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Modeling of Production Strategies from Common Offshore Gas Field with Game Theory Approach

Seyed Pendar Toufighi *, *Mohammad Reza Mehregan* *and Ahmad Jafarnejad*

Abstract

Common oil and gas fields are among the most valuable income and national wealth sources, so production delays cause irreparable damage to the national economy. The existing functions of revenues and production costs of gas fields have been identified and extracted from the current literature to optimize the production strategy. Cost func-tions include exploration, development, operation, production facility and wellhead, facility depreciation costs, and revenue functions include demand and income functions. After designing the model using mathematical optimiza-tion, the decision variables' values have been calculated as optimal production, selling price, and profit for each play-er. For this purpose, two strategies of cooperation and non-cooperation were considered for each player. Solving the designed games showed that the best strategy and Nash equilibrium for the research case study is the strategy of co-operation. Also, according to the results of the equilibrium of designed games based on cooperation strategy, it is suggested that one of the main approaches of research case study in common fields is the process of multilateral and cooperative development.

Keywords: common fields, optimization, game theory, offshore, Arash gas field

2020 Mathematics Subject Classification: 91A10, 91A05, 91B08.

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1. Introduction

The legal production pattern from common hydrocarbon reservoirs is essential due to the simultaneous ownership of such reservoirs by two or more independent countries. This model is influenced by the technical considerations necessary for the operation of common hydrocarbon reservoirs and the legal considerations, whose legal considerations are influenced by the reservoir countries' political will to implement the technical consid-erations [17]. The most basic principle that should be considered in the production of common fields is reservoir conservation management, the implementation of which in common reservoirs requires the efforts and will of all reservoir governments, which must implement it in coordination with each other [18].

Given the importance of energy resources, especially oil and gas, and the global de-mand for oil and gas resources, and the potential that the Persian Gulf has in this regard, it can be an opportunity for countries to extract these resources in principle and cooperate with other Gulf countries and other oil and gas producers to improve its position region-ally and globally [7]. The production of common oil and gas fields onshore and offshore is essential for countries [13]. The neighbors' relative production of common fields should be carefully considered. This production from common oil and gas fields by neighboring countries can be studied using the game theory approach [6], [10]. Each player is trying to increase their interests and make the most beneficial decision. In situations where each player's behavior affects another situation and vice versa, one can look for the equilibrium behavior they choose, called equilibrium [23]. In this research, we seek to answer the fol-lowing questions:

RQ1. What is the structure of the mathematical model of production of offshore common gas fields?

RQ2. What are the values of the decision variables of each player in the optimal state?

RQ3. What games can be designed for each player, and what is the equilibrium of each game?

In the second section, a review of the theoretical foundations and description of the research background explains the research gap. After explaining the methodology, the third-party fully describes the mathematical model. After collecting the data, in the fourth part, the mathematical model is solved, the optimal values of the decision are calculated, and the desired games are designed. Finally, the fifth part describes the research findings, and suggestions based on the findings are presented.

2. Literature Review

According to reports, some country such as Qatar and Russia is one of the largest holders of gas in-place reserves in the world; out of a total of about 34 trillion cubic meters of reserves in place, approximately 14 trillion cubic meters are located in the South Pars common gas field and 20 trillion cubic feet in the Arash common gas field [26]. Regardless of the optimal production method, each party intends to make the maximum possible production from its position; therefore, this is an important issue for a country with many common fields. Each day, countries potential benefits are lost in these common fields and are extracted through neighbors, doubling the need for special attention. In contrast to this non-optimal competitive method, other methods have been used in some countries [9] based on interaction and cooperation. In a way that gradually increases, the two sides gain more benefits [2].

Given that there is no specific legal agreement or binding international treaties for producing these common fields between the interested parties, any country that uses shared resources more benefits the most. From the perspective of reservoir engineering, the rapid withdrawal of each party can have a great impact on the behavior of the reservoir and pave the way for the production and greater benefit of that country from the common reservoir; meanwhile, the neighboring country will suffer from a lack of timely and rapid extraction. Therefore, in common field development operations, the issue of speed in de-velopment and extracting will be of considerable importance [24].

Esmaeili et al. (2015) used the Game Theory Approach to Select sustainable strategies for common oil and gas resources case study with Iraq and Qatar. A game with incom-plete 2 * 2 information was used. Prison dilemma, chicken, and hunter games have been used to optimize the production strategy. The game was predicted as incomplete because of the unavailability of players' strategies. According to the different scenarios, players' best strategy was cooperation [9]. Havas Wilma (2015) has conducted self-research on the subject of an erosive war on the North Pole coast: oil spill technology and risky invest-ments in oil and gas extraction. The model developed in that paper examines Norway and Russia's oil and gas extraction strategies, which seek to enter the Arctic coast. These strat-egies are analyzed using an erosive war game in which both countries play a mixed strategy. Oil spills are likely to reduce countries 'willingness to enter the North Pole, while the cyclical decline is likely as a result of expected investment to increase countries' will-ingness to enter the North Pole because the sooner extraction begins, the greater the ex-pected return on investment will be [16]. In their article, Salimian and Shahbazi (2017) examined case studies strategies in using common oil and gas fields with a game theory approach. Using two approaches of the cooperative and non-cooperative game and static game with complete information and simplifying assumptions in the number of reserves and the same costs and strategies, the authors identified the best strategy for case study and other countries in using common oil fields [29]. Toufighi et al. (2020) optimized pro-duction in the forouzan common oil field based on game theory. In this research, revenue, cost, and profit functions were developed for each player's desired field and game theory approach [34]. Table 1 summarizes the most important surveys in terms of game ap-proach, a game mode, and validation of the proposed model and research achievements.

Table 1: Summary of optimization research in the field of oil and gas fields.

