The Study on Portfolio Optimization Methods for Overseas Petroleum Development Projects

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Abstract. Based on the research of other major foreign petroleum companies management process and evaluating the characteristics of operation for overseas petroleum projects, the portfolio optimization workflow for overseas petroleum investment was established; The multi-objective optimization model considering multiple objectives and constraints such as production, investment capital, IRR, project risk, and NPV was established. Four optimized portfolio cases were separately analyzed. By proposing the strategies of postponing some projects to build capacity, selling the part of working interests or quitting whole projects, and purchasing some new projects, the requirements of multi-objective planning were ultimately satisfied. The results and suggestions can provide a theoretical basis for the decision choices of overseas petroleum investment.

Keywords: Portfolio optimization · Risk indicator · Multi-objective optimization model · Investment strategy

1 Introduction

Under the long-term low oil price environment, oil and gas companies are shifting the goals from the original production scale development to high-efficiency development. Therefore, in order to pursue the efficiency for the company, it is necessary to

appropriately control the scale of investments, focus on efficiency and cash flow, and enhance the company's operational capabilities. The exploration and development of overseas oil and gas resources involve not only geological conditions, technological requirements, market rules, policies and regulations, environment, and transportation conditions, but also related to complex geopolitics and diplomacy. Therefore, it is necessary to analyze the risks of overseas investment projects and carry out multi-objective optimization research. It can optimize asset structure and provide information support for oil and gas companies by providing information support such as geology, development environment, investment environment, and development strategies. It can ensure maximum investment returns, improves overall efficiency, and enhances the international competitiveness of oil and gas companies.

At present, many scholars have done a lot of research on oil and gas investment portfolio optimization. Chang [1], Qu [2, 3] established the characteristics of domestic oil field development planning production optimization model. Jin and Wei [4] combined the new technology of projection pursuit with the ideal point method in multi-index decision theory and proposed a new method to deal with dynamic multiple index decision problems. Zhang [5, 6] established an optimal planning model using the gray system theory and integer programming methods which have considerations of capital, workload, incremental power consumption, water production, and oil production constraints. Luo [7] adopted a mathematical planning method to optimize the investment in the capacity building projects according to the need for two-level optimization of the oil production capacity. Wu [8] established an oil company investment portfolio optimization mathematical model and constructed a portfolio optimization model solving method based on the improved simplex method with variables having upper and lower bounds. Zhang [9] established a portfolio model under the constraints of capital and reserves and selected a portfolio that satisfies constraints. Foreign scholars Back [10], Erlingsen [11], etc. used linear programming or genetic algorithms to choose the best portfolios (within the constraints of the availability of rigs, facility capabilities, availability of funds, availability of human resources, etc.). Brashear [12], Burns [13], and others [14–16] in the portfolio planning exploration and production projects adopted a multi-objective evolutionary algorithm with innovative constraint handling for portfolio optimization. The above research methods are mainly applied to the optimization of specific oil field development at home and abroad, and they lack reference for CNPC's overseas investment strategy. Therefore, according to the characteristics of CNPC's overseas oil and gas operations and development, the research on overseas oil and gas project portfolio optimization will be carried out.

2   Investment Optimization Process for Overseas Oil and Gas Projects

From the perspective of project management theory, an investment optimization process for overseas upstream development projects was constructed [17, 18]. A complete portfolio optimization process includes seven steps (Fig. 1): they are economic evaluation for individual project; determination for the comprehensive risk factor of a

