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Optimization of Exploration and Production Sharing Agreements Using the Maxi-Min and Nash Solutions

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Abstract: Cooperation between supply chain partners in the oil industry is essential, especially when oil prices suffer from fluctuations that affect the profitability of each party. An essential task in oil field development projects is to create an optimum agreement between the national oil company and the international oil company to guarantee agreement optimization. In this paper, the national oil company is the first party (FP) and the international oil company is the second party (SP). The paper's purpose is to investigate the use of game theory to obtain the best agreement between the FP and SP in order to enhance the cooperation and reduce conflict. In this paper, Nash and Maxi-min solutions have been applied for the first time in a special type of petroleum agreement, called exploration and production sharing agreements (EPSA). This is conducted for a case study in Libya. The study considers nine negotiation factors (issues) in the EPSA, which are the share percent, the four "A" factors, and the four "B" factors, which are usually affected by the fluctuations of oil prices; and the study investigates their effect on the total payoff function, the net present value (NPV), and internal rate of return (IRR) for both parties. The Maxi-min solution has shown an improvement in the NPV and IRR of the SP, where NPV increased from USD 148 million to USD 195 million, and IRR from 15.65% to 17.01%. The Nash solution has shown a little more improvement than the Maxi-min solution in the NPV and IRR for the SP, where the NPV and IRR have increased from USD 148 million to USD 222 million and from 15.65% to 17.94%, respectively.

Keywords: oil fields; oil companies; negotiation; game theory; Maxi-min solution; Nash solution; agreement optimization

Citation: Balhasan, S.; Alnahhal, M.; Shawan, S.; Salah, B.; Saleem, W.; Tabash, M.I. Optimization of Exploration and Production Sharing Agreements Using the Maxi-Min and Nash Solutions. *Energies* **2022**, *15*, 8970. https://doi.org/10.3390/en15238970

Academic Editors: Jiachao Peng, Le Wen, Jianzhong Xiao, Ming Yi and Mingyue (Selena) Sheng

Received: 2 November 2022
Accepted: 25 November 2022
Published: 27 November 2022

1. Introduction

Negotiation is described as a process in which two or more parties negotiate or cooperate in order to reach an agreement. Systematic studies of the primary sources of negotiation literature have been published by Kemper and Kemper [1]. The origins of negotiation research can be traced back to game theory. Raiffa's dissertation, which is included in his book *"The Art and Science of Negotiation"*, focuses on game theory to explore negotiation theories' strategic choices. He claims that the effectiveness of negotiations is contingent on specific decisions [2]. Pruitt and Carnevale [3] addressed the social conflict negotiation outlines of the dominant normative negotiating paradigm's faulty principles; these traditional models assume that there are only two negotiating sides, each structured to maximize self-interest.

The use of specific methodology and scientific research to identify the best alternatives is an important aspect of the process of evaluating viable investment opportunities and assisting decision making. The general characteristics of petroleum project evaluation are comparable to those of other industries. There are, however, some unique and distinct challenges, most of which are related to the nature and conditions of petroleum projects and necessitate specialized knowledge and experience. [4].

In comparison to other oil agreements, exploration and production sharing agreements (EPSA) are currently more widespread. Many EPSA conditions allowed for negotiations between the national oil company, which is the first party (FP), and the international oil company, which is second party (SP). The FP retains rights to petroleum resources and production under the EPSA, but the SP receives a part of hydrocarbon production in exchange for services rendered [5]. The EPSA is used to split the profits from developed oil and gas fields' hydrocarbon output. The EPSA allows for a variety of profit-sharing arrangements between the two parties. Production share, profit split, production rate, bonus, discounted cash flow, royalty, and income tax are some of the most used methods [6]. In profit oil split, most EPSAs use a production-based sliding scale and R-factor method. Around 75% of EPSAs in the world use a sliding scale based on daily production and annual SP investment [6].

In this research, the Libyan EPSA IV model was applied to an oil field with secondary recovery and water injection. The development costs are split evenly between the FP and the SP (50% −50%). The running costs are split among the partners based on their output shares (production share). All costs for exploration, appraisal, and development can be recovered from the SP's production share. Taxes, royalties, and other fees are not applied to the SP [7,8]. To estimate the net present value (NPV) and internal rate of return (IRR) of this field, an economic model was created in Excel. Compared to the FP, the SP's NPV and IRR of the economic model are both low. The FP's main goal is to maximize profit from existing oil and gas reserves. The SP intends to increase oil output while lowering expenses and increasing profit. The SP has highlighted concerns about potential conflicts of interest between the FP and the SP. This issue arose as a result of the SP's unsatisfactory return of the agreement's earnings.

A smooth process of agreement between the two parties might face some challenges in determining the terms in the contract. This is especially important in the time of heavy fluctuations of prices of oil. Every party wants the best agreement terms to maximize its profit. Therefore, a fair agreement based on a certain methodology is necessary. The methodology needs to be practical and easy to understand by practitioners in the two parties. This study concentrates on the variables that are reflective to the changes in the prices of oil. Based on Nash and Maxi-min solutions, the study proposes a method that can be applied with Excel spreadsheets to make it easy for the two parties to accomplish. To validate the methodology and give full details of its steps, a real case study was presented to show the effect of the proposed methodology. The effect of the production share, A factors, and B factors on the economic indicators NPV and IRR for the two parties (government and international company) was identified in the literature. The agreement on the levels of these factors needs to be investigated. In this study, the key nine negotiable factors are used and thoroughly examined using two game theory models in order to assist decision makers in determining the best course of action for each of them. Furthermore, a strategy for resolving the conflict between FP and SP has been developed to help remove conflict as a barrier to the development of oil fields.

Two solutions approaches have been used in this paper to resolve the conflict and optimize the agreement output. The Nash bargaining solution and Maxi-min solution are used to enhance the payoff and eventually the SP's NPV and IRR. The concentration on the SP is because its margin for profit is much less than that for the FP. However, there is a threshold for the minimum score that the FP can demand in negotiation, and this threshold was taken into consideration. The two methods show a significant improvement of the NPV and IRR. Agreement optimization for the parties has been achieved. The study proposes a practical methodology that is deep and yet easy to be applied by practitioners using Excel Solver. The study starts from the situation that currently exists and proposes a different way for more gain that guarantees the basic requirements of the two parties.

For the FP and SP alike, the division of economic rent is the primary focus of concern. It is the driving force behind a fiscal system and the focal point of negotiations and, at times, tensions and controversies [9].