No.	Reference	Used Tools	Game Type	Validity	Goal/Results
1	[22]	GT/Nash Eq.	Static/Perfect/ Cooperative	Numerical Example	Game analysis and China-Russia oil project cooperation measures
2	[36]	Optimization with Rough Numbers	Non-Game	Numerical Example	Resolving environmental disputes in offshore oil and gas operations
3	[8]	GT/Nash Eq.	Static/Perfect/ Cooperative	Numerical Example	Investigating Global Energy Market Cooperation for South American Energy Producers
4	[37]	GT/Nash Eq./ Coalition G.	Non-Cooperative /Complete Information /Non -Rep.	Numerical Example	Determining the optimal strategic reserves of the oil company in each country
5	[31]	GT/Nash Eq.	Static/ Cooperative /Prison Dilemma /Nash Eq.	Numerical Example	Review of oil and gas production contracts
6	[5]	GT/Bargaining Game/Shapely Value	Static/Perfect/ Cooperative	Model Sensitivity Analysis	Assessing the bargaining power of players in the Eurasian gas trade
7	[27]	Mathematical Modeling	Non-Game	Simulation	Test design of an intelligent wireless sensor network for early detection of leaks in oil pipelines
8	[35]	GT/Nash Eq./ Stackelberg Eq.	Non-Cooperative	Numerical Example	Defense against cyber-physical attacks in oil pipeline systems
9	[1]	GT/Nash Eq./ Shapley Value	Non-Repeatable / Static	Numerical Example	Reduction the cost of drilling oil wells
10	[39]	Optimization/ Random Programming	Genetic Algorithm	Numerical Example	Design of optimal biofuel sup-ply chain under uncertainty
11	[40]	GT/Nash Eq.	Evolutionary game /Non-Rep./Nash Eq.	Model Sensitivity Analysis	Pollution treatment of oil and gas companies' activities
12	[41]	GT/Nash Eq.	Evolutionary symmetric game	Numerical Example	Environmental Sovereignty in International Collaborations for an Oil Leak Article
13	[20]	GT/Return Method	Dynamic/ Complete Information	Numerical Example	The optimal economic model between oil producers
14	[21]	GT/Nash Eq./ Stackelberg Eq.	Dynamic/ Perfect/ Non-Repeatable	Model Sensitivity Analysis	Review of regenerative strate-gies to prevent oil production in the Arctic

No.	Reference	Used Tools	Game Type	Validity	Goal/Results
15	[15]	GT/Nash Eq./ Shapley Value	DStatic/ Non-Rep.	Numerical Example	Contractual investment in global gas trade
16	[25]	GT/ Mathematical Optimization	Stackelberg Eq./ Nash Eq./MILP	Numerical Example	Investigating the issue of environmental pollution in the oil supply chain
17	[30]	GT/Nash Eq./ Math. Optimization	Static/Mixed Eq.	Numerical Example	Mathematical simulation of pipeline reliability
18	[32]	GT/Nash Eq.	Static/ Zero-Sum Game	Numerical Example	Resolve contractual disputes between owners and contractors in a refinery construction project
19	[33]	GT/ Stackelberg Eq./Math. Optimization	Static/MIP	Numerical Example	Optimization of biogas value chains
20	[4]	GT/ Stackelberg	Nash Eq./ Stackelberg Eq.	Numerical Example	Distributed energy management in smart grids
21	[28]	GT/Stackelberg	Stackelberg Eq./ Non-Repeatable	Numerical Example	Power grid optimization in industrial parks
22	[38]	GT/Nash Eq./ Cooperative Agreement	Static/Perfect/ Nash	Numerical Example	PPrevent oil spills and control modes in the area of the three George reservoirs

Table 2 presents the research results conducted with a modeling approach in common fields.

Table 2: Summary of research in the field of modeling in oil and gas fields.

No.	Ref.	Research's Goal	Research Tools: Analysis Tool	Research Tools: Modeling Tool	Case Study/Validity
1	[9]	Choosing sustainable strategies for common oil and gas resources with Iraq and Qatar	GT	Prison Dilemma, Chicken & Hunter	Investigating oil and gas conflicts with Iraq and Qatar and comparing the two countries' strategies.
2	[16]	Review of oil and gas extraction strategies of Norway and Russia	GT	Nash Mixed Equilibrium	Common oil and gas fields of Russia and Norway
3	[29]	Investigating strategies in using common oil and gas fields	GT	Static - Complete information	Hypothetical data
4	[3]	Investigating the cooperation between countries in extracting South Pars reserves	GT	Prison Dilemma	South Pars Common Field (Qatar: North Dome)
5	[34]	Optimization of Production in Forouzan Common Oil Filed based on Game Theory	GT	Mathematical Modeling	Forouzan Common offshore oil field

In previous literature, simple models with incomplete information were solved based on simple games such as prison dilemma. The passage of time plays a key role in the per-ception of each player. Therefore, parameters such as extract time, managers' deci-sion-making, political conditions, and the possibility of cooperation or non-cooperation of players make the relevant model more realistic. Therefore, in addition to considering the uncertainties in gas tanks and the fuzzy behavior of fluids over time during extracting, this study will study how to decide whether to cooperate or not. In other words, various methods have been used to model the behavior of countries in oil. Given that the stable output that game theory predicts is not necessarily Pareto optimal, and knowing that the game payoff will be a set of players' decisions, each player will seek to optimize their prof-it function. As a result, game theory provides a more realistic simulation of stakeholder profit-based behavior. This self-optimized behavior of players and stakeholders will usually lead to non-collaborative behavior, even when cooperative behavior is more beneficial to all players. Therefore, the game theory tool was selected to achieve the research goal in this research.

3. Research Methodology

Research methods can be divided into surveys, field studies, and experiments [11]. Real data of gas fields have been used in this research, so the research method is a survey. Based on the type of data collected, this research is quantitative [12]. The present study is legal from a macro perspective, and the researcher is not fully involved. In terms of pur-pose and result, it is fundamental that specialized texts and research backgrounds were used for modeling. After modeling the different modes, a sensitivity analysis was per-formed on the model, and the model was examined; in this regard, it led to the develop-ment of knowledge related to exploitation in the field of common gas fields. Due to the development of this research and the fact that it is studied at the level of common gas fields and seeks to model the research conditions and its assumptions, it can apply to all countries with common gas fields. The implementation steps of the research are described in Figure 1.

The case study of this research is the Arash gas field. Arash gas field is one of the common gas fields with Kuwait and Saudi Arabia, located in the north of the Persian Gulf in Hormozgan province. Arash gas field was discovered in 1967. Arash field gas reserves are estimated at 20 trillion cubic feet, and oil reserves in place are estimated at 310 million barrels [26]. Arash gas field is called the Al-Dora field by two Arab countries. The Japanese oil company AOC discovered the Arash gas field in the north of the Persian Gulf in 1967, most of which was paid for by the government. But now, Kuwait and Saudi Arabia intend to exploit this gas field in the north of the Persian Gulf with all their might and as soon as possible.

