Establishing Minimum Economic Field Size and Analysing its Role in Exploration Project Risks Assessment: Three Examples*

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Search and Discovery Article #41827 (2016)**
Posted July 11, 2016

*Adapted from extended abstract prepared in conjunction with oral presentation given at AAPG GEO 2016, The 12th Middle East Geosciences Conference and Exhibition March 7-10, 2016, Manama, Bahrain

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Abstract

The Upstream E&P industry is one of the most risky businesses to invest in and is dominated by different types of uncertainties: political, economic, social and technical. There are many areas that can lead to optimistic or pessimistic risk assessment. Overestimation, underestimation, misidentifying critical risks, overselling and underselling projects are some of the common problems that are encountered. For consistent exploration project risk analysis, a systematic approach has been used which includes geological risk, minimum economic field size (MEFS), resource size distribution, development cost, rate streams, commodity price, discount rate and cash flow estimation. This approach requires highly skilled geoscientists and engineers to estimate field development costs and generate the economic indicators to rank the exploratory prospects potential success and to support the informed business investment decisions. The "exploration success" contains two main variables: (1) probability of geologic success (P_g), and (2) probability of economic success (P_e).

To remove sub-economic volumes from the volumetric distribution, the industry uses the estimation of minimum required (break-even) resources for the full project life cycle considering the most likely development scenario in exploration projects. For appraisal and development projects, the minimum required resources are used to benchmark the confidence level of already discovered resources with their chance of success to be an economically viable project. Despite several contributions made in the past and available in the literature, to the best of authors' knowledge, most often a deterministic MEFS value is being used for the exploration project risk assessment. This single MEFS value does not allow capturing the risks associated with the different input parameter uncertainties which are used for the MEFS estimation. In this article, an effort has been made to review and systematically describe the appropriate MEFS estimation methodology. The influence of key parameters on MEFS estimation, including some illustrative examples, have been used to demonstrate the MEFS criticality and its impact on exploration projects risk assessment to achieve an overall economic success.

Introduction

Successful exploration, efficient appraisal and profitable extraction of hydrocarbons are the three main phases of any E&P project; each in turn is dependent upon the previous one. Each phase of the E&P project carries significant uncertainties and hence makes upstream industry an extremely high risk business (Alexander and Lohr, 1998; Dunn and Parnell, 2002). Usually the largest risk in the upstream oil industry is geological risk which, in comparison with other natural resources development, is extremely high. Worldwide hydrocarbon exploration has become so mature that exploration has been extended to new frontiers such as the deep and ultra-deep water areas, remote areas which are difficult to access with insufficient developed infrastructure; and areas with hazardous environments such as permafrost, deserts, swamps, etc. However, these are not the only factors which have increased the costs of exploration, the recent upsurge in economic nationalism and the steep decline of success rates in mature areas have also increased the acquisition costs in new frontiers. Under these situations, risk analyses or feasibility studies for new projects, especially for exploration projects have increased in importance.

In the past, several articles (Woods et al., 1985; Grecco, 1987; Bradley and Wood, 1994; Antia 1994; Syahrir and Partowidagdo, 1996; Rose, 2002; Ferro et al., 2014) have been published in this subject to describe the technical and economic evaluation of conventional and unconventional resources. One of the initial efforts (Woods et al., 1985) was to use the field size distribution of development projects and generate an empirical relation for the finding rate and cost of discovery. However, this approach does not account for any improvement which has taken place in the last several decades. In the late 1980's and early 1990's, efforts were made to establish relationship between economic parameters, field size, new technologies, development strategies, impact of fiscal regime and hydrocarbon prices (Grecco, 1987; Bradley and Wood, 1994). In 1994, Bradley and Woods have emphasized the need of building a detailed and integrated evaluation which can allow relating liquid production (oil, gas, and water), CAPEX, OPEX and economic models in order to forecast the economic performance. Some of the articles have illustrated the procedures for maximizing the value of the satellites and marginal deep water fields (Antia, 1994; Chitwood et al., 2004) but they did not consider any geological risks in these evaluation. Very recently, Ferro et al. (2014) have analysed the impact of reservoir performance of two exploration projects (Onshore Unconventional Shale Oil and Shale Gas Resources, Offshore conventional Oil) on economic analysis, using stochastic approach, taking into account the main input, resource, EUR/well and drainage area to determine the range of MEFS distribution. However, none of this published work has analysed the direct impact of reservoir characteristics in the economic forecasts. Given the problems inherent in transforming subjective data for decision making, a systematic process and set of principles is required to evaluate different exploration prospects and place them in context which is described in the next section.

Integrated Project Valuation Process

For several decades, the most common form of E&P projects valuation has been the standard discounted cash-flow analysis in the petroleum industry which incorporates forecasts of (1) production volumes of oil and gas, (2) capital and operating costs, (3) product prices, and (4) fiscal regimes to calculate the stand-alone (non-portfolio) commercial value of a project. This evaluation requires an integrated project model with highly skilled geoscientists to transform elusive evidence into geologic prospects, reservoir engineers to convert subtle geologic concepts into potential rate streams, drilling and facility engineers to estimate development costs (CAPEX/OPEX) and economic analysts to calculate the net present and risked expected value needed to estimate the risk/reward of projects (Bilderbeck et al., 2005). In general, there will always be significant uncertainties at least in some of these parameters which will directly affect the resultant determination of the project value. Within the framework of integrated project evaluation, influence diagrams (Figure 1) are most often used to describe a decision indicator such as “Net Present Value (NPV)” or “Expected Monitory Value (EMV)” of a business decision in relation to uncertain variables, including inter-dependencies and correlation between these variables. To be successful, geologically and economically, it is necessary to understand E&P business from the concept to the point of consumption, the variables and constraints that affect pricing for the seller and buyer, consumption, transportation and methods to stem volatility and risk.

Exploration Prospect Risk Assessment Process

In order to understand the exploration evaluation risk assessment, it is necessary to describe some of these key concepts for estimating:

A) Probability of Geologic Success

Probability of the presence of attic accumulation of at least minimum resource size (or greater) to sustain the flow of hydrocarbons. It does not include any consideration of the size of the accumulation beyond the volume being sufficient for the well to be described as discovery, i.e. to have demonstrated the existence of movable petroleum. The geologic success for any prospect is assessed by considering the probability that the following five groups of independent factors exist:

- Hydrocarbon source rock components (P_{source})
- Timing of trap formation, hydrocarbon migration and preservation ($P_{timing/migration}$)
- Reservoir rock components ($P_{reservoir}$)
- Trap geometry (closure) components (P_{trap})
- Seal effectiveness (P_{seal}).

The P_g is obtained by multiplying the probabilities of the occurrence of each of the five factors of the play concept.

$$P_g = P_{source} \text{ x } P_{timing/migration} \text{ x } P_{reservoir} \text{ x } P_{trap} \text{ x } P_{seal}$$

The geologic success is defined as having some flow of hydrocarbon on well testing. For better understanding of P_g, the checklist of critical factors is summarized by Otis and Schneidermann (1997). More recently, Milkov (2015) has published an excellent review summarizing several methodologies used for evaluating the exploratory prospect risks.

B) Resources Distribution

Based on G&G studies, once the geologic risks are defined for the identified exploration prospect, the OHIP and recoverable resources distribution are estimated using inputs data/information from analogues (PRMS, 2011). The ranges of these parameters should cover all the possible values and benchmarking of the extreme ends for each input. The main reservoir parameters to be considered for the OHIP and recoverable resources distributions are: porosity, water saturation, permeability, gross rock volume, area, net pay thickness and their respective distributions, fluid properties and composition, recovery factor range. All these factors and their associated assumptions will have tangible effects on the estimated recoverable resources and overall field development economics. The recoverable resources will control the following design parameters for the facilities, schedule, CAPEX, OPEX and economics: the maximum sustainable field production rate, number of wells to be drilled (producers/injectors/disposals), recovery by well, requirement of reservoir-pressure maintenance, requirement of assisted lift in production and anticipated field life. For different inputs and outputs, the probabilistic distribution boundaries limits are represented by the P1 and P99 which require thorough validation using reality checks. These input distributions can be visualized in linear/logarithmic scales (X-axis) and probability of occurrence (Y-axis).