single scenario; formation of multi-project investment candidate projects; definition of project business rules, constraints, and filter conditions; use of multiple optimization algorithms for portfolio optimization, and analysis or comparison for portfolio results; and the final determination for optimal investment portfolio. The seven steps involve the establishment of optimized mathematical models, the representation of business rules and constraints, and the optimization of the algorithm theories and methods.
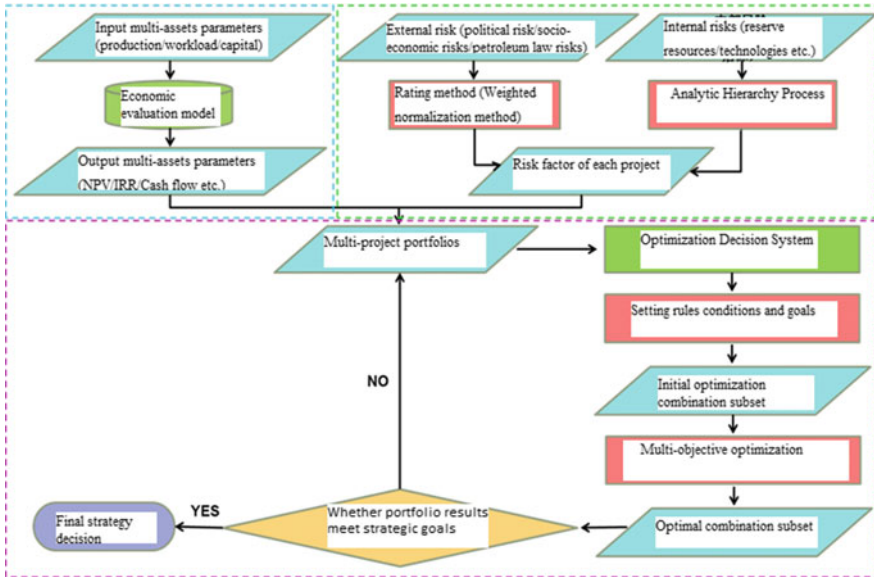

Fig. 1. The portfolio optimization workflow for overseas petroleum investment

1. Economic evaluation for individual project. By inputting the project's parameters such as production, workload, and investment cost into the economic evaluation model, the basic economic indicators such as operating expenses, cash flow, net present value, internal rate of return, and barrel oil cost are calculated.

2. Determination for the comprehensive risk factor of a single scenario. Comprehensively consider external risks include external risks and internal risks. External risks include the country's political risk, socioeconomic risks, and oil and gas business risks in resource countries. Internal risks include eight indicators such as reserve resources, technologies, and project management. The comprehensive risk factor of a single project can be quantified by using analytic hierarchy process and normalized methods.

3. Formation multi-project investment candidate projects. The economic evaluation results and comprehensive risk factors of single scenario are input into the decision optimization database system. Through the analysis of the company's existing project assets and potential project assets, it is determined which projects are the targets of investment portfolio optimization and the gap between the current results and the planning goals can be found.

4. Definition of business rules, constraints, filter conditions and optimization goals.

   (1) Set business rules. Due to the complex contracts model of overseas project, there are dependencies or mutually exclusive relationships between certain projects in each region, and there are also mutual constraints on the time order for projects implementation that requires several phases to be built. Therefore, in the process of investment portfolio optimization, it is necessary to definite contractual obligations, production share or construction restrictions, and other related constraints and business rules. The business rules mainly include setting the affiliation and mutually exclusive relationship between the projects; setting the project's scope of work rights and equity types; setting the project implementation time order and constraints.

   (2) Set the constraints. Conditions such as production and total investment can be set. For example, set the minimum production value that needs to be reached each year and the maximum allowable value for annual investment.

   (3) Set filter conditions. Set economic or risk indicator thresholds and filter candidate scenario. If the risk indicator exceeds the highest set threshold or the internal rate of return is below the set threshold, the scenario will be filtered out and will no longer enter the subsequent optimization pool.

   (4) Set optimization goals. Set the portfolio target to be single or multiple goals, and the single target has maximum net present value, minimum risk, maximum output, etc. Multi-target refers to multiple economic indicators or risk indicators, and the weight coefficient according to the importance of different indicators can be set.

5. Use of multiple optimization algorithms for portfolio optimization. For different optimization models, linear and genetic algorithms are used to optimize the investment portfolio for different target models, and it can achieve the lowest cost, best single barrel return, the largest profit, minimum risks and ensure that the internal rate of return is not lower than the specified standard.

6. Analysis and comparison for portfolio results. After solving the optimization model, a series of optimal portfolio solutions are obtained. The results of economic indicators such as project production, investment, after-tax cash flow, and net present value for each investment portfolio can be compared and analyzed.