The SP wants to maximize the value of their assets. They examine investment possibilities around the world and assess their relative risk–reward profiles using economic indicators. Oil companies monitor the revenue generated by assets throughout their economic lives to ensure that the capital investment and expenditures have been covered and the return on capital is compatible with the risk associated with the asset and the corporation's strategic objectives. The host government is interested in determining if a fiscal system achieves its goals. To do so, host governments utilize economic and system measures at the project level to analyze whether the project's financial and social benefits are commensurate with the project's risk level and the government's sector policy objectives. At the country level, host governments assess the influence of the oil sector's overall revenue flow on important macroeconomic variables (mainly inflation, GDP growth, the balance of payments) [10].

Better negotiation results will lead eventually to better NPV and IRR. The NPV is the difference between the present value of the investment's cash outflow and the present value of the project's cash inflow. Technically, when the cash flow of an activity is discounted at a certain given discount rate, either a positive or negative value is obtained, depending on the conditions. To obtain the maximum possible profit or benefit, the company will choose the activity with the highest NPV. The IRR is defined as the discount rate at which the sum of all future discounted cash flow present values equals zero. In the case of overseas investment, it will be significantly fair if an IRR of 13–17% is guaranteed to the SP. IRR becomes a more important profit indicator when its value is less than 20%. The IRR is thought to be considerably more significant for the SP than it is for the FP in oil development projects. This is the only issue that needs to be taken into account in EOR and offshore development projects where the IRR is crucial to the FP and SP. Therefore, the minimal IRR of 18% to 20% is taken into consideration as an economic criterion in the current study for economically recoverable resources [11].

The main contribution in this study is to include, for the first time, agreement variables (share, "A" factor, and "B" factor) in the decision-making process in EPSA agreements, using the two methods of Nash and Maxi-min solutions. This is done by investigating the effect of these variables on the profitability of the SP and FP. Moreover, a comparison is made between the proposed methodologies with the original strategy followed currently in the case study in Libya. In order to optimize their economic benefits, the two parties will decide which agreement factors to concentrate on during the agreement negotiation with the help of the proposed tool. Additionally, the NPV and IRR of the SP was significantly improved using the two new approaches without violating the profit requirements of the FP. Furthermore, the two fair solution approaches, Nash and Maxi-min, used in this research, for the first time in oil agreements, will offer a novel technique for further studies to modernize the current approaches being used in the negotiation of the equity split in the oil and gas industry to achieve agreement optimization.

The rest of this paper is organized as follows: After this introduction, the next section is about the literature review, which explains the previous related studies and the contribution of the current research. Then, the case study with full details is presented. Then, the methodology section explains the Nash and Maxi-min methods. Then, the section of results and analysis presents the results and main insights of the methods. Finally, the conclusion summarizes the main findings and recommendations for future research.

2. Literature Review

Applications of game theory in the oil and gas industry typically fall into one of three categories. The first category is competitive bidding, in which companies compete for a limited number of opportunities. The second type of partnership is a joint venture, in which a group of companies work together to implement a project or other opportunity. The third one is the negotiation that involves partners, clients, vendors, and governments, in which each side aims to secure the maximum possible share [12]. Game theory is known in the literature to be applied in the field of oil production and price [13]. However, none of the previous studies investigated game theory methods such as the Nash solution in EPSA agreements. For example, strategic exploration and production were derived jointly in a three-period subgame perfect equilibrium in a work by [14]. They found the subgame perfect Nash equilibrium in a game where firms compete not only in the output market but also in the exploration process. A game theoretic framework has been applied in a study by Willigers et al. [15] in the oil and gas industry, where the Nash equilibrium was used in the analysis. Esmaeili et al. [16] used a game theory approach to investigate the policies for Iran's oil and gas shared resources conflicts with Iraq and Qatar. The outcomes of mathematical models demonstrate how countries could devise an acceptable plan for utilizing their common resources. Langer et al. [17] used a partial-equilibrium global energy market model. The problem was modeled as a Generalized Nash Equilibrium (GNE) between non-cooperative players. They discovered that eliminating the US crude ban will benefit domestic producers by allowing them to sell their petroleum at global market prices rather than prices skewed by local constraints.

Tominac and Mahalec [18] created a game-theoretic framework for strategic production planning in petroleum refineries. The problem is expressed as non-cooperative potential games with Nash equilibria as solutions. According to game theory, the production planning choices are sound, and they can withstand changes in competition strategy. Moradinasab et al. [19] investigated the petroleum supply chain in light of sustainability and pricing challenges, and a model for a sustainable competitive petroleum supply chain was developed to reduce pollution while increasing profitability and job creation. Araujo and Leoneti [20] analyze relevant realistic and real-world oil and gas sector examples in the form of 2×2 strategic games, with the goal of investigating game theory methodologies to aid in the discussion and resolution of the major challenges encountered. They investigated the use of the Nash equilibrium and Max-min methods, plus other methods, to obtain solutions in different case studies.

Nicoletti and You [21] modeled the crude oil supply chain from oil well to refinery as a mixed-integer program that allows for competing objectives and interactions among various stakeholders. They applied the Stackelberg game theory. The crude oil refiner takes the lead and selects how much oil to buy in order to maximize profits while limiting the environmental impact of its operations. The profitability of investment in refinery development was investigated in a work by Babaei et al. [22], and the effects of the model on each agent were considered using a multi-agent method. Using a game theory approach, they discovered substantial investment problems with consequences for the future of the gasoline sector. Xue et al. [23] determined the optimum negotiation technique for oil corporations taking part in global oil and gas development projects. They created a model of bilateral bargaining and examined the variables that affect the equilibrium income ratios. Bidding order and information asymmetry are shown to be the two key influencing factors. The findings indicated that information asymmetry has no impact on the two parties' relative real income levels. Araujo and Leoneti [24] suggested using game theory to simulate and assess the stability of Brazil's regulatory framework for exploration and production. They suggested a method for modeling a multi-criteria group problem as a multi-criteria game and solved it by applying the Graph Model for Conflict Resolution methodology, to comprehend and measure the preferences of the players and find fair and stable solutions. Csercsik [25] constructed a simple game-theoretic model to capture the fundamental elements of the gas supply dilemma. The model was used to build a method for supply–security cooperation.