C) Minimum Economic Field Size (MEFS)

The MEFS is defined as the minimum volume of recoverable oil and gas necessary to make the project an economic success. Some of the most important variables used in MEFS estimation include: the value of oil and gas, the finding costs, the productivity, recovery by well, the proximity to and cost of infrastructure, development options, the cost of applicable technology, royalty payments, transportation tariffs, regulatory costs and tax structure. The MEFS is used as input to truncate the low end of recoverable resources probabilistic distribution and to eliminate those resources which are non-economic. This truncation becomes extremely critical for the areas (e.g. ultra-deep waters) where very large investments are involved. One of the identified major steps in evaluating the exploration projects is the estimation of MEFS and the probability of economic success (P_e). Industry uses the estimation of minimum required resources which provide Net Present Value (NPV) equal to zero for the full project life cycle considering the most likely development scenario. In other words, it is the step where a risk analysis is performed by the Exploration Team introducing a cut off on the estimated resource distribution through removal of volumes below MEFS value and estimating the corresponding probability of economic success which will always be lower or equal to P_g.

D) Probability of Economic Success

"Probability of an economic field (or larger) in the play given at least one or more discoveries of sufficient reservoir hydrocarbons to at least sustain commercial flow". The Probability of Economic Success (P_e), is the probability of finding a field in excess of the predicted Minimum Economic Field Size accumulation, can be obtained by multiplying P_g with the Probability of MEFS (P_{mefs}).

$$P_e = P_g \times P_{mefs}$$

The generic definition of probability of geological success for onshore and offshore projects is the same. However, to make the offshore projects economically viable, the required minimum resources must be higher due to variations in CAPEX and OPEX.

E) Expected Monetary Value (EMV)

Once the P_g, resources distribution and P_e are established, it is important to assign some monetary value to compare the evaluation outcomes. They can be estimated using the concept of NPV, where the NPV represents the present day discounted equivalent of the cash flow stream associated with the outcome. So this will provide us a NPV of success and NPV of failure. For the case where the expected outcome are expressed as profits and losses, the expected monetary value (EMV) can be expressed as:

EMV= [P_e*NPV (Success case) – (1-P_e)* NPV (Failure Case)]

As MEFS is one of the five identified steps for the exploration prospect risk evaluation and is least described in the literature, understanding the major pitfall and challenges in MEFS estimation and MEFS methodology is necessary for a consistent exploratory project risk analysis. These aspects have been described in the following sections and illustrated through three examples.

MEFS Estimation Methodologies

All the data to be used as input in MEFS estimation should be collected from the different sources of project activities, validated and analysed. The MEFS estimation is an iterative process which requires inputs from a multi-disciplinary team to calculate a resource size associated to zero NPV. Different methods (analogue based, graphical, probabilistic and analytical), used for MEFS estimation, are described below:

A) Analogy Based

This methodology allows adopting a MEFS for a project based on the analogy. In those regions or basins where the exploration and exploitation activities have not yet begun, occasionally a minimum amount of hydrocarbon that would make a project economic is defined. Recognized international financial institutions estimate a MEFS using statistical evaluation from the available global database and this MEFS value is assigned to the project under study as a reference. This methodology is used at an early stage of exploration where costs estimation associated to exploration and development activities is purely assumed. There is no reference available in the region or basin to validate these assumptions and the cost accuracy of extrapolation from the existing matured assets, located at some distance away from the area, is difficult. As a consequence, the MEFS estimate obtained through this methodology carries a high degree of uncertainty and there could be significant difference (in excess or deficiency) when the actual exploration and development project is executed. It is important to note that the MEFS obtained from analogy can be used as a starting point for deterministic and probabilistic methodologies.

B) Graphical

The most commonly used method in the industry is the graphical method which include the following steps:

- From the estimated resources distribution of the identified prospect, choose a resource size which is expected to be close to the minimum economic field size for potential development, considering the nearby or similar development projects. Using reservoir inputs (e.g. area, net pay), estimate the production profile, number of producer and injector wells for the selected resource case.

- Estimate the drilling and facilities CAPEX, OPEX including drilling and development schedule for overall project life cycle.

- Calculate the NPV of the subject case following internal company's norms.

- Repeat first three steps (given above) increasing or decreasing the resource sizes. Ensure that at least one resource size provides negative NPV of the project.

- Draw a regression line using positive and negative NPV cases (Figure 2). Make the preliminary assessment of a resource size which will yield NPV close to zero. As the NPV versus resources regression is not linear, iterate this process several times until few positive and negative NPV's (minimum three values) are obtained to estimate a case having NPV equal to zero.

The use of P90, P50 and P10 resources values for MEFS is not recommended as the relationship between NPV and resources is often nonlinear. To overcome the nonlinearity problem, it is more prudent to use three cases (low, mid and high) close to the expected MEFS.

C) Probabilistic

In this methodology a simulation technique (Monte Carlo) is being used to generate the multiple development scenarios assuming different exploration, drilling, development and exploitation costs plus fiscal terms and conditions of the project. Regarding those last two inputs, different fiscal terms and conditions could be assumed only when it is permitted or subject to negotiation; otherwise they are fixed as per contract terms. The relation between NPV and recoverable resources [NPV = f (Resources)] is established to obtain the MEFS value, using the analytical functions suitable to fit on the data points instead of linear regression function. This methodology allows estimating a range of MEFS values to capture the variance of MEFS due to the changes in the development assumptions. The range MEFS values obtained from this approach can be validated using MEFS value obtained from analogy of matured basin projects, if appropriate.

D) Analytical

This methodology is based on the elaboration of a function of NPV versus Resources Volume, NPV = f (Resources), where NPV is not linearly related with the resources. The methodology is applicable in a mature basin or region where some discoveries are small and considered non-economic fields, but they are being developed as commercial ones. Taking into consideration exploration, drilling, development and exploitation costs, fiscal terms and conditions of the project, it is possible to establish a relation between NPV and Recoverable resources [NPV = f (Resources)], using an analytical function. MEFS is the value of resources that makes this function equal to zero. The MEFS value obtained from this approach can be validated using MEFS values obtained from analogy of matured basin projects, fitting the current scattered points of all producing discoveries in the region.

As part of the common procedure, and in order to estimate the P_e for a stand-alone exploration project, the MEFS is used to truncate the resource distribution below the economic limit. This provides increased mean resources with a reduced P_e for finding larger accumulations. P_e is always lower or equal to the P_g for an exploratory project. Truncated resources are used as input for estimating the project economics.

Some Illustrative Examples

To illustrate the impact of MEFS estimation on the overall exploration project and decision making, a graphical method (deterministic) for MEFS estimation, as described in the previous section, has been used. Multiple scenarios have been developed to help understand the impact on MEFS results due to uncertain variables. For this purpose, three examples have been generated and are discussed in detail below.

Example 1

The evaluated exploratory prospect is located in shallow water offshore at a water depth of around 110 m. The reservoir is located at 2744 m TVDSS depth. Based on the offset analogs, Table 1 shows the summary of the reservoir and fluid input parameters. The initial reservoir pressure is around 5200 psi, temperature is around 210 °F. The assumed fluid is black oil with 30° API and GOR of 350SCF/Bbl. There is no CO_2 and H_2S content in the reservoir fluid.

The assumed production mechanism for all cases was natural depletion. The produced water will be disposed using an injection well in a specific formation on land. The production constraints used for generating production forecasts assumes minimum manifold pressure of 50 psi, maximum oil rate in the range of 12-16% of the recoverable resources and a maximum production during the plateau of 50% of the recoverable resources. The down time assumed around 5% and a minimum oil rate is around 500 Bbls/day. For the NPV calculation of each resource case the fiscal terms and conditions assumed are: Production Sharing Contract (PSC) with Cost oil limit 50% (in this case, 100% of CAPEX/OPEX and Exploration costs are considered as recoverable), Profit oil is 25% of Sharing Oil, Inflation 2% /year, Income Tax 30% /year, Royalty 12%/year and oil price constant 100 US$/Bbl and it escalate by 2% every year until the end of production life. The other legal and economic conditions are assumed similar for all the evaluated cases.

In order to analyze the impact of different development assumptions on the MEFS value, the evaluated cases assume: Different development scenarios, permeability variation, oil gravity variation (API), aquifer strength variation, presence of pollutants and Oil Price variations.