7. Final determination for optimal investment portfolio. After comparing and analyzing optimal portfolio solutions, according to different strategic objectives and decision-making needs (such as considering geography, geology, technology, and other comprehensive factors), the optimal portfolio to meet the strategic decision can be selected.

3   Establishing a Multi-objective Optimization Model

The multi-objective optimization problem is much more complex than the single-objective optimized problem. The goal in the single-objective optimization model is generally a single factor, so it can be clearly defined. But in the multi-objective optimization problem, multiple objectives may conflict with each other such as investment, production capacity, revenue, and payback period are conflicting goals [19, 20].

In this paper, the multi-objective optimization model takes the net present value rate, internal rate of return and investment payback period as optimization objectives, and production, investment, and project risk as constraints. The net present value rate considers both the net present value and the investment parameters, so under the same net present value, the higher the net present value rate, the less the investment. The oil–liquid ratio refers to the ratio of crude oil production to equivalent oil and gas production, the greater the oil–liquid ratio, the higher the proportion of crude oil in oil and gas equivalents. The three objectives of net present value ratio, internal rate of return, and oil–liquid ratio are inversely related to the target of payback period, in order to maximize the net present value ratio, internal rate of return, oil–liquid ratio, and minimize the payback period. The method of maximizing multiplication is used, and the objective function model is as follows:

$$\max f(x_1, x_2, \ldots, x_n) = \frac{\sum_{j=1}^{m_i} \sum_{i=1}^{n} \mathrm{npv}_{i,j} x_i \times \sum_{j=1}^{m_i} \sum_{i=1}^{n} \mathrm{ron}_{i,j} x_i \times \sum_{j=1}^{m_i} \sum_{i=1}^{n} \frac{P_{\mathrm{oil}}}{P_{\mathrm{BOE}i,j}} x_i}{\sum_{j=1}^{m_i} \sum_{i=1}^{n} c_{i,j} x_i \times \sum_{i=1}^{n} P_{ti} x_i}$$

$$s.t. \begin{cases} \sum_{j=1}^{K} \sum_{i=1}^{n} q_{i,j} x_i \geq Q_K \\ \sum_{j=1}^{K} \sum_{i=1}^{n} c_{i,j} x_i \leq C_K \\ \mathrm{ron}_i \geq \mathrm{RON} \\ \mathrm{risk}_i \geq \mathrm{RISK} \end{cases}$$

$$(1)$$

x_i 0–1 decision variable: 1 indicates that item i is selected, 0 indicates that item i is not selected.

m_i the development contract period of project i, year.

K year of optimization investment, year.

n the number of overseas development projects optimization, a.

$\mathrm{npv}_{i,j}$ net present value of project i in the jth year, million dollars.

P_{ti} payback period of project i, year.

$P_{\mathrm{oil}i,j}$ oil production of project i in the jth year, million tons.

$P_{\mathrm{BOE}i,j}$ oil and gas equivalents of project i in the jth year, million tons.

$q_{i,j}$ production of project i in the jth year, million tons.

Q_K the minimum total production of overseas development projects in the Kth year, million tons.

$c_{i,j}$ the investment of project i in the jth year, million dollars.

C_K the maximum total investment constraint value of overseas development projects in the Kth year, million dollars.

ron_i internal rate of contract period of project i, %.

RON   the lowest acceptable internal rate of return for the project, %.

risk_i the comprehensive risk values of project i.

RISK   the maximum comprehensive evaluation risk value can be accepted.