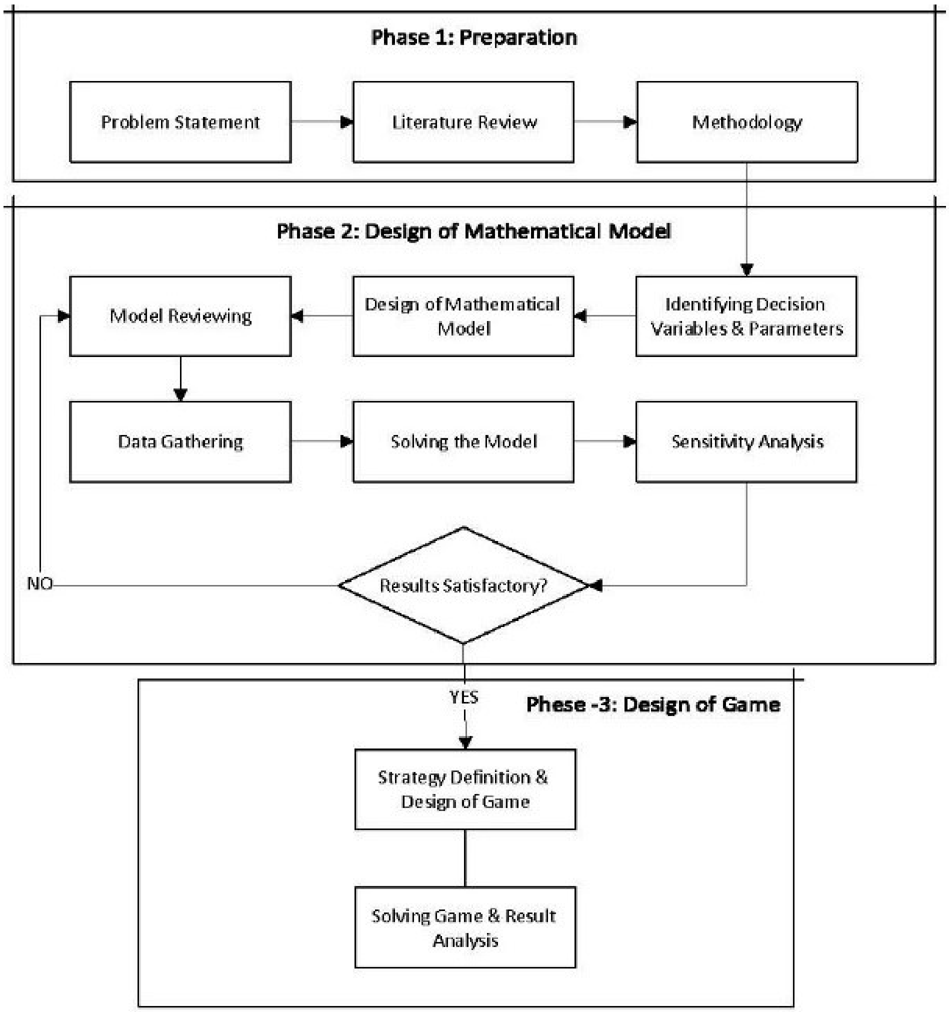

Figure 1: Research steps.

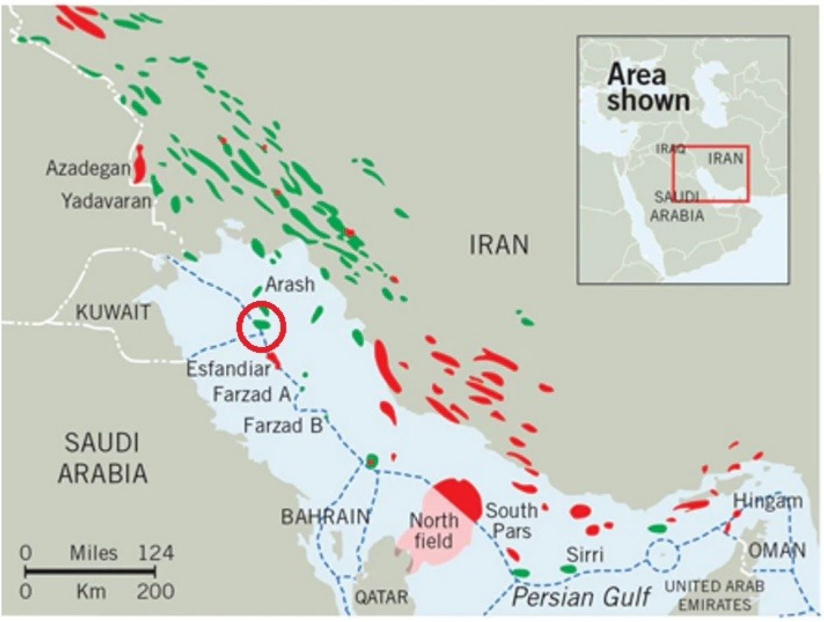

Figure 2: Arash gas field position.

3.1. Mathematical Model

In this section, mathematical models related to gas fields were described. Table 3 describes the variables and parameters used.

The costs of natural gas exploration from reservoirs in a certain period are as follows and are a function of two factors: the volume of extraction of resources in the desired period (q_t) and the remaining volume of the reservoir in the desired period (R_t). In addition to these two variables, the variables of time (t) and month of production (pm) as economic effects and the effects of reservoir age (well) affect the cost function [25].

$$\ln T_{CE} = \alpha + \beta_q \ln q_t + \beta_R \ln R_t + \beta_t \ln t + \beta_{pm} \ln pm + e_{ij},$$
$$TC_E = e^{\alpha+\beta_q \ln q_t+\beta_R \ln R_t+\beta_t \ln t+\beta_{pm} \ln pm+e_{ij}}.$$

Development costs are divided into two parts: 1- the cost of infrastructure and maintenance of facilities and 2- the wells' cost. These costs were measured and reported by the Energy Information Administration in 1996 for different fields of different sizes and different geological roles [42].

$$TC_D = \mu_1 \cdot G_t + \mu_2 \cdot N_t.$$

Operating costs include the costs of operating the field. Considering the details of the necessary costs at this stage and based on previous studies, it is possible

Table 3: The variables and parameters used.