For more about game theory with application to oil production and price, the reader can refer to Ibrahim et al. [13]. The above studies investigated the use of game theory in the petroleum field in general. However, little was published on using game theory in petroleum contracts between the national company and the contractor. An example for that is the study by Keshavarz et al. [26], who investigated the Iranian petroleum contract fiscal regime using bargaining game theory for the purpose of guiding contract negotiators. The methodology presented depends on a certain type of contract (risk service contract) devolved by the Iranian government. Besides its narrow application field, the model presented is complex. Another study that investigated the game theory in petroleum contracts was the one by Dirani and Ponomarenko [27], who analyzed the production sharing contract system. The principle of win-win game theory was presented when the interests of the international oil company and the state are coordinated. However, they depended on a literature review and did not investigate the principle with data in detail. Moreover, none of the mentioned previous studies investigated the EPSA agreement. Therefore, the novelty of the current study is to investigate petroleum contracts using two types of game theory models, namely, the Nash and Maxi-min solutions, and propose two general models that can be applied easily in EPSA agreements and can be easy to understand. This is done with a real case study. To the best of the authors' knowledge, this study is the first one that investigates the application of a game theory method in EPSA agreements and their negotiation factors. The study depends on practical models that can be applied by companies to reduce the conflict between the two parties. Excel Solver was used because of its availability in every computer.

3. Case Study

The focus of the case study is to resolve the conflict between the Libyan National Oil Corporation (NOC) and an International Oil Company to develop the AA oil field. The National Oil Corporation was established in 1970. Its purpose is to organize petroleum development plans and to oversee the administration and financial operations of oil and gas enterprises. The NOC is in charge of all oil and gas exploration, production, and marketing both domestically and abroad through its subsidiaries (National Companies) or through agreements with foreign companies [28]. The NOC has plans to raise Libyan oil production capacity to 2 million barrels per day. The NOC highlighted its plans for exploration and production by the following steps:

1. Maximize the profit from each oil and gas agreement.
2. Minimize the SP share in any oil and gas agreement to obtain the highest revenue.

The SP has to bear a high portion of the risk. The SP expects to meet the benchmark economic criterion. In the proposed development scenario, the IRR did not reach the minimum limit.

To maintain the production plateau and boost the oil recovery factor, the AA oil field is expected to be developed by a water injection project. The two parties intend to drill 50 producing wells with a daily flow rate of roughly 60 thousand barrels to develop the field. This rate is likely to push the plateau out for another six years. The remaining four peripheral water injections will be drilled to guarantee the requisite oil rate and pressure are met. Table 1 shows the capital CAPEX and OPEX of the AA oil field. The total production is expected to reach 219 million barrels by 2037, according to projections. A three-phase separator is recommended in the field due to the relatively high gas–oil ratio of 800 SCF/STB and water output. The condensate output of the field is estimated to be 30 STB/MSCF. As a result, a gas plant would be required to remove liquid hydrocarbon by-product (LHP) from the field.

Table 1. The capital expenditure and operating costs of AA field.

Cost Type	Value, USD MM
CAPEX	569.18
OPEX	464.5
Other Costs	91.35
Total Costs	1125.03

A coded spreadsheet model was utilized to estimate the profitability indicators of NPV and IRR for this scenario based on the AA field data. The purpose of this coded model is to create a decision-making model for the initial development scenario.

This field development scenario assumes that the field was created using primary and secondary recovery methods, as well as water injection. Oil field size, oil prices, gas prices, LHP prices, and others are decision factors in this regard. Table 2 shows the assumptions for the decision factors of the AA field in the economic model.

Table 2. The capital expenditure and operating costs of AA field.

Project Variable	Value
Original Oil in Place	1 billion
The initial production	60,000 STB/D
Plateau time	6 years
The decline model	Hyperbolic
The annual decline rate	25%
The hyperbolic constant	0.6
The oil price (escalated)	USD 65/barrel
The HLP price (escalated)	USD 75/barrel
The gas price (escalated0	USD 5/MMBTU
The discount rate	10%
The inflation rate	2%
The borrowed money (50% of the CAPEX)	USD 321 million
The payment period	5 years
The loan interest rate	7%
The SP Production Share	15%

The Equity Split Mechanism

In 2004, the Libyan EPSA IV modified version was launched. The agreement requires the SP to assume full responsibility for all exploration costs. The FP pays the entire share of operational costs (equivalent to its contractual share, 85% to 90%) but only half of development costs. Once production begins, the SP sets their proportion of share at 10% to 15% of total production in order to recover their share of the exploration and development costs. The term "production share" refers to this percentage. Furthermore, according to the "A" and "B" factors, the excess profit oil (the remaining oil from the second party's share of production "10% to 15%") is shared between the two parties. As will be explained later, the "A" and "B" factor values are a matter of negotiation between the two parties. Signature and Production Bonuses must be paid by the second party. The first party, on the other hand, pays the income tax of the second party from its share of the revenue to the Libyan government. Furthermore, the second party is exempted from customs duties under Libyan petroleum law. The following are specific rules in EPSA IV:

1. Similar to EPSA III, except with added Gas and LHP Clauses.
2. SP is entirely responsible for exploration expenditures.
3. CAPEX is split 50/50 between the two parties.
4. SP's percent of output provided for SP cost recovery.
5. OPEX is shared according to the production share.
6. There is no royalty and no tax paid by a third party.
7. The original "B" factors are as shown in Table 3, and they are a step function of field oil output. The results of this study provide better settings as will be shown later.
8. Just like the "B" factors, the original "A" factors are obtained to compare the results of this study to them. They are shown in Table 4, and they are a step function of the R ratio. The two parties' negotiating parameters include both "A" and "B" factors.

Table 3. Initial settings of Production Rate and Production Index, B factor.

Production Rate (bbl/Day)	Production Index B
1–20,000	0.95
20,001–30,000	0.8
30,001–60,000	0.6
60,001–85,000	0.45
>85,000	0.2

Table 4. Initial settings of A Factor and R Ratio.

R Ratio	A Factor
1.0–1.5	0.9
1.5–3.0	0.8
3.0–4.0	0.6
>4.0	0.4

The net cash flow (NCF) in the EPSA IV model can be found by using the following equations [28,29].

$$\begin{aligned} \text{FP NCF} = {} & [(\text{FP Share\%} * \text{oil production*price}) + (\text{excess profit, oil}) - (\text{SP excess profit, oil})] \\ & + [(\text{FP Share\%} * \text{LHP production*price}) + (\text{excess profit, LHP}) - (\text{SP excess profit, LHP})] \\ & + [(\text{FP Share\%} * \text{gas production*price}) + (\text{excess profit, gas}) \\ & - (\text{SP excess profit, gas})] + \text{Production Bonus} - \text{CAPEX} - \text{OPEX} \end{aligned} \tag{1}$$

$$\begin{aligned} \text{SP NCF} = {} & [(\text{SP Share\%} * \text{oil production*price}) - (\text{excess profit, oil}) \\ & + (\text{SP excess profit, oil})] + [(\text{SP Share\%} * \text{LHP production*price}) \\ & - (\text{excess profit, LHP}) + (\text{SP excess profit, LHP})] \\ & + [(\text{SP Share\%} * \text{gas production*price}) - (\text{excess profit, gas}) \\ & + (\text{SP excess profit, gas})] - \text{CAPEX} - \text{OPEX} - \text{Production Bonus} - \text{Capital cost} \end{aligned} \tag{2}$$

The net present value represents the discounted values of future cash inflows and outflows related to a specific project. The project lifetime is 29 years. After finding the NCF based on the above equation, NCF of the SP was deflated. Then, IRR was estimated using the function of IRR in Excel. Then, the NPV was determined by taking the sum of the negative and positive cash flows and discounting the deflated NCF (from the IRR) by using the NPV function.