4 Study of Multi-objective Optimization Case for Overseas Oil and Gas Projects

4.1 Setting Business Rules, Constraints, Filtering Conditions, and Optimization Goals

1. Set business rules according to the project's dependence degree and the logical relationship between the projects.

(1) Set project dependency degree. For example, set oil sand project 1 to be put into production before oil sands project 2.
(2) Set asset structure. Combining the business philosophy of "quality, efficiency, and sustainable development" and the country's strategic concept of "One Belt One Road," overseas projects put emphasis on consolidating and nurturing the six major program groups: they are the Central Asia and the project groups along the oil and gas pipelines between China and Kazakhstan, project groups of large scale and super large scale in the Middle East, project groups of Nile River Basin and Sub-Saharan, unconventional project groups in Venezuela, Canada, and Australia, sea areas project groups in East Africa, and project groups of Bay of Bengal and Brazilian, Arctic, East Siberia, and Far East. In order to take into account the six program groups, each project group in the optimization portfolio contains at least two projects.
(3) Set proportion for oil and gas projects. In order to meet the gas supply demand of the Sino-Kazakhstan gas pipeline and balance the percentage of oil projects and gas projects, the optimized combination includes at least three gas production projects in Central Asia.
(4) Set proportion for contract types. The overseas oil and gas development contract models mainly include royalty and tax contracts, product sharing contracts, service contracts, and buy-back contracts. Set the minimum number of items to include in each type of contract in the optimized portfolio based on the current contract model.

2. Set constraints

According to the long-range planning objectives, the oil and gas equity production in 2020 will reach 100 million tons, the oil and gas equity production in 2030 will reach 150 million tons, and the total project investment will not exceed 12 billion US dollars per year. Make constraint for the oil production and investment in different years.

3. Set filter conditions

(1) The highest risk filter conditions. The maximum permissible total risk for a single project is 0.75.
(2) Minimum internal rate of return filter conditions. Scenario whose risk exceeds the highest risk threshold and internal rate of return is lower than the IRR threshold will be filtered out and no longer enter the subsequent optimization pool. The threshold of the highest risk and the lowest internal rate of return can be dynamically changed according to the requirements of the decision makers and the current investment environment.

4. Set optimization goals

Set the objective function according to the multi-objective optimization model. The weight value of the target is, respectively, assigned according to the importance of the target (Table 1). The larger the weight value of the target is, the better the investment optimization program is to be met for such goals.

Table 1. Different objective weight values in multi-objective model

Variable	Unit	Weight value
Net present value rate	%	0.3
Internal rate of return	%	0.3
Investment recovery period	year	0.2
The oil–liquid ratio	%	0.2

4.2 Comparative Analysis of Investment Portfolio Optimization Programs in Different Situations

1. Scenario 1

The existing and new projects are invested and built according to the original plan. It can be seen that the production of the existing projects has a certain margin for planning objectives. Considering the production factors alone, existing projects can guarantee the completion of planned production targets (Fig. 2). However, taking into consideration the factors of equity investment, the existing equity investment in the planned project far exceeds the annual investment limit of US$12 billion (Fig. 3). Therefore, it is necessary to optimize the overall overseas project portfolio that meets the planning objectives with good efficiency, so that we can reasonably arrange the production rhythm and eliminate projects with poor economic returns.

2. Scenario 2

Under the condition of not selling the projects, the existing development projects continue to be operated. The pending construction projects will be postponed according to the implementation conditions; we can control the constructing pace of the project, adjust the production structure, and reduce the total investment of the previous period.