A) Development Scenarios

Following three development scenarios (Figure 3a) were analyzed:

- Scenario A: Platform with dry tree connected to Production Fluid Treatment on land. The distance between Production Fluid Treatment and platform and is 10 km while the delivery point is located 2 km from the center. This scenario is the most likely Base Case development option based on the assumed economic scenario.

- Scenario B: Platform contents dry tree and Production Fluid Treatment. The delivery point is to 12 km from platform.

- Scenario C: Platform contents dry tree and Production Fluid Treatment, subsea well production tied in platform. The delivery point is to 12 km from platform.

Using MEFS estimation methodology described in the previous section, MEFS value for the three development scenarios were estimated which were 32, 40 and 45 Million BO, respectively (Figure 3b). These differences are mainly due to the changes in the investment and maintenance costs (CAPEX/OPEX) as production profiles are similar for all the three cases. Therefore, the selection of appropriate development scenario is critical when evaluating the MEFS and development assumptions for the exploratory prospects. Figure 3c shows the truncated resources and corresponding P_e. For analyzing the impact of other parameters on MEFS, Scenario-A development option has been assumed as the most likely Base Case scenario.

B) Permeability Impact

Formation permeability is one of the most critical reservoir properties to determine and distribute throughout the reservoir. It is a measure of the ease with which fluids can pass through the reservoir, and hence is needed for estimating well productivity, reservoir performance and hydrocarbon recovery. The permeability for exploratory project evaluation is normally taken from analogue fields or from discovery wells. This single permeability value, used for generating the production profiles, often does not account for any variance in the permeability distribution (i.e. its anisotropic behaviour) and hence does not represent the most likely average value. Any change in the permeability will have impact the reservoir performance, number of wells required to develop the reservoir and hence in the production forecasts and associated costs. To assess the impact of the permeability changes in terms of well productivity and number of wells in the development assumptions, a lognormal probability permeability distribution was considered for the targeted reservoir to generate the production profiles for P99, P90, P50, P10 and P1 permeability values. The mean permeability value is around 151 mD. The estimated MEFS Values for the different permeability cases which range from 29 Million BO to 40 Million BO along with truncated resources and corresponding P_e. Permeability values lower than the mean value increase the MEFS significantly (up to 40%) and higher than the mean decrease it (up to 8%) with reference to mean permeability case. This analysis emphasizes the need of using appropriate permeability value for the Base Case development assumptions.

C) Oil Gravity Impact

The reservoir fluid viscosity plays an important role not only in the well productivity but also in the reservoir fluid displacement efficiency which affect the final recovery of the Original-Oil-In-Place (OOIP). To analyze the impact of fluid properties (oil viscosity, GOR and API gravity) in the MEFS estimation due to changes in the well productivity and reservoir production performance, several cases were evaluated: (1) heavy oil with 22° API, GOR of 100 SCF /Bbl and viscosity 4.6 cP, (2) Black oil 26° API, GOR 220 SCF/Bbl and viscosity 2.1 cP, and (3) Volatile Oil with 36° API, GOR 1000 SCF/Bbl and viscosity 0.3 cP. The Base Case oil gravity was assumed around 30° API and 350 SCF/Bbl and viscosity 1.0 cP. The variation in the oil API gravity, the MEFS value has changed from 31 to 43 Million BO. For the heavy oil case, the MEFS has increased 40% with reference to black oil Base Case mainly due to lower recovery, more number of wells and higher investment. To analyze the combined impact of oil gravity and permeability on MEFS estimation (worst case scenario), the development assumptions were generated for two extreme cases: (1) oil with 36°API and permeability of around 800 mD, and (2) oil with 22° API and permeability of around 13 mD. The estimated MEFS values for these cases were 27 Million BO and 58 Million BO, respectively. This variation is around 16% lower value for the first case and 81% higher value for the second case with reference to original Base Case MEFS value (32 Million BOE).

D) Impact of Drive Mechanism and Presence of Hydrocarbon Impurities

For this specific example, the impact of change in aquifer strength and hydrocarbon impurities (CO_2 and H_2S) in fluid composition was relatively very small in the estimated MEFS value as compared to other variables. When the ratio of radius equivalent for aquifer and reservoir vary from 0 to 16, the change in MEFS value is from 31.8 Million BO to 30.6 Million BO (i.e. around - 4%). Due to the change of CO_2 content from 2.2% to 4.8% and H_2S content from 500 ppm to 5210 ppm, the MEFS Values are 32.2 Million BO and 34.2 Million BO, respectively which represent 1-8% difference with reference to Base Case MEFS value. However, it is important to note that in this case the effect of hydrocarbon impurities is not so relevant but in other cases it may have significant impact if the concentrations of these components in the fluid are higher than 5% for CO_2 and 5500 ppm for H_2S. Therefore, as a best practice it is always useful to analyse the impact of contaminants based on each assumed development scenario. The Table 2 shows the summary of estimated MEFS values for the different analysed cases.

E) Oil Price Impact

The oil price is one of the most important parameters which is most often volatile and has significant impact on the any E&P project NPV and its overall value. In order to capture the oil price issue, three oil prices (US $50/Bbl, US $75/Bbl and US $125/Bbl) were assumed, keeping all other inputs the same. The estimated MEFS for these cases are 76, 42.8 and 20 Million BOE, respectively. The truncated resources for these cases are 147 Million BO (17.1% P_e), 187 Million BO (13.1% P_e) and 229 Million BO (9.1% P_e), respectively. These resources and corresponding P_e are significantly reduced (see Table 2) with reference to the Base Case values (MEFS 31.8 Million BOE, truncated resources 164 Million BO and 15% P_e).

In order to capture complete range of MEFS values, probabilistic method was used considering the Base Case development scenario-A and key inputs variability (e.g. subsurface inputs recoverable resources, number of wells, CAPEX/OPEX, Oil Price, Project schedule, first production sensitivity cases). Around 500 realizations were made and MEFS values were estimated. A Gaussian MEFS distribution was generated which has provided P90 (26.4 Million BOE), P50 (51.8 Million BOE) and P10 (101.4 Million BOE) MEFS values. Based on this method, the most likely MEFS value is around 51.8 Million BOE which is around 62% higher than deterministic Base Case MEFS value (32 Million BOE). The truncated resources for these cases are 156 Million BO (15.9% P_e), 194Million BO (12.0% P_e) and 262 Million BO (7.7% P_e), respectively (Figure 4). The extreme values (low as well high end) were validated based on the offset analogues. These analogues indicate that several discovered fields in the area, with less than 25 Million BOE recoverable resources and similar fluid characteristics, have not yet been developed. On the other hand all the fields with more than 100 Million BOE Recoverable resources are under production. Therefore, the comparison of different MEFS methods allows validating the most likely MEFS value and helps to improve the overall confidence on the exploratory success. Comparison of P_g, MEFS with P_{mefs}, P_e and truncated resources with probability of occurrence between different exploratory prospects allows to rank and prioritize the exploration portfolio based on their risk and confidence level.

Example 2

To illustrate the importance of MEFS estimation and its impact in project with associated high level of investments, for the most likely Base Case development assumptions for the targeted reservoir, including new data acquisition and associated CAPEX and OPEX, the full life cycle of the evaluated project is evaluated. The development assumptions consider finding an oil reservoir with a gas cap. The producer wellheads are planned to be connected with a subsea system tied back to a FPSO. For economical evaluation purposes, only the oil resources are considered. In this example, between the preliminary evaluation and the final economical evaluation before the spud of the exploration well, the project team performed different evaluations considering newly reprocessed seismic data, different fluid assumption, production strategy and consequently revised production profiles, cost estimation for the economic evaluation which resulted in different MEFS values. The input parameters for different economic evaluations (untruncated/ truncated resources, P_g, P_e, exploration cost, Development CAPEX/OPEX, Abandonment cost, etc.) are summarized in Table 3. This example clearly shows the change in MEFS as inputs are updated over the time.