Description	Abbreviation	Dimension	Extracted
Natural Gas Price	P_{tg}	Dollar per Cubic Meter	EIA
Produced Gas Rate	q_t	Cubic Meter	NIOC
Residual Gas	R_t	Cubic Meter	NIOC
Month of Productio	pm	Month	Standard
Gas Production Period	t	Day	Standard
Demand Function Intercept	α	-	Research Finding
Regression Parameter	β_q	-	EIA
Regression Parameter	β_R	-	EIA
Regression Parameter	β_t	-	EIA
Regression Parameter	β_{pm}	-	EIA
Component of Disruption	e_{ij}	-	Research Finding
Cost of Dev. & Main. Of Facilities	μ_1	Dollar per Day	EIA
Cost of Gas Well Development	μ_2	Dollar per Day	EIA
No of Gas Well	N_t	Quantity	NIOC
Daily Gas Production	G_t	Cubic Meter Per Day	NIOC
Production Variable Cost	TC_{VP}	Dollar per Day	Research Finding
Cost of Repair and Depreciation	TC_{PFM}	Dollar per Day	Research Finding
Gas Demand Function	Z_t	Million Barrel Per day	Research Finding
Actual Revenue	I_t	Dollar per Day	Research Finding
Regression Parameter	α_0	-	Research Finding
Regression Parameter	α_1	-	Research Finding
Regression Parameter	α_2	-	Research Finding
Regression Parameter	α_3	-	Research Finding
Production Cost Update Index	$d(t)$	-	Research Finding
Depreciation Cost Update Index	$d'(t)$	-	Research Finding
Exploration Cost Function	TC_E	Dollar per Day	Research Finding
Development Cost Function	TC_D	Dollar per Day	Research Finding
Production Cost Function	TC_P	Dollar per Day	Research Finding
Total Cost Function	TC	Dollar per Day	Research Finding
Players Pay-off	πi	Dollar per Day	Research Finding

to divide all the costs of field operation operations into two, except the variable cost of operation and the cost of repairs of production facilities and wells. The variable cost of operation refers to the costs of manpower and other running costs of the operation. Numerous studies have been performed to calculate this cost. However, one of the most conventional and fundamental studies on determining the cost of the production function of hydrocarbon fields in the Persian Gulf region was conducted by the US Energy Information Administration (EIA) in 1996. Since this function is estimated based on the values of 1996, to use this function in the present study, its coefficients must be updated according to the time domain of the research; Of course, to estimate the depreciation costs of the exploitation facilities of the fields, like the variable cost function of the exploitation, the mentioned function must be updated concerning the period of the exploitation of the fields. Finally, the cost of these fields' operation during their lifetime can be estimated from a set of two functions: variable cost of operation and cost of repairs of production facilities and wells.

$$TC_P = (1 + d(t))(0.7714 \times (G_t)^{-0.2423}) + (1 + d'(t))(0.44 \times G_t).$$

The total cost function for a gas field is as follows:

$$TC = TC_E + TC_P,$$

$$\begin{aligned} TC = {} & e^{\alpha+\beta_q \ln q_t+\beta_R \ln R_t+\beta_t \ln t+\beta_{pm} \ln pm+e_{ij}} + \mu_1 G_t + \mu_2 N_t \\ & + (1 + d(t))(0.7714 \times (G_t)^{-0.2423}) + (1 + d'(t))(0.44 \times G_t). \end{aligned}$$

According to economic concepts, it is a function of natural gas demand as follows [19]

$$Z_t = f(I_t, P_{tg}).$$

In this regard, (Z_t) represents the demand for natural gas, (I_t) represents the real income, (P_{tg}) represents the price of natural gas. Accordingly, the general function of natural gas demand will be as follows:

$$Z_t = \alpha_0(\exp(\alpha_1 t)) I_t^{\alpha_2} P_{tg}^{\alpha_3}.$$

And to calculate the profit of each player, we deduct the income from the expenses, which is a function of the total outcome in the form of Equation (1):

$$\pi i = TR - TC, \tag{1}$$

$$\begin{aligned} \pi_i = {} & [G_t \times \alpha_0(\exp(\alpha_1 t)) I_t^{\alpha_2} P_{tg}^{\alpha_3}] \\ & - \big[e^{\alpha+\beta_q \ln q_t+\beta_R \ln R_t+\beta_t \ln t+\beta_{pm} \ln pm+e_{ij}} + \mu_1 G_t + \mu_2 N_t \\ & + (1 + d(t))(0.7714 \times (G_t)^{-0.2423}) + (1 + d'(t))(0.44 \times G_t)\big]. \end{aligned}$$

4. Findings

In the first step, after collecting research data from global databases, the mathematical model was estimated using econometric and regression approaches. Table 4 describes the estimated values of gas field demand function parameters.

Table 4: The variables and parameters used.

Country	**Parameter**	α_0	α_1	α_2	α_3
Case Study	Estimated Values	33.96	-1.98	-1.195	2.54
	Standard Error	0.0548	0.0369	0.1014	0.0365
	R^2	0.4695	-	-	-
Saudi Arabia	Estimated Values	15.486	-0.248	0.957	6.0478
	Standard Error	0.03695	0.0005	0.0874	0.0048
	R^2	0.9863	-	-	-
Kuwait	Estimated Values	21.475	-1.49	-1.095	2.343
	Standard Error	0.005	0.0149	0.1546	0.0658
	R^2	0.6927	-	-	-

Based on the above, calculating the profit of each player in the Arash gas field is as follows. Each player's optimal amount of production is observed by taking the derivative of the above function to the variable of the amount of production and solving the resulting equation, which can be seen below. After solving the above model, each player's optimal values were calculated as described in Table 5.

Table 5: Optimal values of players in Arash field.

Description	**Case Study**	**Saudi Arabia**	**Kuwait**
G_t^* Optimum Value, Cubic Meter per Day	52,741,548	94,247,638	29,874,651
Actual Production, Cubic Meter Per Day	0	80,000,000	30,000,000
π_t^*- Dollar per Day	15,822,464	28,274,291	8,962,368

Figure 3 shows the current and optimal harvest status of the three countries of the case study, Saudi Arabia and Kuwait, in the Arash gas field.