4. Methodology

The Nash bargaining solution is an optimization procedure used to maximize the product of the payoffs. Almost all bargaining, according to Nash, is a method of achieving and distributing benefits. A collection of possible variations of the division of the jointly obtained benefits from all possible arrangements of the subjects can be considered as such a negotiation scenario, with the point of conflict "d" determining the subset of the set "S" within which the solution will be sought, see Figure 1.

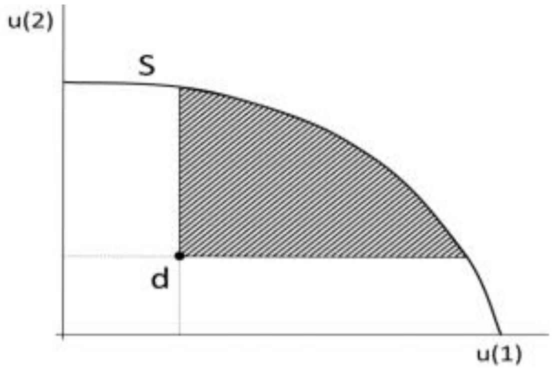


Figure 1. Negotiation as a Nash's bargaining problem.

The point of contention defines a compromise to which all negotiating sides agree without further discussion. Alternatively, the negotiation is the product of both parties' alternatives—thus, a compromise for a lower profit than that specified by point is not worth it. The point of contention may also be found at the crossroads of axes (x, y) if neither party can come to an agreement and there are no alternative options, as even minor improvements are beneficial for both parties [30].

Nash's bargaining solution is a precise solution based on a number of assumptions. Perfect details, fair negotiating skills, knowledge of the power of negotiation, and so on are examples of these. Nash suggests a solution which is the so-called Nash product, which can be found using the formula:

$$Max\ [u_1\ (x^*) - u_1\ (x^0)][u_2\ (x^*) - u_2\ (x^0)] \tag{3}$$

where u_1 and u_2 correspond to utilities of the first and second subject, point x^0 is the benefit at the point of disagreement, and the point x^* relates to the point of interest. Thus, as a result, the formula shows the maximum benefit that entities can receive [30].

On the other hand, Maxi-min is used to maximize the minimum, to change the objective function of the agreement output from maximizing the product of the payoffs to FP and SP to maximizing the lesser of the two payoffs.

It is an optimization procedure used to maximize the minimum of the proportional of the potential (POP) of the FP and SP. The POP is the ratio of the "excess" to the difference between the maximum feasible value and the reservation value (RV). Excess is the difference between the obtained value by the method used and the RV. Later, these relationships are expressed using mathematical equations. The Excel 2016 Solver will be used to find the agreement that would maximize the FP's and SP's scores. Okoro et al. [31] used Excel to make their analysis of game theory, where they used the Maxi-min solution.

There are some similarities between the two methods (Nash and Maxi-min solutions). Therefore, some previous studies such as Araujo and Leoneti [20] and Turbay and Reyes [32] compared and investigated both of them. However, the objective function of both of them is different. The Nash equilibrium seeks the best possible strategic option when compared to the options of other players, and this is true for all players. The Maxi-min strategy, on the other hand, seeks payoffs that are at least as good as the worst payoff from any other strategy [33]. Robinson and Goforth [33] proposed a 2 × 2 strategic game classification based on the players' payoff-space representation, particularly in the understanding and interpretation of the Nash equilibrium and Maxi-min strategies. In the next section, the difference between the results of both of them is presented.

The Optimization Method Using Maxi-Min and Nash Solution Models

The methodology in this study depends on subjective estimation of the importance of the negotiable variables, and the score of each level of the variables for both parties. The two parties might set together to estimate the importance and the score. The following steps are used for the optimization method [2]:

1- Identifying the variables (issues) to be negotiated by the FP and SP. In the terminology of negotiations, issues are used to represent the negotiator factors that need to be set by both parties. In this study, issues and variables are used interchangeably to mean the same thing.

The two parties have to determine whether the share, "A" factors, and "B" factors need to be negotiated or just "A" and "B" factors.

2- Determining the best values of each variable

The FP and SP should list for each issue a set of best and possible resolutions. In this paper, larger variable values are usually for the advantage of the SP.

3- Determining the preferences and value tradeoffs

The FP and SP should ordinally rank their preferences for a different resolution level for each issue. Moreover, the two parties have to place the issues in rank order from the highest importance to the lowest importance. It is known in the literature and based on some equations that some variables have a larger effect on the NPV and IRR. The exact effect, however, depends on uncontrollable factors that are not easy to forecast such as future prices and inflation. Therefore, subjective numbers are used in this study based on the experience of the authors.

4- The additive scoring system

The FP and SP should score their issues preferences. It would rather go from the most important to least important. Additionally, it would rather go from the worst to the best choice.

5- Determining the reservation values (RV)

The FP and SP should decide what the lowest acceptable score (RV) for each bargaining issue is.

6- Finding efficient contracts

The Maxi-min and Nash solutions have been used in this paper to find the most efficient contracts. Firstly, the FP and SP are jointly going to negotiate contracts and select one contract for the nine variables (share, four "A" factors, and four "B" factors) using Full, Open, Truthful Exchange. Secondly, Excel Solver is used to find the results. Solver will try to find the best contract that would maximize the minimum of the FP and SP POP. Finally, Solver is used to find a fair contract based on the Nash solution by maximizing the product of excesses [2].