A) Original Case: Original MEFS Calculation for Prospect A (Preliminary evaluation)

The project team considered producing only the oil zone. The appraisal wells will be completed as water injectors. The discovery is assumed in 2013 and first oil is expected after 7 years (in 2019). The untruncated P_{mean} resources were estimated around 282 Million BO with P_g of 17%. Figure 5a shows the MEFS estimation (92 Million BO) for the project and Figure 5b the truncated resources probability distribution that would be economically viable for the development (Table 3). The P_e of the project was estimated around 11.8%.

B) Revision 1 Case MEFS

The project team reviewed the appraisal strategy and decides not to use the appraisal wells as water injectors due to their location and included additional wells to be used as injectors. Figure 6a shows the revised MEFS (96 Million BO) which additionally included the cost of the injectors in the project evaluation and Figure 6b shows the truncated resources probability distribution that would be economically viable (Table 3). This indicates that there was no impact on the truncated resources as MEFS increase was relatively small.

C) Revision 2 Case MEFS

The project team included additional wells to be used as injectors, delay the first oil two years (first oil: 9 years after discovery) and additional wells to mitigate the impact of early gas breakthrough in the producers. Cash flow was delayed for 2 years. These changes affect the production profile and reduced the plateau from 4 to 3 years. The number of development wells increased from 36 to 54 due to increased producers and injectors. Additionally, the CAPEX, OPEX and Abandonment cost were increased. The changes significantly increased the MEFS to 143 Million BO (see Figure 6a) from 92 Million BO. The truncated resources probability distribution (Figure 6b), to be economically viable, was reduced (Table 3). The P_e of the project was reduced from 11.8% to 9.4%. In general, based on authors' experience, the probability of economic success below 10% is considered high to very high risk projects. Such projects have rarely been commercially successful. However, in addition to technical and economic evaluation, the investment decisions for the exploration projects are taken based on several other factors which are related to company short, mid and long-term exploration strategy, fiscal terms and conditions of the exploration block including minimum commitments and penalties due to noncompliance, risk taking appetite of the company.

D) Revision 3 Case MEFS

The team obtained new information from a new field discovery; reprocessed and reinterpreted the 3D seismic data. This new information permitted an increase of P_g from 17% to 20%, without major changes in the field size distribution (FSD). The mean untruncated resources were reduced from 282 to 227 Million BO for the Base Case of project. The development assumptions are similar to Revision 2 but include additional appraisal wells that are not used as injectors. The cost of the exploratory well was increased with respect to the previous estimate. Furthermore, Weighted Average Cost of Capital (WACC) increased from 7.67% to 8.42%. Additionally, the oil price was also updated. The CAPEX for this case shows an increase, mainly due to an increase in number of wells. The revised MEFS (Figure 6a) has increased from 143 Million BO (revision 2 case) to 207 Million BO. The resources probability distribution (Figure 6b) has been revised (Table 3 Pmean Untruncated and P_g). Figure 6 shows the resources and risk assessment using risk assessment tool including the MEFS plots for all cases. This figure shows the increase in MEFS value due to the changes in the development assumptions and cost estimates. This increase in MEFS value (from 92 to 207 Million BO) has removed the non-economic part of recoverable resources distribution significantly (i.e. low-end of the truncated resources distribution starts from estimated MEFS Value with P_e of 0%). As a result the mean truncated resources have increased to 515 Million BO compared to 383 Million BO. This higher truncation in the resource distribution has resulted in a reduction of the P_e to 6.6% compared to 11.8%.

In order to understand the reasons of the decrease in P_e between the resources of the Original case and Revision 3 case, it is important to analyze the behaviour of P_{mefs} (probabilities to find MEFS) as the P_e directly depends on P_g and P_{mefs}. The P_{mefs} decrease can be divided in two components: First one is originated by MEFS value which has increased due to decrease of Pmefs from 70% to around 47% (Figure 6b), and second component is FSD shift towards lower range. During revised G&G evaluation (Revision 3 case), the FSD (P1 and P99 values) has reduced compared to the original G&G evaluation (Figure 6b) but the associated P_g has increased from 17% to 20% based on new 3D seismic data. On the other hand, the regression line has moved towards left and reducing the P_{mefs}, which gives a final value of 33%.

Example 3

This example illustrates the impact of different possible development scenarios on MEFS estimation and overall project value. Given the exploration immaturity of the Basin, the development assumption considers the possibility of finding the volatile oil (35-39° API and GOR 1800 SCF/Barrel with 65 ppm H_2S, and 12.5% CO_2, 1.17% N2, no wax and asphaltenes) based on the modeling studies and offset discoveries. The prospect (a 4-way dip closure located at water depth of 900 m) is interpreted using 3D PSDM data and offset well information. The identified targets are pre-salt carbonate reservoirs. The pre-drill un-risked mean OOIP is around 496 Million BO and the mean recoverable resources are 232 Million BOE (172 Million BO of Oil and 336 BCF of solution gas) with a P_g of 39.7%. The reservoir quality is considered as the main risks (due to poor seismic image quality, unknown diagenesis, performance). For analyzing the economic value of the Project Base Case, the MEFS, P_e and truncated resources have been estimated for three development cases (Gas and water re-injection, Gas and water re-injection with higher permeability and water injection with gas export) with 2 first Oil scenarios (aggressive - 5.5 year first oil from discovery and realistic project schedules - 8.5 years from discovery) according to the identified key uncertainties. One appraisal well assumed for appraising the field in case discovery will be converted as injector. The facilities development assumptions are subsea wells with tie back to a leased FPSO vessel with production facilities on board. For the first two development cases, the produced water and gas is planned to be reinjected in the reservoir. Third case assumes water injection and produced gas to be exported to onshore facilities located at around 150 km away from the prospect. The estimated MEFS for these cases varies from 151 to 246 Million BO, mean truncated resources from 422 to 488 Million BO and the P_e from 12 to 20%. Table 4 shows the summary of different development scenarios and their impacts on MEFS estimates. This analysis clearly demonstrates the criticality of MEFS estimation on high investment project during exploration phase when this is updated with new data/information, cost estimation and revised development assumptions over time.

Conclusions

The MEFS estimation is a time consuming and complex process which requires coordinated and iterative efforts between different technical disciplines as it depends on many variables with large uncertainties. Use of appropriate analogues in generating the reservoir inputs and their ranges, the fluid type and composition, the drilling and facilities costs and the selection of the Base Case development scenario are critical in obtaining a reasonable MEFS value. Understanding the dependency between different inputs used in MEFS, eliminating bias, checking for misinterpretation and maintaining consistency in the evaluation is essential. Before generating the production forecasts to be used as input in MEFS, it is essential to define the most likely exploitation strategy (natural depletion, pressure maintenance, etc.), criteria for the selection of production scenario (economical, availability in market, others). Sensitivity analysis for the most uncertain key parameters should always be performed as part of standard procedure to assess the impact of MEFS uncertainty on overall truncated resources and therefore probability of economic success which directly impacts project economics. In case of significant MEFS input parameters uncertainties, simple graphic approach of MEFS estimation based on linear regression, described in this article, may not be appropriate as NPV could be nonlinearly related to the resources and it may not allow capturing the impact of particular variable of interest. Under such situations, other methods (analogue based, stochastic approach, etc.) would be required to validate the outcomes of deterministic (single and or limited multiple scenario based) methods.

The Minimum Economic Field Size should be used as a powerful tool to benchmark and assess the profitability of the Exploration project. Comparison of key parameters such as P_g, MEFS (Economic Threshold), key economic indicators (NPV, Unit cost per barrel, IRR un-risked and risked, EMV, and P_e, etc.), for different exploration projects can be used as the basis to improve ranking and portfolio management. Such comparison, as demonstrated through examples, has proven to be a highly efficient and comprehensive way of ensuring more informed investment decision makings.

Acknowledgements

The authors thank Repsol management for providing the facilities, guidance and encouragement during the execution of this work and permission to publish this material. Sincere thanks to Delfin Fidalgo, Director Dirección de Calidad Técnica (DCT), and Alvaro Racero, Dirección Ejecutiva de Desarrollo Técnico (DEDT) for their support in exchanging the ideas and formulating the strategy for this work.

References Cited

Alexander, J.A., and J.R. Lohr, 1998, Risk analysis: Lessons learned: SPE 49020, presented at ATCE in New Orleans, U.S.A, September 27-30.