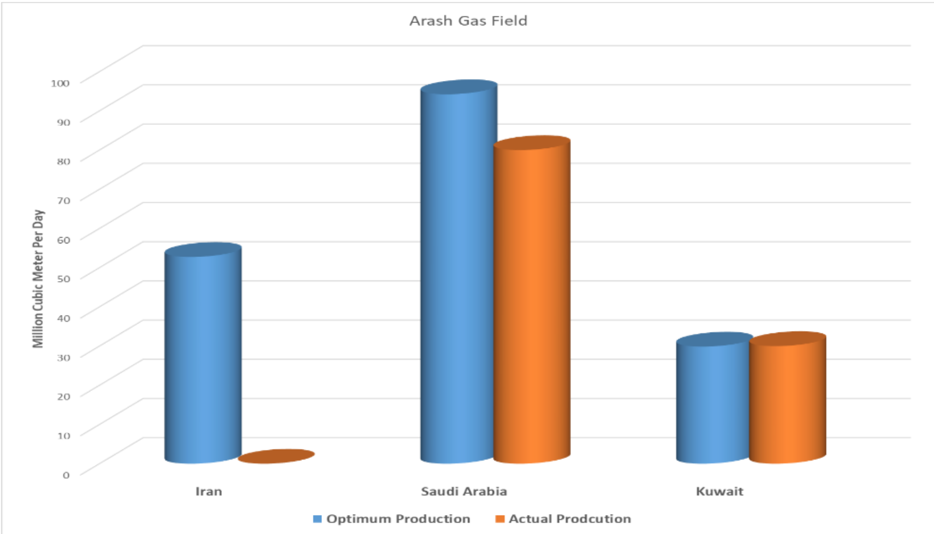

Figure 3: The current and optimal situation of players in the Arash field.

As can be seen, case studies share of the current Arash gas field is zero percent, Saudi Arabia 73 percent, and Kuwait nearly 27 percent. The current production ratio to case studies optimal production equals zero percent, Saudi Arabia 85 percent, and Kuwait 0.4 percent surplus production.

Based on the previous part's results and determining each player's strategies, the game design and equilibrium are found in each game. In this case, two strategies of coop-eration and non-cooperation are defined for each player, which are presented separately for each equilibrium field resulting from the designated games.

According to the strategies, their cumulative profit was calculated to calculate each player's payoff in this field. For this purpose, the master development plan of this gas field and the previous step's optimal values are used. The following chart shows the amount of production in the case study based on the master development plan of the Arash field from 2020 to 2045.

The volume of extractable gas in this field is equivalent to 829 million cubic meters during 25 years. Given that the life of gas fields considered 25 years and taking into ac-count the amount of pressure drops in the tanks, the following assumptions defined to design the game between the two countries:

Assumptions of non-cooperation: Given the political situation and international and confidential sanctions, common field information for each competitor

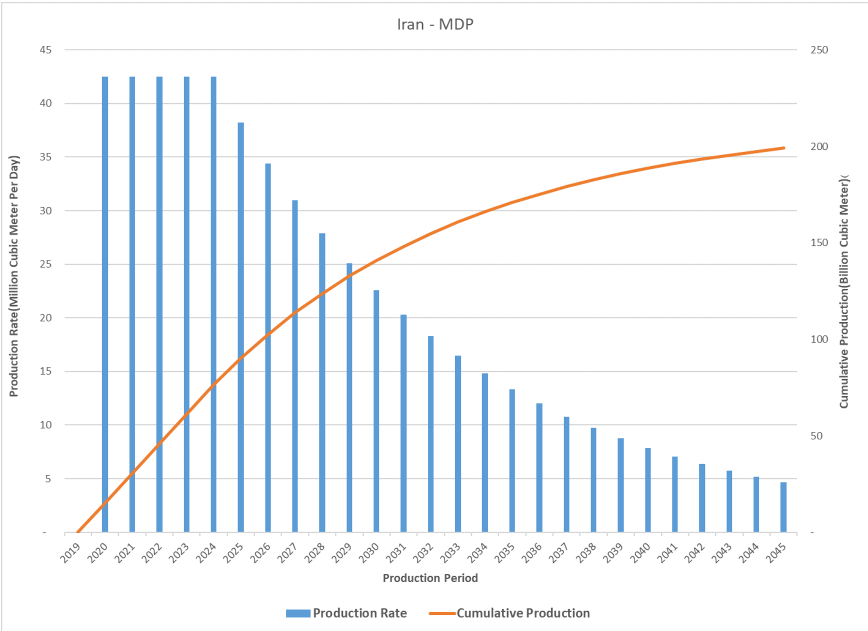

Figure 4: Production forecast of Arash field (master development plan).

is the basis for non-cooperation of MDP information. Considering that the results of the proposed model of this dissertation are consistent with the information contained in MDP, so to find the harvest values and consequently the consequence of each player, the answers obtained from the mathematical model of Arash field based on the logic of reservoir engineering and processing in MDP calculated. If the two countries do not cooperate, the amount of withdrawal of each player, in this case, is as follows.

Assumptions of cooperation: If an agreement is reached and the countries cooperate, it is assumed that based on the information of the field development plan, each of the ac-tors will produce, and the calculations related to the reservoir pressure drop are also included in the development plan. It should also be noted that if one of the parties cooper-ates, the non-cooperating party produces in the same way as before. If the three countries sign a cooperation agreement for the production of one-third of the field and assume that the parties observe the production amount, the chart below shows each player's with-drawal profile.

In this section, the results of each country's profit calculations in terms of billions of dollars over 25 years are presented in terms of strategic form.

Table 6 represents the profit in different cases for all three countries. Rows 1-3 show the profit in which all three countries cooperate to extract common reserves, equal to \$ 274 billion for the case study, \$ 187 billion for Saudi Arabia, and \$

Table 6: Optimal values of players in Arash field.