The following sets are needed:

I is the number of variables, in the case study it is 9
J_i is the number of options for the variable i
The following parameters are given:
y_{ij1} is the payoff (score) for the FP if option j is selected for the variable i
y_{ij2} is the payoff (score) for the FP if option j is selected for the variable i

The following variables are needed:

$$x_{ij} = \begin{cases} 1\ if\ option\ j\ is\ chosen\ for\ the\ variable\ i\ in\ the\ optimal\ solution \\ \quad\quad 0\ otherwise \end{cases}$$

The objective is to maximize the objective function

$$max\ Z = \left(\sum_{i=1}^{I} \sum_{j=1}^{J_i} y_{ij1} x_{ij} - vr_1 \right) \left(\sum_{i=1}^{I} \sum_{j=1}^{J_i} y_{ij2} x_{ij} - vr_2 \right) \tag{4}$$

Subject to:

$$S_{i1} = \max_{1 \le j \le J_i} y_{ij1} \qquad \forall\ i = 1..I \tag{5}$$

$$S_{i2} = \max_{1 \le j \le J_i} y_{ij2} \qquad \forall\ i = 1..I \tag{6}$$

$$\sum_{i=1}^{I} S_{i1} = 100 \tag{7}$$

$$\sum_{i=1}^{I} S_{i1} = 100 \tag{8}$$

$$x_{ij}\ \ binary$$

The objective function defined in Equation (4) is the product of the excesses for both parties, which are the surpluses for both of them. Equations (5) and (6) are to define the score or importance of each variable, which is the maximum possible payoff that the party can obtain if the best option can be obtained. Equations (7) and (8) are to force the summation of the payoffs for all the variables for each party to be 100. For Maxi-min, the equations will be different. The constraints from (5) to (8) are used in the second model. However, the objective function is changed. To further explain that, some variables are defined as follows:

M_{F1} and M_{F2} maximum feasible value for the first and second party, respectively.
E_1 and E_2 excess are the excess for the first and second party, respectively.
P_1 and P_2 are potential for the first and second party, respectively.

The new equations will be:

$$max\ Z_2 = min(POP_1, POP_2) \tag{9}$$

S.T.

$$E_1 = \left(\sum_{i=1}^{I} \sum_{j=1}^{J_i} y_{ij1} x_{ij} - vr_1 \right) \tag{10}$$

$$E_2 = \left(\sum_{i=1}^{I} \sum_{j=1}^{J_i} y_{ij2} x_{ij} - vr_2 \right) \tag{11}$$

$$P_1 = M_{F1} - vr_1 \tag{12}$$

$$P_2 = M_{F2} - vr_2 \tag{13}$$

$$POP_1 = \frac{E_1}{P_1} \tag{14}$$

$$POP_2 = \frac{E_2}{P_2} \tag{15}$$

The objective is to minimize POP for the two parties. As explained before, the POP value is the excess divided by potential, and both of them are defined in Equations (10)–(13). The second model is linear, and that means it is easier to solve.

5. Results and Analysis

In this section, the results obtained using the two used methods are compared with the initial results set by the two parties without using our methods. In the original setting and on the basis of EPSA IV, the SP's NPV for estimated reserves of 219 million barrels was estimated to be USD 148 million and the IRR was 15.65%. The FP's NPV was estimated to be USD 5386 million and the IRR was 409%. Later in this section, the comparison is made. The FP and SP have determined nine issues and options (share, four A factors, and four B factors) to be negotiated. The negotiation issues and options have been prepared by the FP and SP for the negotiation to improve the SP's economic indicators, see Table 5. The table contains four to five options for each one of the nine decision variables. The methodology presented in the paper tries to select the best options for each variable. The importance of the share is much larger than the other variables. The ranges shown in Table 5 are determined based on the experience of the decision makers in both parties.

Table 5. The nine issues and options for the NOC and IOC.

Negotiation Issues and Options	Possible Options	Values
Production Share	Option 1	10%
	Option 2	12%
	Option 3	15%
	Option 4	18%
	Option 5	20%
A Factor 1 When R = (1.0–1.5)	Option 1	0.90
	Option 2	0.92
	Option 3	0.94
	Option 4	0.96
	Option 5	0.98
A Factor 2 When R = (1.5–3.0)	Option 1	0.78
	Option 2	0.80
	Option 3	0.82
	Option 4	0.84
	Option 5	0.86
A Factor 3 When R = (3.0–4.0)	Option 1	0.55
	Option 2	0.60
	Option 3	0.65
	Option 4	0.70
	Option 5	0.75
A Factor 4 When R = (>4.0)	Option 1	0.35
	Option 2	0.40
	Option 3	0.45
	Option 4	0.50
	Option 5	0.53
B Factor 1 When Production (bbl/day) (1–20,000)	Option 1	0.85
	Option 2	0.90
	Option 3	0.95
	Option 4	0.98
B Factor 2 When Production (bbl/day) (20,001–30,000)	Option 1	0.70
	Option 2	0.75
	Option 3	0.80
	Option 4	0.85
B Factor 3 When Production (bbl/day) (30,001–60,000)	Option 1	0.55
	Option 2	0.60
	Option 3	0.65
	Option 4	0.70
B Factor 4 When Production (bbl/day) (60,001–85,000)	Option 1	0.40
	Option 2	0.45
	Option 3	0.50
	Option 4	0.53

5.1. Effect of the Production Share, A factors, and B factors of EPSA IV on the SP's NPV and IRR

Minimizing the production share, A factors, and B factors in the EPSA IV adversely affect the NPV and IRR of the SP. This effect may appear clearly in oil projects that require large capital for such development facilities by using secondary and tertiary recovery. The EPSA IV determines the production share, which is supposed to recover expenses of the SP and give it a reasonable percentage of profits. By limiting the production share to a small value, the risk to the SP to recover their capital is increased when the payback period is increased. So, "A" factors reduce the profit of the foreign investor in case of stopping the investment or investing in limited range.

The positive impact of the value of investment on the profit of the SP only appears in the period of investment, which is the first period of the project. So, the SP will obtain the highest return from the profit oil when the "A" factors are kept at higher values. "B" factors are directly affected by the production rate, where a higher production rate will decrease the value of "B" factors and thus decrease the value of the oil profit and ultimately negatively impact the SP's produced share. The decline in the value of B factors due to increasing production gives a negative indicator to the SP and makes it not motivated to increase the production rate. The SP must negotiate the "B" factors that are dominated by the plateau of the production profile. On the other hand, the FP wants to minimize the benefit of the SP by minimizing the production share, "A" factors, and "B" factors [34]. The generated options, score, negotiation score for each issue, and the reservation value of the interest deal of the FP and the SP are shown in Table 6.

Table 6. Ranking issues by importance by the FP and SP.