Antia, D.D.J., 1994, Economic strategies to maximise profits from satellite field developments: OTC #7429, Presented at the 26th Annual OTC in Houston, Texas, U.S.A., May 2-5.

Bilderbeck, M.G., and I.V. Beck, 2005, Using integrated project models to evaluate field development options: SPE 93554, presented at the 14th SPE Middle East Oil & Gas Show and Conference, Bahrain International Exhibition Center, Bahrain, March 12-16.

Bradley, M.E., and A.R.O. Wood, 1994, Forecasting oilfield economic performance: JPT, November Issue.

Chitwood, J.E., L. Wanvik, Y. Doreen Chin, and B.J. Sheets, 2004, Techno-economic evaluations of deep-water marginal field developments: OTC #16722, Presented at the OTC held in Houston, Texas, U.S.A., May 3-6.

Dunn, M.D., and L.A. Parnell, 2002, A systematic method to estimate the value of an exploration well: SPE #76735, presented at SPE Western Regional AAPG Pacific Section, Alaska, U.S.A, May 20-22.

Ferro, S., J. Tomasini, P. Gristo, H. De Santa Ana, and P.G. McLeroy, 2014, Economic comparison for the potential development of onshore unconventional resources and offshore conventional prospects in Uruguay: SPE 169302-MS, presented at the SPE Latin and Caribbean Petroleum Engineering Conference held in Maracaibo, Venezuela, May 21-23.

Grecco, M.G., 1987, Deepwater development economics: OTC #5545. Presented at the 19th Annual OTC in Houston, Texas, U.S.A., April 27-30.

Milkov, Alexei V., 2015, Risk tables for less biased and more consistent estimation of probability of geological success (PoS) for segments with conventional oil and gas prospective resources: Earth Science Reviews, v. 150, p. 453-476.

Otis, R.M., and N. Schneidermann, 1997, A process for evaluating exploration prospects: AAPG Bull., v. 80/7, p. 1087-1108.

PRMS, 2011, Guidelines for application of Petroleum Resources Management System SPE.

Rose, P.R., 2002, Risk analysis & management of Petroleum Exploration Ventures: AAPG Methods in Exploration Series No. 12.

Syahrir, H., and W. Partowidagdo, 1996, The economic and risk analysis of oil field development in Timor gap-zone of cooperation area: Proceedings, Indonesian Petroleum Association, 25th Sliver Anniversary Convention, October.

Woods, T.J., K.G. Duleep, and E.H. Violas, 1985, Development of field-size distribution for undiscovered hydrocarbon resources in the Lower 48: SPE 16155, presented at the 80th ATCE, SPE held in Las Vegas, NV, U.S.A., September 22-25.

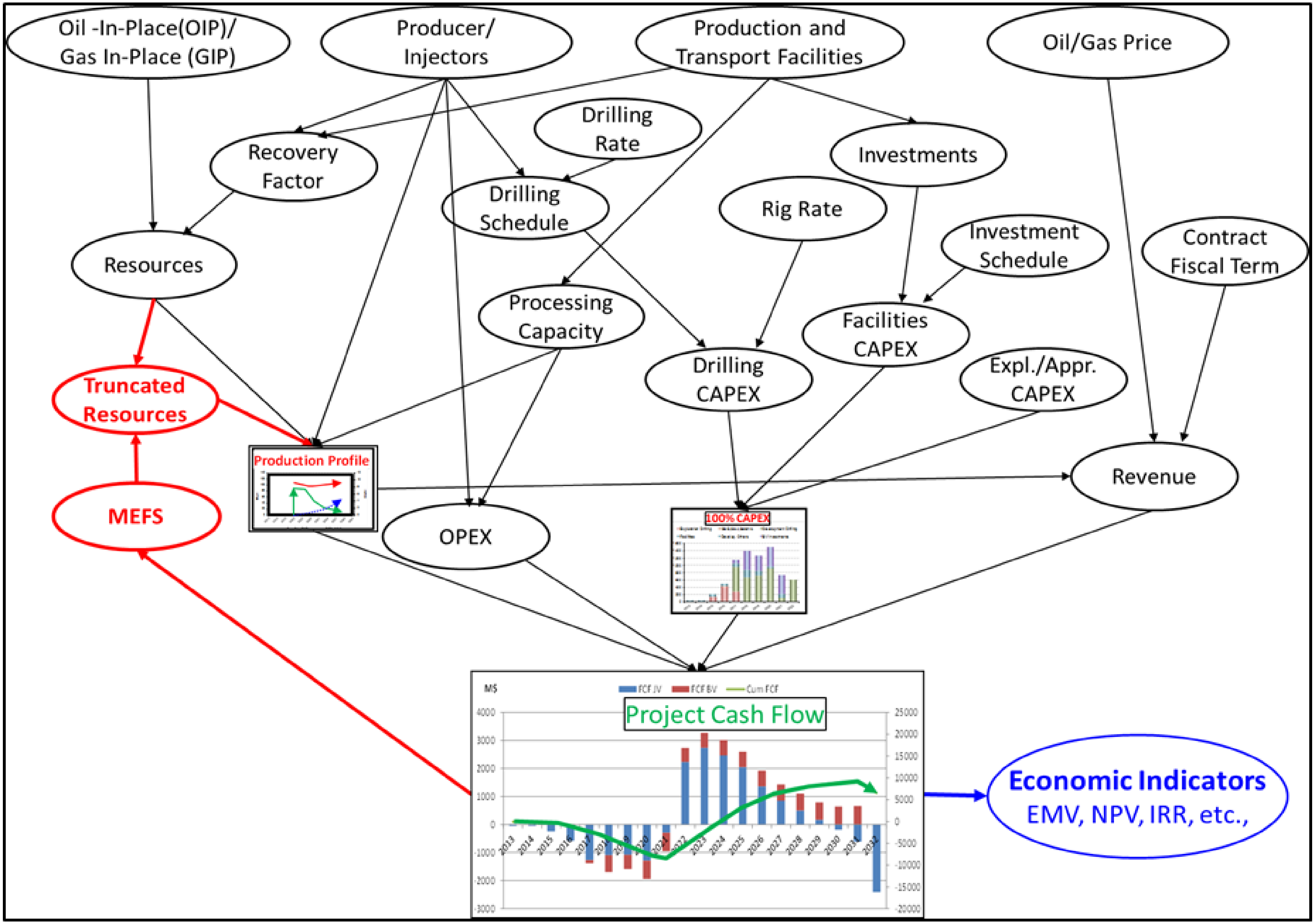

Figure 1. Influence diagram for Integrated Risk/Opportunity Analysis of an E&P Project.