No.	Pay off Function	Profit (Billion USD)	Membership set of Strategies
1	$U_{Iran}(C, C, C)$	274	$C \in S_{Iran}, C \in S_{SA}, C \in S_{KU}$
2	$U_{SA}(C, C, C)$	187	$C \in S_{Iran}, C \in S_{SA}, C \in S_{KU}$
3	$U_{KU}(C, C, C)$	235	$C \in S_{Iran}, C \in S_{SA}, C \in S_{KU}$
4	$U_{Iran}(C, C, NC)$	331	$C \in S_{Iran}, C \in S_{SA}, NC \in S_{KU}$
5	$U_{SA}(C, C, NC)$	222	$C \in S_{Iran}, C \in S_{SA}, NC \in S_{KU}$
6	$U_{KU}(C, C, NC)$	148	$C \in S_{Iran}, C \in S_{SA}, NC \in S_{KU}$
7	$U_{Iran}(C, NC, C)$	229	$C \in S_{Iran}, NC \in S_{SA}, C \in S_{KU}$
8	$U_{SA}(C, NC, C)$	244	$C \in S_{Iran}, NC \in S_{SA}, C \in S_{KU}$
9	$U_{KU}(C, NC, C)$	199	$C \in S_{Iran}, NC \in S_{SA}, C \in S_{KU}$
10	$U_{Iran}(C, NC, NC)$	265	$C \in S_{Iran}, NC \in S_{SA}, NC \in S_{KU}$
11	$U_{SA}(C, NC, NC)$	288	$C \in S_{Iran}, NC \in S_{SA}, NC \in S_{KU}$
12	$U_{KU}(C, NC, NC)$	117	$C \in S_{Iran}, NC \in S_{SA}, NC \in S_{KU}$
13	$U_{Iran}(NC, C, C)$	255	$NC \in S_{Iran}, C \in S_{SA}, C \in S_{KU}$
14	$U_{SA}(NC, C, C)$	194	$NC \in S_{Iran}, C \in S_{SA}, C \in S_{KU}$
15	$U_{KU}(NC, C, C)$	243	$NC \in S_{Iran}, C \in S_{SA}, C \in S_{KU}$
16	$U_{Iran}(NC, C, NC)$	307	$NC \in S_{Iran}, C \in S_{SA}, NC \in S_{KU}$
17	$U_{SA}(NC, C, NC)$	230	$NC \in S_{Iran}, C \in S_{SA}, NC \in S_{KU}$
18	$U_{KU}(NC, C, NC)$	157	$NC \in S_{Iran}, C \in S_{SA}, NC \in S_{KU}$
19	$U_{Iran}(NC, NC, C)$	212	$NC \in S_{Iran}, NC \in S_{SA}, C \in S_{KU}$
20	$U_{SA}(NC, NC, C)$	249	$NC \in S_{Iran}, NC \in S_{SA}, C \in S_{KU}$
21	$U_{KU}(NC, NC, C)$	206	$NC \in S_{Iran}, NC \in S_{SA}, C \in S_{KU}$
22	$U_{Iran}(NC, NC, NC)$	246	$NC \in S_{Iran}, NC \in S_{SA}, NC \in S_{KU}$
23	$U_{SA}(NC, NC, NC)$	287	$NC \in S_{Iran}, NC \in S_{SA}, NC \in S_{KU}$
24	$U_{KU}(NC, NC, NC)$	131	$NC \in S_{Iran}, NC \in S_{SA}, NC \in S_{KU}$

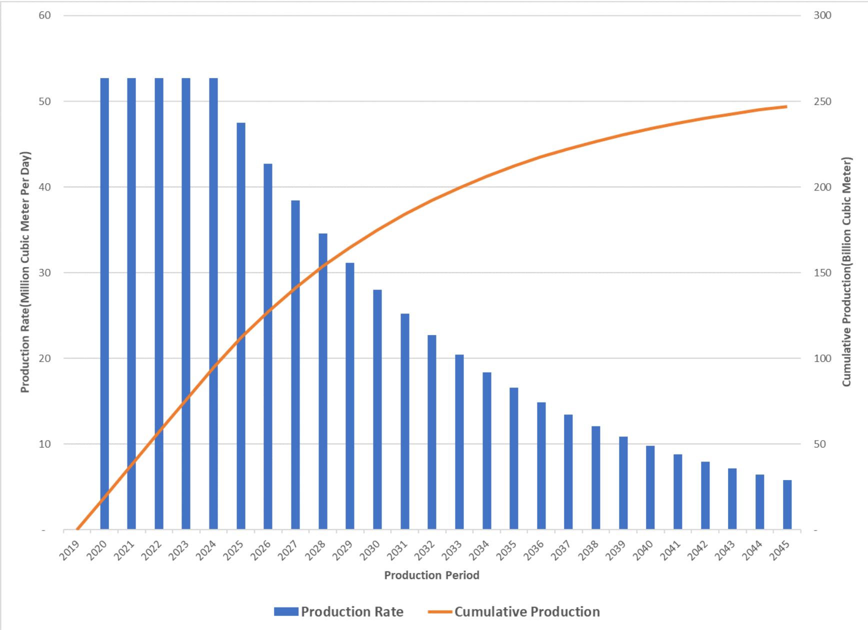

Figure 5: Case study production profile in Arash field.

235 billion for Kuwait. Row 4 shows case studies cumulative profit in a situation based on an agreement with Saudi Arabia. According to the cooperation strategy agreement with Saudi Arabia, Kuwait chooses the non-cooperation strategy, in which case study profit is equal to $ 331 billion. Row 5 shows Saudi Arabia, which will amount to $ 222 billion. Row 6 represents Ku-wait's profit in the case of non-cooperation with the research case study and Saudi Arabia, and its amount is $ 148 billion. Row 7-9 shows the agreement between the case study and Kuwait and the non-cooperation of Saudi Arabia, in which case the profit of the case study is 229 billion dollars, Kuwait 199 (eighth function), and Saudi Arabia equal to 244 billion dollars (ninth function). Row 10 represents case studies cooperation and the non-cooperation of Saudi Arabia and Kuwait. If the research case study profit equals 265 billion dollars, Saudi Arabia's profit is 288 billion dollars (Row 11), and Kuwait is equal to 117 billion dollars (row 12). Rows 13-15 indicate the situation where the research case study and Saudi Arabia do not cooperate with Kuwait, whose profits are equal to 255, 194, and 243 billion dollars, respectively. Rows 16-18 also indicate the non-cooperation of the research case study and Kuwait and Saudi Arabia's cooperation in the case of an agree-ment that the countries' profits will be 307, 230, and 157 billion dollars, respectively. Rows 19-21 indicate the non-cooperation of the research case study and Saudi Arabia in the agreement with Kuwait, whose profits will be equal to 212, 249, and 206 billion dollars.