Pr. Ranking	Issue	Pos. Resolution	FP		SP	
			Determined Value	Score	Determined Value	Score
1	Production Share, %	Option 1	60	60	20	
		Option 2	50		30	
		Option 3	40		40	
		Option 4	30		55	
		Option 5	20		60	60
2	B Factor 3	Option 1	10	10	6	
		Option 2	8		8	
		Option 3	6		10	
		Option 4	4		12	12
3	B Factor 1	Option 1	9	9	4	
		Option 2	8		6	
		Option 3	6		8	
		Option 4	4		10	10
4	A Factor 1	Option 1	6	6	2	
		Option 2	5		3	
		Option 3	4		4	
		Option 4	3		5	
		Option 5	2		6	6
5	A Factor 2	Option 1	5	5	1	
		Option 2	4		2	
		Option 3	3		3	
		Option 4	2		4	
		Option 5	1		5	5
6	A Factor 3	Option 1	5	5	1	
		Option 2	4		2	
		Option 3	3		3	
		Option 4	2		4	
		Option 5	1		5	5
7	B Factor 2	Option 1	3	3	0	
		Option 2	2.5		0	
		Option 3	2		1	
		Option 4	1		2	2
8	A Factor 4	Option 1	1	1	0	
		Option 2	0.5		0	
		Option 3	0		0	
		Option 4	0		0	
		Option 5	0		0	0

Table 6. *Cont.*

Pr. Ranking	Issue	Pos. Resolution	FP		SP	
			Determined Value	Score	Determined Value	Score
9	B Factor 4	Option 1	1	1	0	
		Option 2	0.5		0	
		Option 3	0		0	
		Option 4	0		0	0
			sum	100	sum	100

5.2. Nash Solution

The RV value for both parties must be determined at first. In this study, we assume it is 35 for the FP and 65 for the SP. The negotiation score output of FP and SP from the Nash solution is summarized in Table 7. This result was obtained with the assistance of Solver. Excel Solver is a unique mathematical program that operates within Excel. In Figure 2, the Solver dialogue box maximizes the objective of the product of the FP and SP excess. The product of excess is increased from 296, with the original settings, to 506. The formulation and solution of the problem that maximizes the sum of product of the FP and SP are given in Tables 7 and 8. The negotiation based on the Nash solution yields a solution for the FP and SP with the following production share, A factor, and B factor: production share at 15%, B3 at 0.65, B1 at 0.98, A1 at 0.98, A2 at 0.84, A3 at 0.75, B2 at 0.85, A4 at 0.35, and B4 at 0.40, see Table 8.

Table 7. Nash solution of the negotiation score of FP and SP from the Solver software.

Issue	Possible Options	Optimal Option	FP			SP		
			D. Value	Score	Neg. Score	D. Value	Score	Neg. Score
Production Share, %	Option 1	0	60	60		30		
	Option 2	0	50			40		
	Option 3	1	40		40	50		50
	Option 4	0	30			55		
	Option 5	0	20			60	60	
B Factor 3	Option 1	0	10	10		6		
	Option 2	0	8			8		
	Option 3	1	6		6	10		10
	Option 4	0	4			12	12	
B Factor 1	Option 1	0	9	9		4		
	Option 2	0	8			6		
	Option 3	0	6			8		
	Option 4	1	4		4	10	10	10
A Factor 1	Option 1	0	6	6		2		
	Option 2	0	5			3		
	Option 3	0	4			4		
	Option 4	0	3			5		
	Option 5	1	2		2	6	6	6
A Factor 2	Option 1	0	5	5		1		
	Option 2	0	4			2		
	Option 3	0	3			3		
	Option 4	1	2		2	4		4
	Option 5	0	1			5	5	
A Factor 3	Option 1	0	5	5		1		
	Option 2	0	4			2		
	Option 3	0	3			3		
	Option 4	0	2			4		
	Option 5	1	1		1	5	5	5

Table 7. *Cont.*

Issue	Possible Options	Optimal Option	FP			SP		
			D. Value	**Score**	**Neg. Score**	**D. Value**	**Score**	**Neg. Score**
B Factor 2	Option 1	0	3	3		0		
	Option 2	0	2.5			0		
	Option 3	0	2			1		
	Option 4	1	1		1	2	2	2
A Factor 4	Option 1	1	1	1	1	0	0	0
	Option 2	0	0.5			0		
	Option 3	0	0			0		
	Option 4	0	0			0		
	Option 5	0	0			0		
B Factor 4	Option 1	1	1	1	1	0	0	0
	Option 2	0	0.5			0		
	Option 3	0	0			0		
	Option 4	0	0			0		
			Total Negotiation Value		58	Total Negotiation Value		87

