{fa}	Royalty factor per unit of production per year a	\$
Roy_{ra}	Royalty rate per year a	%
s	Index of operating service contracts per year a , $s = 0,1;..S$	number
SC_a	Operating service cost per year a	mm \$
$Surfacefee_2a$	Surface fee rate per unit of production per year a	\$
$SurfaceFee_a$	Surface fee per year a	mm \$

$TangCAPEX_a$	Tangible CAPEX per year a	mm \$
TAX_a	Taxes per year a	mm \$
$TAXin_{ya}$	Taxable income per tax y per year a	mm \$
$TAXrate_{ya}$	Tax rate per tax y per year a	%
TC_a	Transportation of petroleum cost per year a	mm \$
TCP_a	Petroleum transport cost per pipeline per year a	mm \$
TCT_a	Petroleum transport cost per tanker per year a	mm \$
$Treat_a$	Treatment cost of the production area cost per year a	mm \$
u	Index of the utilities used per year a , $u = 0,1,..U$	number
UC_a	Utilities cost per year a	mm \$
uc_{ua}	Quantity of the utility u consumption per year a	unit
$Ulife$	Useful life of the depreciable assets	number
$UnCostRec_a$	Unrecovered cost carried over from previous periods to year a	mm \$
up_{ua}	Price of unit utility u	\$
w	Index of production well, where $w=1,2..W$	number
Wa_{ae}	Wages rate per hour per employee per year a	\$
y	Index of tax types applied per year a , $y = 0,1,..Y$	number
π	Fiscal regime type, where $\pi = 1$ or 2	-
τ	Index to calculate the operating cost	number
ω	Index to calculate the royalty	number
φ	Index of fiscal regime types	number
ϖ	Index to calculate the contractor take per one fiscal regime type	number
ς	Index to calculate the expected monetary value per one phase of project life	number