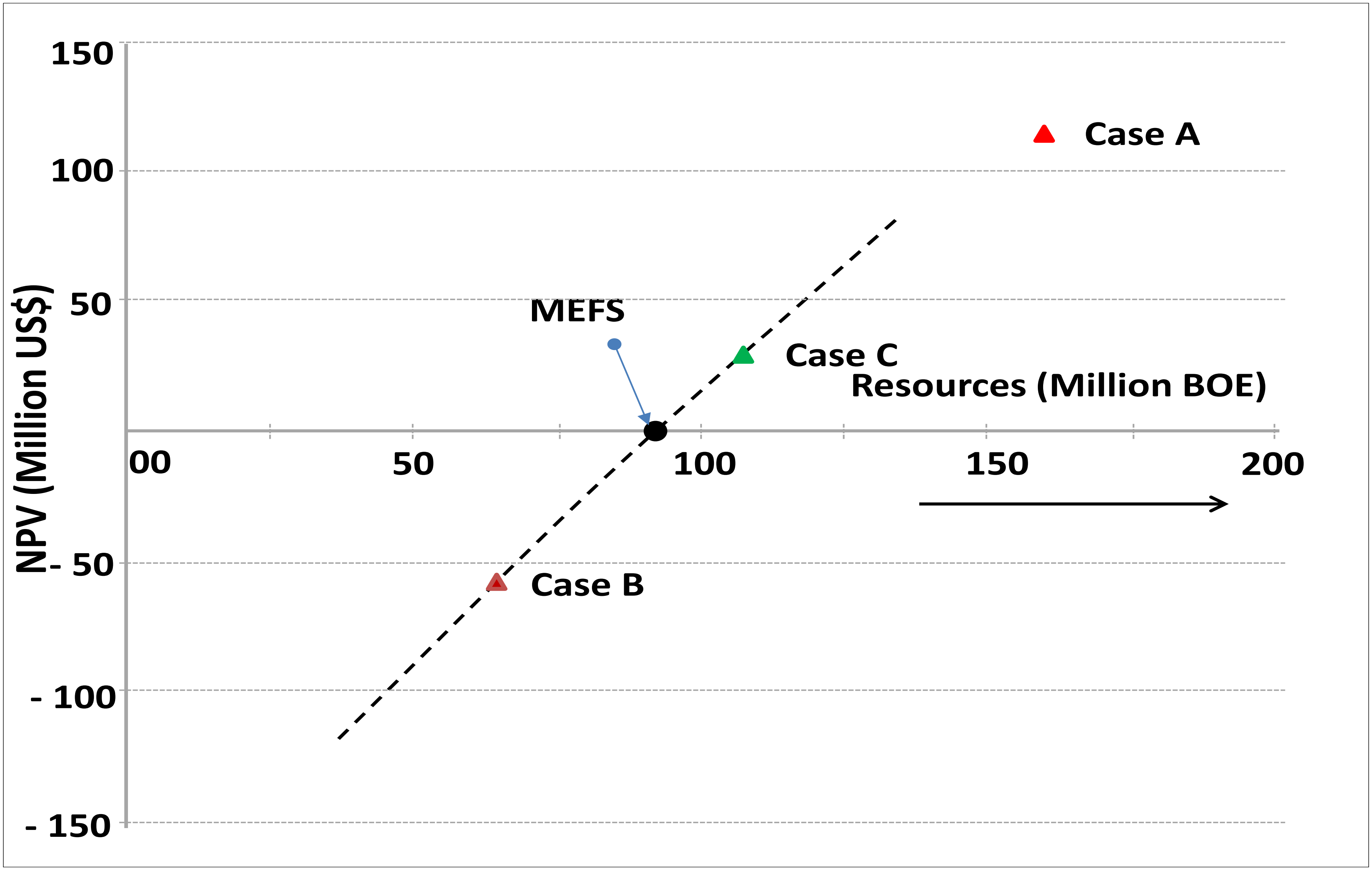

Figure 2. Graphical method of MEFS estimation.

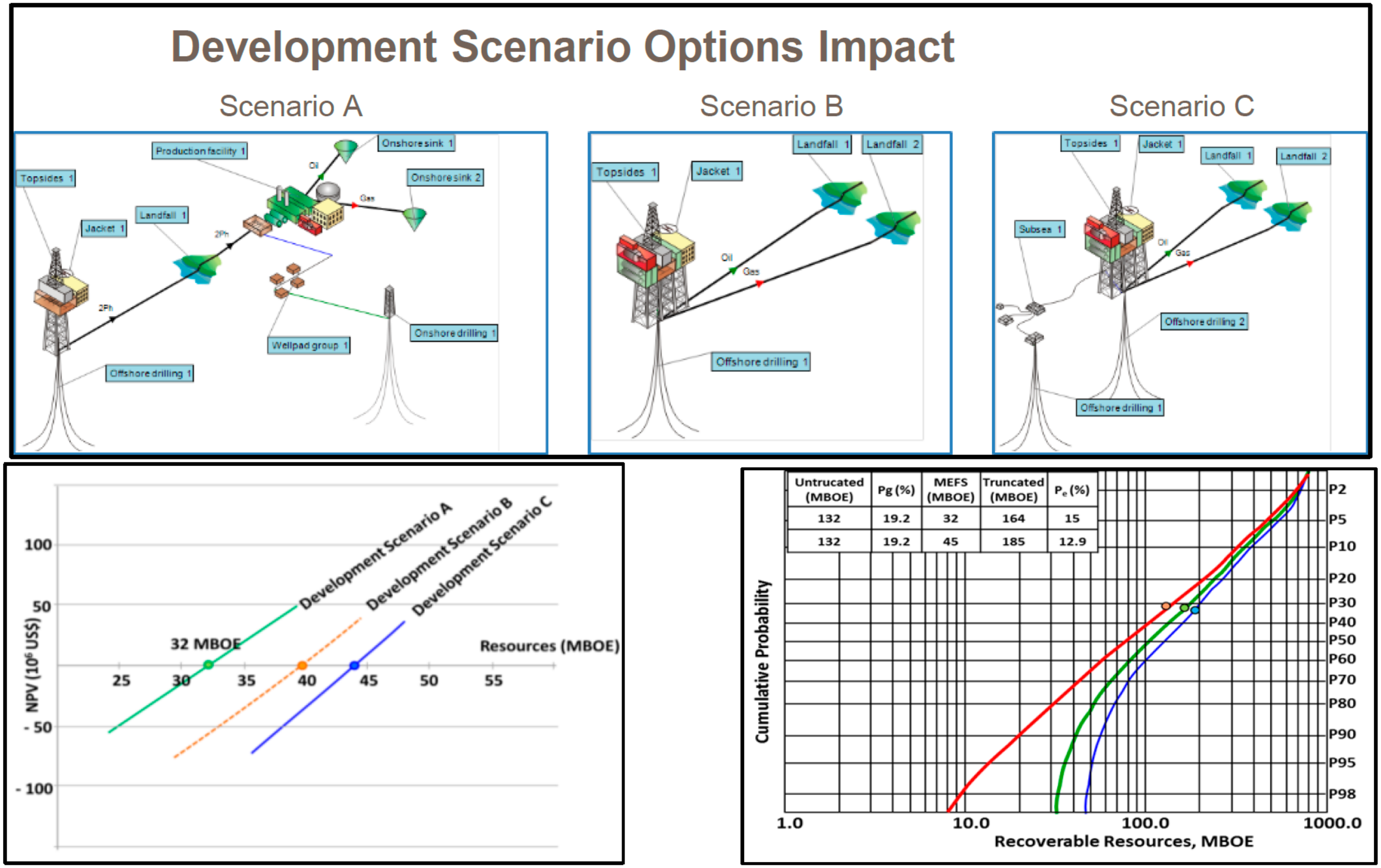

Figure 3. (a) Schematic diagram showing three possible development, (b) Different development scenarios lead to different MEFS values (Table 3), and (c) Truncated resources and corresponding P_e for Development Scenario A which is Base Case (Green line, MEFS = 32 Million BOE) and Development Scenario C (Blue line, MEFS = 45 Million BOE). For development Scenario B the distribution (MEFS 40 Million BOE) will be between green and blue curves. The Untruncated resource distribution is represented with red line.

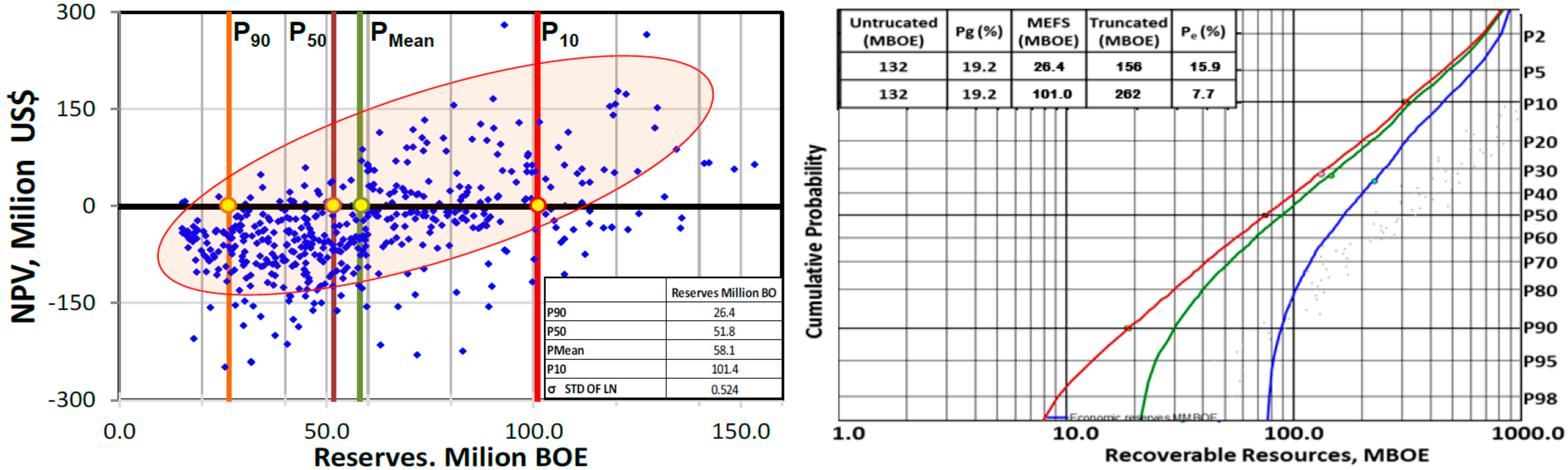

Figure 4. (a) The P90, P50 and P10 MEFS values, obtained from the Probabilistic MEFS estimation method, are 26.4 Million BOE, 51.8 Million BOE and 101.4 Million BOE, respectively. The P1 and P99 ranges between 15 to 154 Million BOE. (b) Truncated resources and corresponding P_e for these Cases: Green line (P90 MEFS value =26.4 Million BOE) and Blue line (P10 MEFS value = 101 Million BOE). The Untruncated resource distribution is represented with red line.