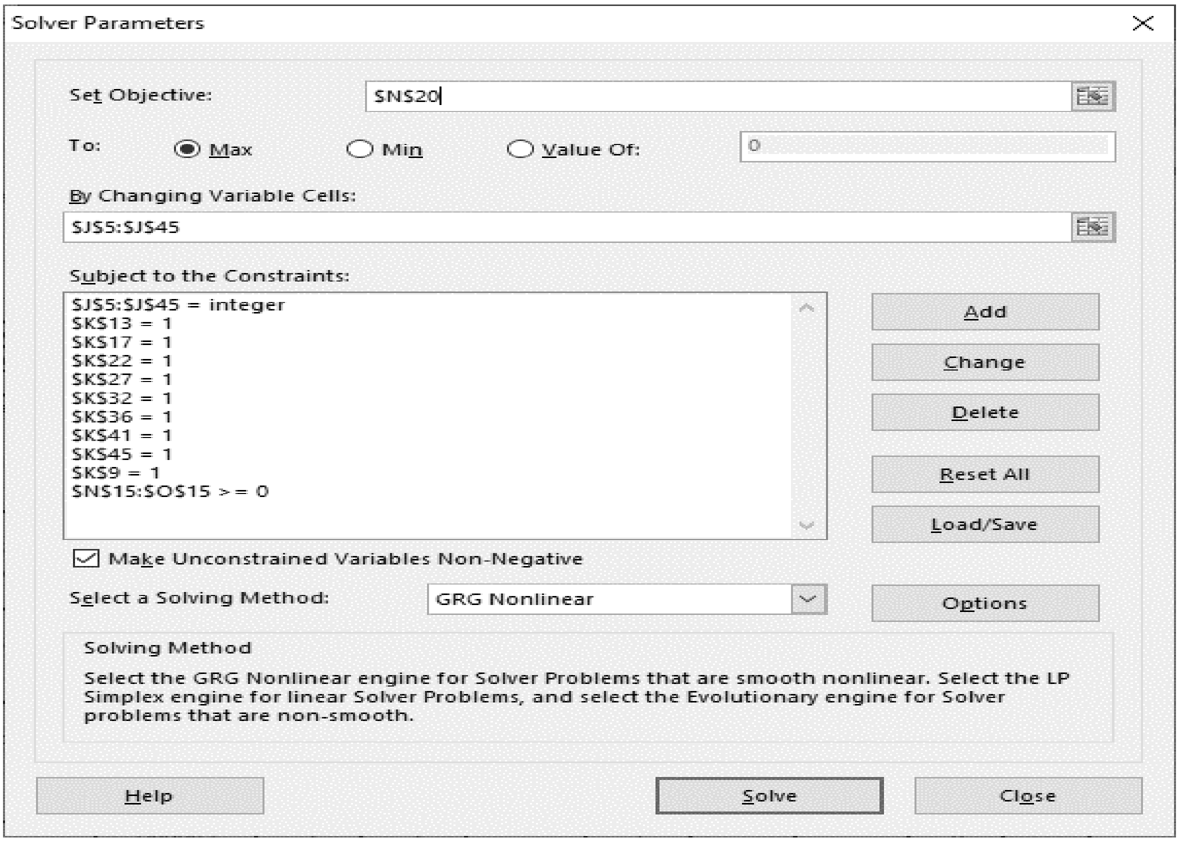


Figure 2. Solver objective and constraints of Nash solution model.

Therefore, we can say that x_{13}, x_{23}, x_{34}, x_{45}, x_{54}, x_{65}, x_{74}, x_{81}, and x_{91} are equal to one, and others are zeros.

Table 8. Solver output of Nash solution of the FP and SP.

Variable	NOC	IOC's
Negotiation Value (1)	58	87
RV (2)	35	65
Excess (3) = (1) − (2)	23	22
Max Feasible (4)	85	100
Potential (5) = (4) − (2)	50	35
POP (6) = (3)/(5)	0.460	0.629
Product (7) = (3) of NOC × (3) of IOC	506	
MinPOP (8) = min ((6) of NOC, (6) of IOC))	0.460	

		Optimal options of the FP and SP								
Solution	Max.	Issue 1	Issue 2	Issue 3	Issue 4	Issue 5	Issue 6	Issue 7	Issue 8	Issue 9
Nash	506	Option 3	Option 3	Option 4	Option 5	option4	option5	option4	option1	Option 1
Variable		Share	B3	B1	A1	A2	A3	B2	A4	B4
Value		15%	0.65	0.98	0.98	0.84	0.75	0.85	0.35	0.40

5.3. Maxi-Min Solution

In the Maxi-min solution, the value of maximizing the minimum POP is improved. The minimum POP is increased from 0.229 to 0.514. This output has been determined with the help of Excel Solver. The formulation and solution to maximize the minimum POP of the negotiation template of the FP and SP are given in Tables 9 and 10.

Table 9. Maxi-min solution of the negotiation score of FP and SP using Solver software.

Issue	Possible Options	Optimal Option	FP			SP		
			D. Value	Score	Neg. Score	D. Value	Score	Neg. Score
Production Share, %	Option 1	0	60	60		30		
	Option 2	0	50			40		
	Option 3	1	40		40	50		50
	Option 4	0	30			55		
	Option 5	0	20			60	60	
B Factor 3	Option 1	1	10	10	10	6		6
	Option 2	0	8			8		
	Option 3	0	6			10		
	Option 4	0	4			12	12	
B Factor 1	Option 1	0	9	9		4		
	Option 2	0	8			6		
	Option 3	0	6			8		
	Option 4	1	4		4	10	10	10
A Factor 1	Option 1	0	6	6		2		
	Option 2	0	5			3		
	Option 3	0	4			4		
	Option 4	1	3		3	5		5
	Option 5	0	2			6	6	
A Factor 2	Option 1	0	5	5		1		
	Option 2	0	4			2		
	Option 3	0	3			3		
	Option 4	0	2			4		
	Option 5	1	1		1	5	5	5
A Factor 3	Option 1	0	5	5		1		
	Option 2	0	4			2		
	Option 3	0	3			3		
	Option 4	0	2			4		
	Option 5	1	1		1	5	5	5

Table 9. *Cont.*

Issue	Possible Options	Optimal Option	FP			SP		
			D. Value	**Score**	**Neg. Score**	**D. Value**	**Score**	**Neg. Score**
B Factor 2	Option 1	0	3	3		0		
	Option 2	0	2.5			0		
	Option 3	0	2			1		
	Option 4	1	1		1	2	2	2
A Factor 4	Option 1	1	1	1	1	0	0	0
	Option 2	0	0.5			0		
	Option 3	0	0			0		
	Option 4	0	0			0		
	Option 5	0	0			0		
B Factor 4	Option 1	1	1	1	1	0	0	0
	Option 2	0	0.5			0		
	Option 3	0	0			0		
	Option 4	0	0			0		
			Total Negotiation Value		62	Total Negotiation Value		83

Table 10. Solver output of Maxi-min solution of the FP and SP.

Variable	**NOC**	**IOC's**
Negotiation Value (1)	62	83
RV (2)	35	65
Excess (3) = (1) − (2)	27	18
Max Feasible (4)	85	100
Potential (5) = (4) − (2)	50	35
POP (6) = (3)/(5)	0.540	0.514
Product (7) = (3) of NOC × (3) of IOC	486	
MinPOP (8) = min ((6) of NOC, (6) of IOC))	0.514	

		Optimal Options of the FP and SP								
Solution	Max	Issue 1	Issue 2	Issue 3	Issue 4	Issue 5	Issue 6	Issue 7	Issue 8	Issue 9
Maxi-min	0.514	Option 3	Option 1	Option 4	Option 4	Option5	option5	option4	option1	Option 1
Variable		Share	B3	B1	A1	A2	A3	B2	A4	B4
Value		15%	0.55	0.98	0.96	0.86	0.75	0.85	0.35	0.40

The negotiation based on the Mix-min solution yields a solution for the FP and SP with the following production share, A factor, and B factor: production share at 15%, B3 at 0.55, B1 at 0.98, A1 at 0.96, A2 at 0.86, A3 at 0.75, B2 at 0.85, A4 at 0.35, and B4 at 0.40, see Table 10.

5.4. Summary of the Effect of the Three Contracts on the Economic Evaluation Model of the AA oil Field

The three outputs of the three agreements, the original EPSA IV, optimized by the Nash solution, and optimized by the Maxi-min solution, are shown in Table 11.