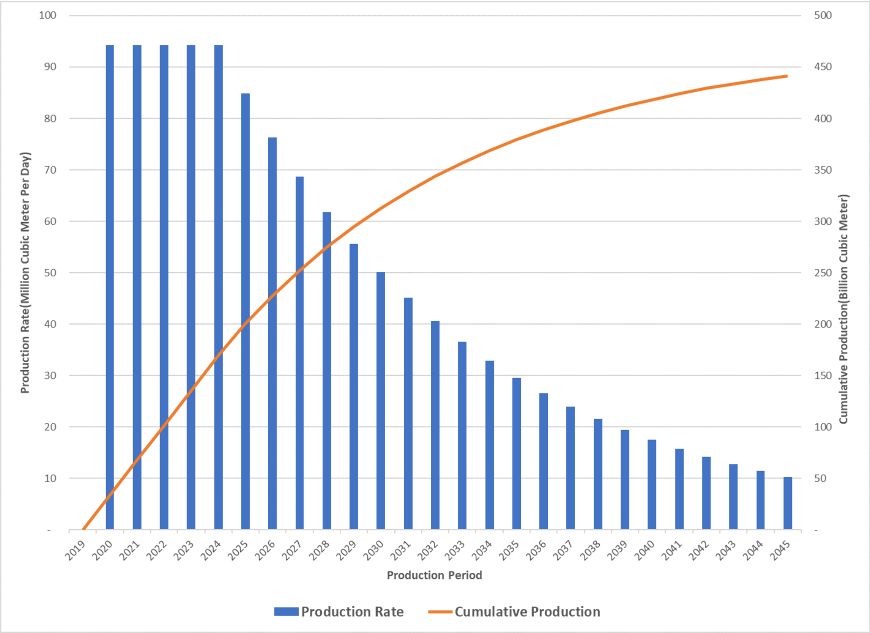

Figure 6: Saudi Arabia production profile in Arash field.

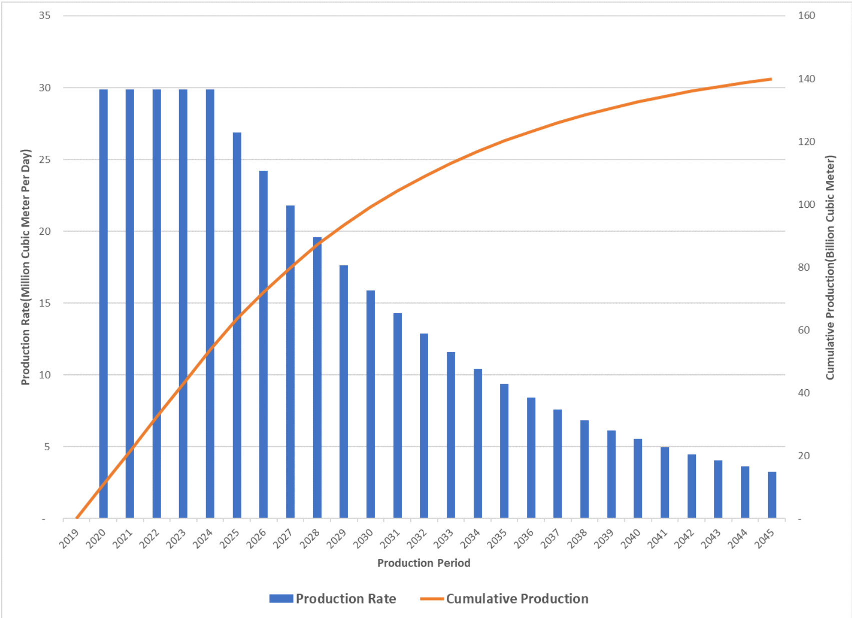

Figure 7: Kuwait production profile in Arash field.

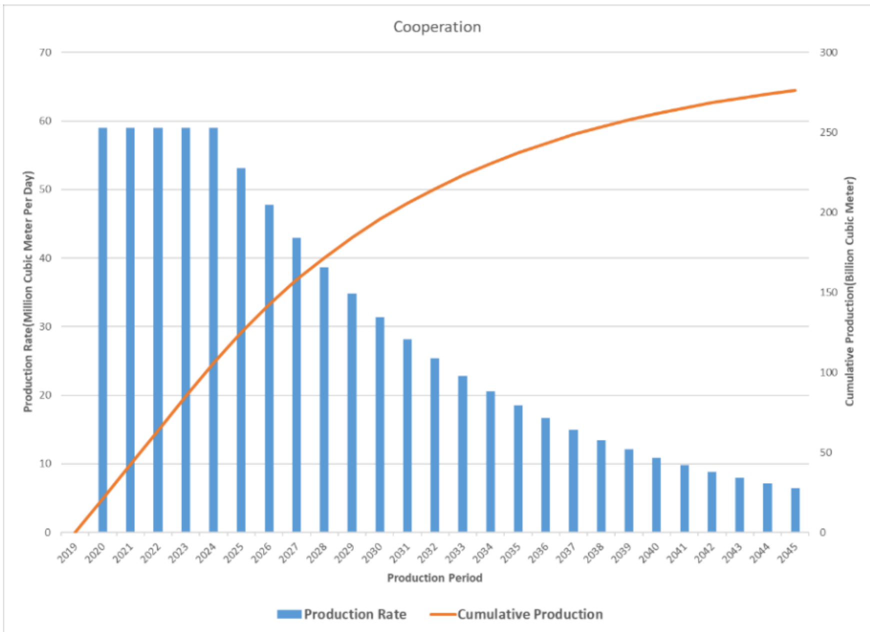

Figure 8: Production profile in Arash field (Cooperation).

Finally, Rows 22-24 indicate a situation in which neither side cooperates, in which case the profits of the countries will be equal to 246, 287, and 131 billion dollars, respectively, over 25 years. The matrix form of the outcomes of the three countries in this field is as fol-lows.

1. When the case study chooses a cooperation strategy:

		Kuwait	
	Strategy	C	NC
Saudi Arabia	C	187, 235, 274	222, 148, 331
	NC	244, 199, 229	288, 117, 265

2. When the case study chooses the strategy of non-cooperation:

In the mentioned tables, the first number on the right shows the outcome of the re-search case study; the middle number shows Kuwait's outcome, and the number on the left shows the outcome of Saudi Arabia. Then, using the best answer of each player, find-ing the balance of the game discussed.