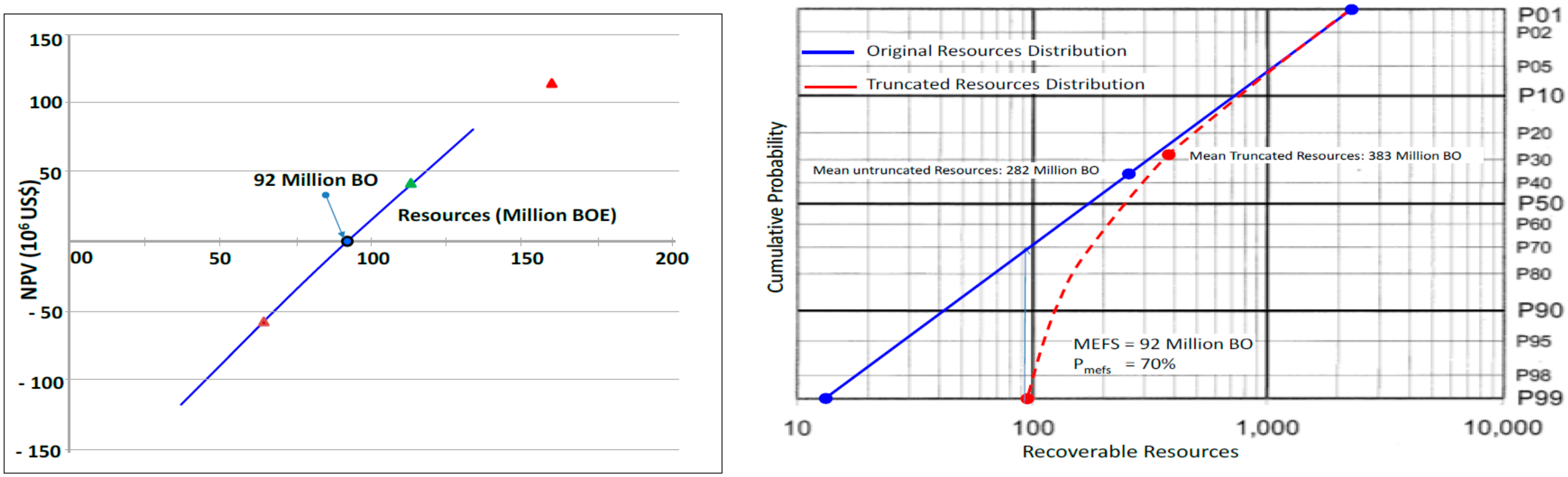

Figure 5. (a) MEFS estimation, and (b) Truncated Resource Estimation using risk assessment tool for MEFS of 92 Million BO.

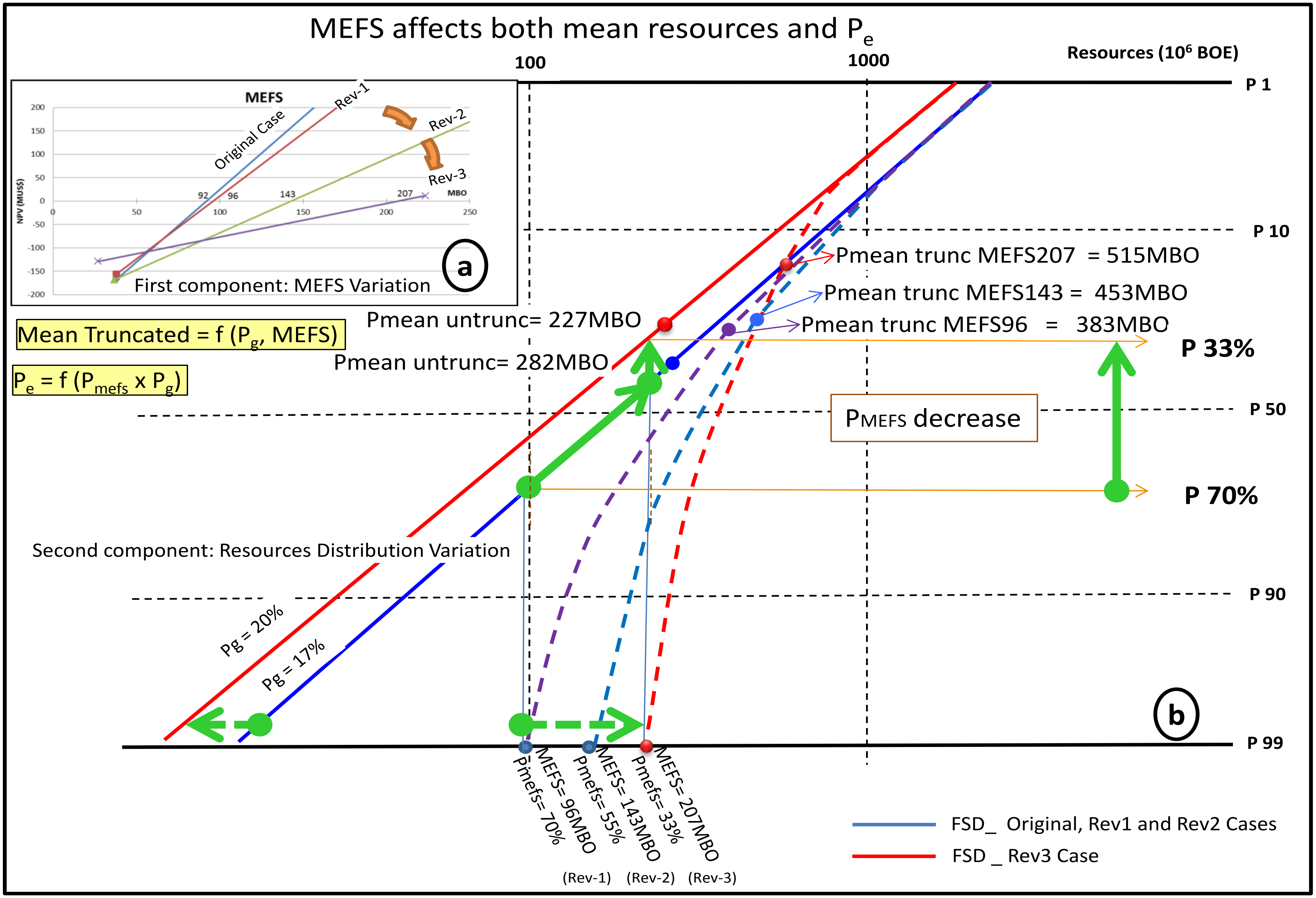

Figure 6. (a) Comparison MEFS estimation, and (b) Comparison Truncated Resource Estimation for all the cases (Original, Rev 1, 2 and 3).