The economic indicators, NPV, and IRR of FP and SP of the three contracts are shown in Table 12 and Figure 3. For the SP, the optimization by using the Nash solution has shown the best improvement. The SP's NPV and IRR are increased from USD 148 million and 15.63% to USD 222 million and 17.94, respectively.

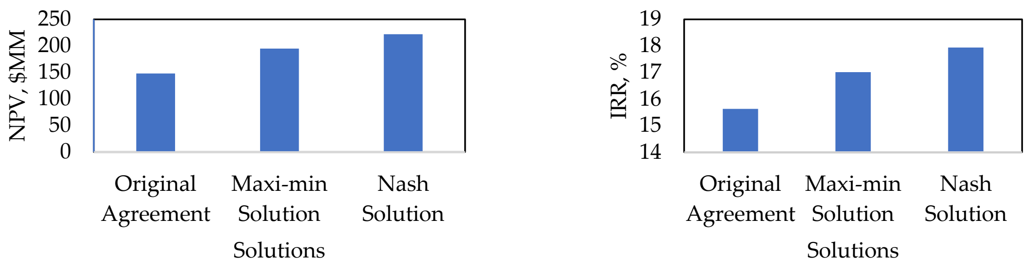
Table 11. Summary of the issues and options of the three contracts of the FP and SP.

Solution	OF *	Issue 1	Issue 2	Issue 3	Issue 4	Issue 5	Issue 6	Issue 7	Issue 8	Issue 9
Variable		Share	B3	B1	A1	A2	A3	B2	A4	B4
Original Agreement		Option 3	Option 2	Option 3	Option 1	Option2	Option2	Option3	Option2	Option 1
Value		15%	0.6	0.95	0.90	0.80	0.60	0.80	0.40	0.40
Nash	506	Option 3	Option 3	Option 4	Option 5	Option 4	Option 5	Option 4	Option1	Option 1
Value		15%	0.65	0.98	0.98	0.84	0.75	0.85	0.35	0.40
Maxi-min	0.514	Option 3	Option 1	Option 4	Option 4	Option5	Option 5	Option 4	Option1	Option 1
Value		15%	0.55	0.98	0.96	0.86	0.75	0.85	0.35	0.40

* Objective Function value.

Table 12. The effect of the original agreement, Maxi-min, and Nash solutions on the economic indicators of FP and SP.

	FP		SP	
Solutions	**NPV, USD MM**	**IRR, %**	**NPV, USD MM**	**IRR, %**
Original Agreement	5386	409	148	15.63
Nash Solution	5312	406	222	17.94
Maxi-min Solution	5339	408	195	17.01



(**a**) NPV, USD MM (**b**) IRR, %

Figure 3. The SP's NPVs and IRRs of the original agreement and the optimization solutions of the Maxi-min and Nash solutions.

The above calculations show the impact of applying the proposed two models on the performance of both parties. The RV for both parties was respected, and better scores were found. Eventually, the effect on NPV and IRR was found to be promising. The effect of different levels of the nine decision variables was found in the literature. Different variables were found to have different weights (Balhasan, et al., 2020). However, determining the best options for the levels based on these weights is new in this study. Decision makers in both parties can utilize the tool used in this study to enhance their agreement terms based on a win-win strategy. Using a common tool can reduce the needed efforts in the negotiation process and reduce the conflict between both parties. The tool used can be easily understood and applied by practitioners. The previous results, especially Figure 3, show how useful it is to use the proposed tool.

6. Conclusions

The EPSA agreement is a complicated method of equity split used in the oil industry. Usually, a production-based sliding scale and R-factor system is used. The SP's NPV and IRR from the original EPSA agreement conditions were USD 148 million and 15.63%, respectively. At the beginning, the IRR was too low to satisfy the SP. Therefore, better configurations were needed. Two approaches were used to find the best negotiation agreement. The Maxi-min solution maximizes the minimum of the two parties' proportion of the POP. The Nash solution maximizes the product of excesses. The two models have shown a significant improvement in the SP's NPV and IRR. The Nash solution has shown the best improvement in favor of the SP. The SP's NPV and IRR were increased from USD 148 million and 15.63% to USD 222 million and 17.94, respectively. The Maxi-min solution also showed an improvement, but less than the Nash solution. The SP's NPV and IRR were increased from USD 148 million and 15.63% to USD 195 million and 17.01, respectively. Such gains for the SP were acceptable by the FP. The two parties achieved agreement optimization.

There are some limitations in this study. For example, the study presents the results for a certain case study. More case studies, especially in the region, can provide more insights. Moreover, Excel Solver does not guarantee an optimal solution always. Other methods for optimization, such as the genetic algorithm, can be investigated in the future. Moreover, the EPSA agreements can contain other negotiation issues that can be investigated in further research.

Author Contributions: Conceptualization S.B. and S.S.; methodology, S.B. and S.S.; software, S.B. and M.A.; validation, M.A., S.B. and M.I.T.; formal analysis, M.A. and S.B.; investigation, S.B.; resources, B.S., S.S., M.I.T. and S.B.; data curation, S.B.; writing—original draft preparation, S.B. and M.A.; writing—review and editing, S.B., S.S., M.I.T. and M.A.; visualization, B.S., W.S. and S.S.; supervision S.S. and S.B.; project administration, B.S., W.S. and S.B.; funding acquisition, B.S. and W.S. All authors have read and agreed to the published version of the manuscript.

Funding: This study received funding from King Saud University, Saudi Arabia through researchers supporting project number (RSP-2021/145). Additionally, the APCs were funded by King Saud University, Saudi Arabia through researchers supporting project number (RSP-2021/145).

Data Availability Statement: Not applicable.

Acknowledgments: The authors would like to thank King Saud University, Riyadh, Saudi Arabia, with researchers supporting project number RSP-2021/145. Furthermore, the authors would like to thank the Libyan National Corporation for providing the necessary data for this paper. Thanks in particular to A. Omar, A. Ali, and O. Mohamed for their assistance and assistance throughout the course of this work.

Conflicts of Interest: The authors declare no conflict of interest.

Nomenclature

FP	First Party
SP	Second Party
NPV	Net Present Value
IRR	Internal Rate of Return
EPSA	Exploration and Production Sharing Agreement
GDP	Gross Domestic Product
POP	Proportional of the Potential
RV	The Reservation Value
CAPEX	Capital Expenditures
OPEX	Operating Costs
LHP	liquefied hydrocarbon by products
NCF	Net Cash Flow
EOR	enhanced oil recovery
NOC	National Oil Corporation
IOC	International Oil Company

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