		Kuwait	
	Strategy	C	NC
Saudi Arabia	C	194, $\underline{243}$, 255	230, 157, 307
	NC	$\underline{249}$, $\underline{206}$, 212	$\underline{287}$, 131, 246

$$
\begin{aligned}
&B_{Iran}(S_{-Iran} = (C, C)) = C \\
&B_{Iran}(S_{-Iran} = (C, NC)) = C \\
&B_{Iran}(S_{-Iran} = (NC, C)) = C \\
&B_{Iran}(S_{-Iran} = (NC, NC)) = C \\
&B_{SA}(S_{-SA} = (C, C)) = NC \\
&B_{SA}(S_{-SA} = (C, NC)) = NC \\
&B_{SA}(S_{-SA} = (NC, C)) = NC \\
&B_{SA}(S_{-SA} = (NC, NC)) = NC \\
&B_{KU}(S_{-KU} = (C, C)) = C \\
&B_{KU}(S_{-KU} = (C, NC)) = C \\
&B_{KU}(S_{-KU} = (NC, C)) = C \\
&B_{KU}(S_{-KU} = (NC, NC)) = C
\end{aligned}
$$

As can be seen, the Nash equilibrium is where both players react to each other sim-ultaneously. Here Nash equilibrium is where all three elements are marked simultane-ously. Based on the best answers above, the game's equilibrium is as follows.

$$
\begin{cases}
B_{Iran}(S_{-Iran} = (C, NC)) = C \\
B_{SA}(S_{-SA} = (C, NC)) = NC \\
B_{KU}(S_{-KU} = (C, NC)) = C
\end{cases}
\rightarrow NG = \{C, NC, C\}.
$$

Figure 9 shows the amount of profit of each player in different situations.

5. Conclusions and Suggestions

Arash gas field is one of the research case studies underdeveloped strategic fields shared with Kuwait and Saudi Arabia by the neutral zone [23], [14]. The Arash gas field structure in waters and the neutral zone between Kuwait and Saudi Arabia lead to Ku-wait's Al-Dora field. Over the past two years, a memorandum of understanding has been signed between Saudi Arabia and Kuwait to develop the field, and Kuwait has been in charge of developing the field. Thus, the development operation in the Arab part of the Arash field was completed.

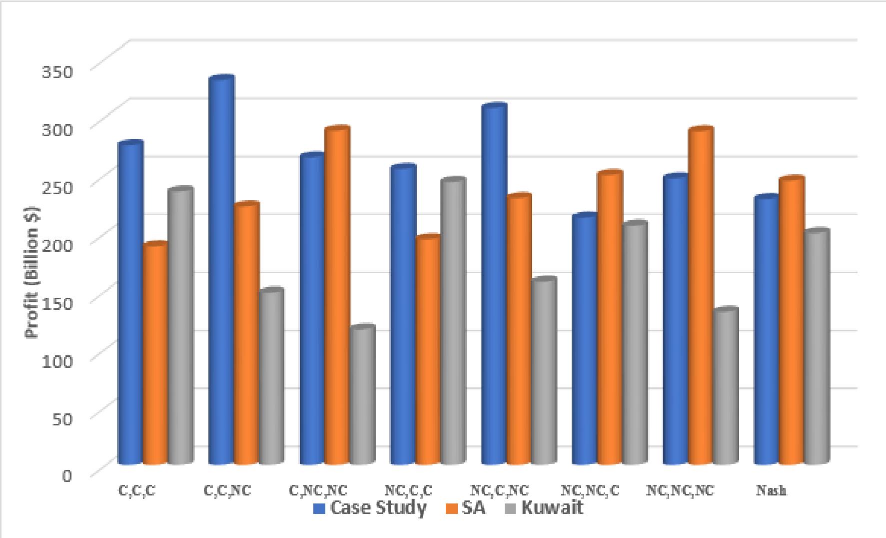

Figure 9: Profit status of players in different strategies and equilibrium.

Accordingly, due to the lack of research case study production in this field and the price of 50 cents of exported gas in the budget of 1399 countries, case studies daily non-profit is 26.4 million dollars. Figure 10 Shows the daily lost profit of case study non-production in the studied oil and gas fields.

The results of solving the designed games showed that the best strategy and Nash equilibrium for the research case study is the strategy of cooperation. Also, considering the development of the common gas field and the current situation of case study in this field and considering the results of the equilibrium of games designed based on cooperation strategy in-field extraction, it is suggested that one of the main approaches of case study in a common field, Consider a multifaceted and collaborative development process. The re-search case studies equilibrium in the underdeveloped Arash field was recognized as a cooperation strategy, Saudi Arabia's equilibrium as a strategy of non-cooperation, and Kuwait's equilibrium as a strategy of cooperation. In general, given that production from common fields is extremely important, setting easier rules for attracting capital and de-velopment activities. The following aspects can be studied in future work:

- Considering the environmental functions and the amount of pollution from harvest-ing in calculating the overall operating outcome.

- Designing coalition games for common pitches with more than two players and comparing the present study results in the overall operating outcome.

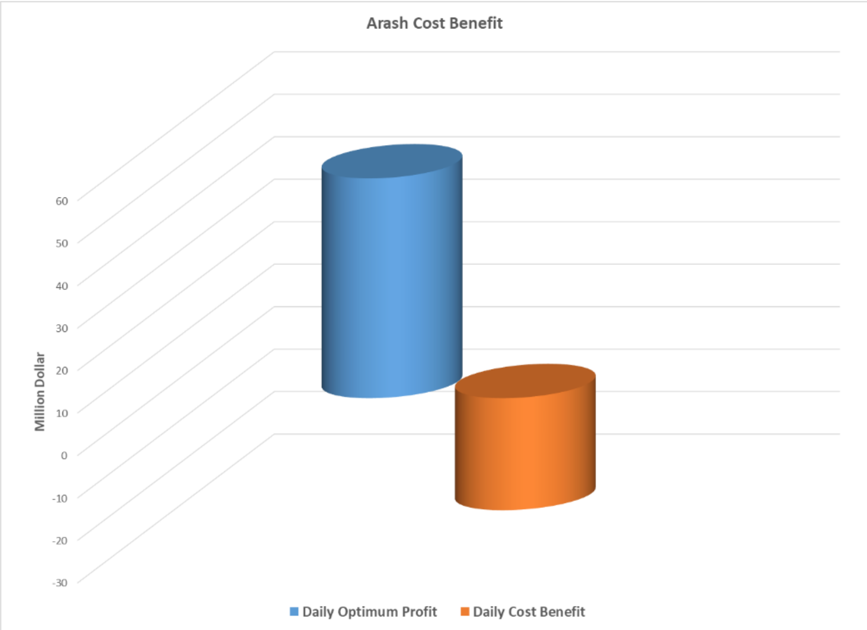

Figure 10: Optimal profit and daily cost-benefit of Arash gas field.

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