	Units	P99	P90	P50	Pmean	P10	P1	Notes
Productive Area:	SqKm	2,7	5,9	15,7	20,4	39,6	86,0	LNorm
Average Net Pay:	Metres	4,1	8,9	22,9	30,7	60,2	127,7	LNorm
Porosity:	%	10,9	14,0	19,1	19,6	26,0	33,5	LNorm
Permeability	mD	13,2	33,2	102,8	151,6	318,3	800,0	LNorm
Hydrocarbon Saturation:	%	67,0	70,0	74,0	74,0	78,3	82,0	LNorm
Oil Recovery Efficiency:	%	12,0	17,0	26,1	30,0	40,2	57,0	LNorm
Oil Formation Volume Factor:	rb/stb	1,002	1,040	1,089	1,090	1,140	1,184	LNorm
Original Oil In-place	MBO	32,4	77,5	289,0	480,2	1.110,8	2.784,4	at Surface Conditions
Solution Gas	BCF	8,7	21,3	82,5	143,8	338,1	879,0	at Surface Conditions
Untruncated Resources	MBOE	7,8	18,7	74,9	132,4	310,0	812,4	

Table 1. Reservoir input parameters used for estimating oil-in-place and recoverable resources.

	Development Scenario	Oil Price	K	Viscocity	Aquifer	CO_2+H_2S	Kh	IP	MFES@10%	P_{mean} Truncated	P_e
		US$/bbl	mD	cP	Req	%+ppm	mDm	STb/day/psi	MBOE	MBOE	%
Base Case											
A_000	DevA	100	151.0	1.0	4	0 - 0	4560	9.4	**31.8**	164	15.0
Sensitivities Cases											
Development Scenario											
B_000	**DevB**	100	151.0	1.0	4	0 - 0	4560	9.4	**39.6**	176	13.7
C_000	**DevC**	100	151.0	1.0	4	0 - 0	4560	9.4	**45.1**	185	12.9
Oil Price											
A_P50	DevA	**50**	151.0	1.0	4	0 - 0	4560	9.4	**75.5**	229	9.5
A_P75	DevA	**75**	151.0	1.0	4	0 - 0	4560	9.4	**42.8**	187	13.10
A_P125	DevA	**125**	151.0	1.0	4	0 - 0	4560	9.4	**20.0**	147	17.1
Permeability											
A_K13	DevA	100	**13.0**	1.0	4	0 - 0	**393**	**0.9**	**39.9**	177	13.7
A_K33	DevA	100	**33.0**	1.0	4	0 - 0	**997**	**2.2**	**38.6**	174	13.9
A_K103	DevA	100	**103.0**	1.0	4	0 - 0	**3111**	**6.9**	**34.7**	168	14.5
A_K318	DevA	100	**318.0**	1.0	4	0 - 0	**9604**	**10.1**	**30.1**	161	15.3
A_K800	DevA	100	**800.0**	1.0	4	0 - 0	**24160**	**53.6**	**29.3**	159	15.6
ºAPI											
A_API22	DevA	100	151.0	**4.6**	4	0 - 0	4560	**2.1**	**42.8**	181	13.20
A_API26	DevA	100	151.0	**2.1**	4	0 - 0	4560	**5.1**	**34**	167	14.70
A_API36	DevA	100	151.0	**0.3**	4	0 - 0	4560	**28.5**	**31.0**	163	15.20
Aquifer											
A_R00	DevA	100	151.0	1.0	**0**	0 - 0	4560	9.4	**33.8**	167	14.7
A_R16	DevA	100	151.0	1.0	**16**	0 - 0	4560	9.4	**30.6**	162	15.2
Contaminats											
A_CO2	DevA	100	151.0	1.0	4	**2,20 - 500**	4560	9.4	**32.2**	165	14.9
A_CO5	DevA	100	151.0	1.0	4	**4,82-5210**	4560	9.4	**34.3**	168	14.6
Extreme Cases: Combination of extreme values of Permeability and ºAPI											
A_K13API22	DevA	100	**13.0**	**4.6**	4	0 - 0	**393**	**0.2**	**58.2**	203	11.3
A_K800API36	DevA	100	**800.0**	**0.3**	4	0 - 0	**24160**	**157.0**	**27.2**	156	15.9

Table 2. Summary of MEFS estimates made using different parameters for Example 1 (Untruncated mean Resources 192 Million BOE with P_g of 19.2% for all evaluated cases).

		Original Case	Case Rev1	Case Rev2	Case Rev3
Date		Before Farm in	MEFS Revision 1	MEFS Revision 2	Spud Up exploration well
Base Case Description					
Concept Development		Subsea + Tie back to FPSO	Subsea + Tie back to FPSO	Subsea + Tie back to FPSO	Subsea + Tie back to FPSO
Well Strategy		Appraisal converted	**Appraisal no converted**	**Appraisal no converted**	Appraisal converted
Well appraisal		4	4	4	**6**
Total well count		35	***39***	***54***	***39***
First Oil	**Date**	2019	2019	**2021**	**2021**
Forecast Production Behaviour		No gas cap impact	No gas cap impact	**Gas cap impact**	**Gas cap impact**
Plateau duration	**years**	4	4	***3***	***3***
Resources					
Pmean untruncated	**MBOE**	282	282	282	**227**
Pg	**%**	17	17	17	**20**
Production					
Cumulative Oil Production	**MBbl**	275	275	272	257
Gas Rate (Peak Production)	**Mstcf**	25,0	25,0	107,0	73,0
Oil Rate (Production Plateau)	**Bbl/d**	70.000	70.000	75.000	60.000
Cost Estimate					
Exploration phase	**MUS$**	392	360	360	***713***
CAPEX	**MUS$**	5535	***5593***	***6107***	***6130***
OPEX	**MUS$**	5200	5200	***5400***	4923
ABEX	**MUS$**	1202	1202	***1647***	955
TOTAL COST	**$/Bbl**	45	45	50	49
Resources Truncated Case					
Pmean truncated	**MBOE**	383	383	***453***	***515***
WACC+2%	**%**	9,67	9,67	9,67	**10,42**
MFES	**MBbl**	92	***96***	***143***	***207***
P $_{MEFS}$	**%**	70,0	70,0	***55,0***	***33,0***
Pe	**%**	11,8	11,8	***9,4***	***6,6***

Table 3. Key parameters used in MEFS estimation in different revisions for Example 2.

Cases		Case-1: Gas and Water Reinjected		Case-2: Gas and Water Reinjected (Permability Sensitivity)		Case-3: Gas Exported (Water injection sensitibity)	
Description							
Develoment Concept		Sebsea Tie back to Leased FPSO		Sebsea Tie back to Leased FPSO		Sebsea Tie back to Leased FPSO	
Well Type		Vertical/Slanted		Vertical/Slanted		Vertical/Slanted	
Well appraisal		1		1		1	
Total well		14	15	13	15	23	24
Fluid Type		Volatile Oil	Volatile Oil	Volatile Oil	Volatile Oil	Volatile Oil	Volatile Oil
First oil Date from date of discovery		5.5 Years	8.5 years	5.5 Years	8.5 years	5.5 Years	8.5 years
Plateau duration	Year	5	6	3	4	8	9
Field Life	Year	24	24	24	24	24	24
Resources							
Pmean untruncated resources	MBOE	232	232	232	232	232	232
P_g	%	39.7	39.7	39.7	39.7	39.7	39.7
Production							
Cumulative production	MBbl	488	488	443	464	422	450
Oil rate (Peak production)	Bbl/d	90000	90000	110000	110000	110000	110000
Gas rate (Peak production)	M stcf/d	162	162	200	200	200	200
Cost Estimate							
Exploratory phase	MUS$	164	164	164	164	164	164
CAPEX	MUS$	4461	4278	3939	4383	5939	5967
OPEX	MUS$	7007	6993	6609	6751	5593	5208
ABEX	MUS$	547	520	467	528	765	780
Total Cost	MUS$	12179	11955	11179	11825	12461	12118
Resources Truncated Case							
Pmean truncated	MBOE	456	488	443	464	422	450
WACC+2%	%	10.47	10.47	10.47	10.47	10.47	10.47
MEFS	MBOE	**207**	**246**	**186**	**204**	**151**	**167**
P_e	%	**14.90**	**12.40**	**17.00**	**15.00**	**20.00**	**18.00**
EMV	MUS$	-2.3	-21.3	6.0	-12.9	27.9	6.1
TIR Risked	%	12.24	10.16	13.10	11.12	14.51	12.93

Table 4. Summary of different development scenarios and MEFS Estimates for Example 3.