The investment portfolio P1 is calculated through the genetic algorithm. The timing of the proposed production schedule for the proposed projects is shown in Table 2. Chinese equity investment mostly meets the investment constraint requirements of US $12 billion per year only except in 2015 and 2016, but meanwhile, the production does not meet production constraints from 2026 to 2030 (Fig. 4). So in order to achieve the planned objectives, we may consider selling some of the recent projects in 2015 or 2016 to reduce recent investments and consider using surplus funds to acquire new projects to fill production around 2025.
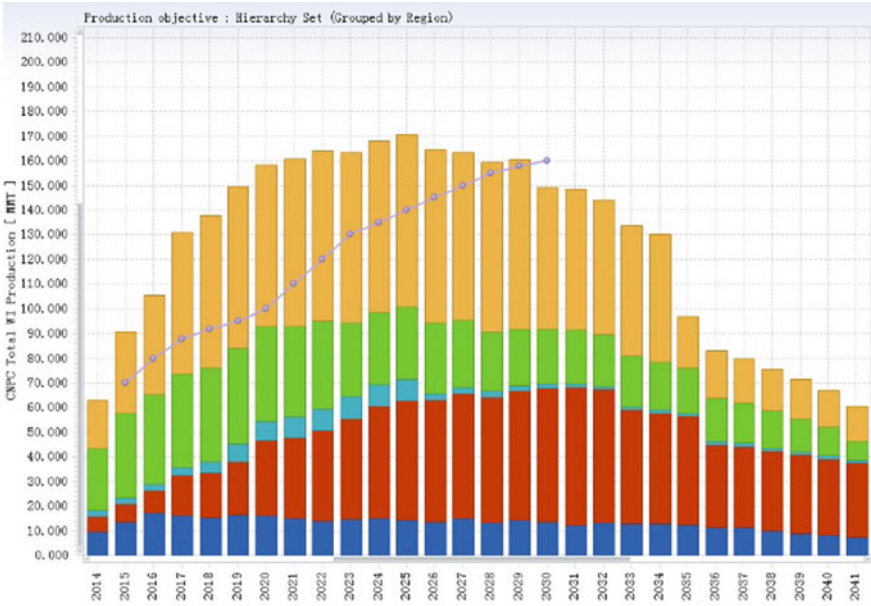
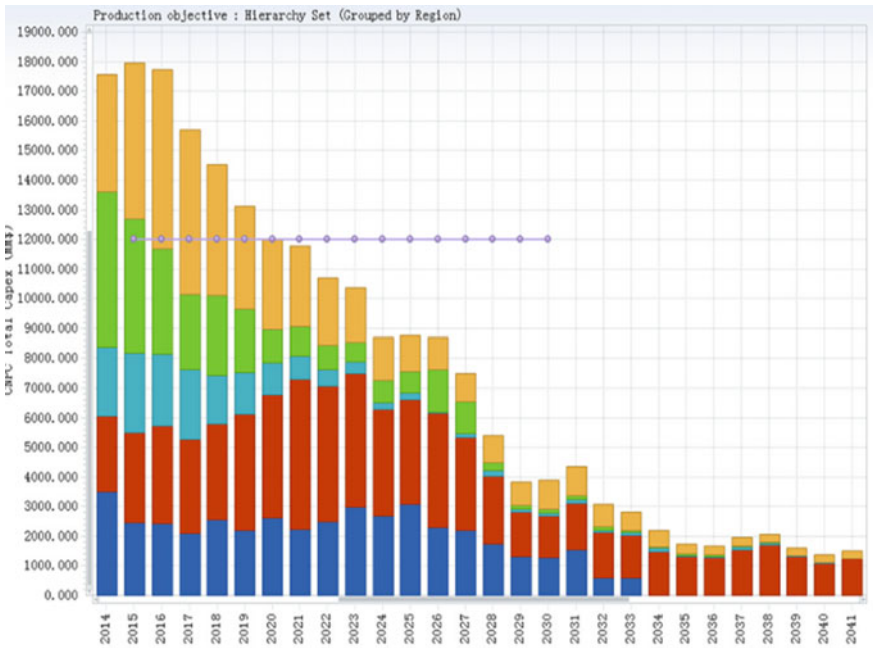**Fig. 2.** Comparison of equity production and planning production goals for existing projects

Fig. 3. Comparison of equity investment and planning investment goals for existing projects

3. Scenario 3

On the basis of scenario 2, according to the economic evaluation results of the current producing projects such as internal rate of return during the contract period, use genetic algorithm method to get optimized portfolio for scenario 3, find out the poorly operating efficiency projects which can be sold partial equity or exit the entire project. The investment can meet the target constraints, but the production does not meet the production constraints in the latter period, so new projects need to be added to make up for the production gap (Fig. 5). The projects which need to sale partial equity or exit for scenario 3 are shown in Table 3.

Table 2. Construction projects which will be postponed and the deferred year

Project name	Planned production time	Optimized production time	Deferred year
Project 3	2016	2019	3
Project 6	2016	2016	1
Project 10	2016	2018	2
Project 18	2017	2018	1
Project 24	2017	2022	5
Project 36	2017	2022	5

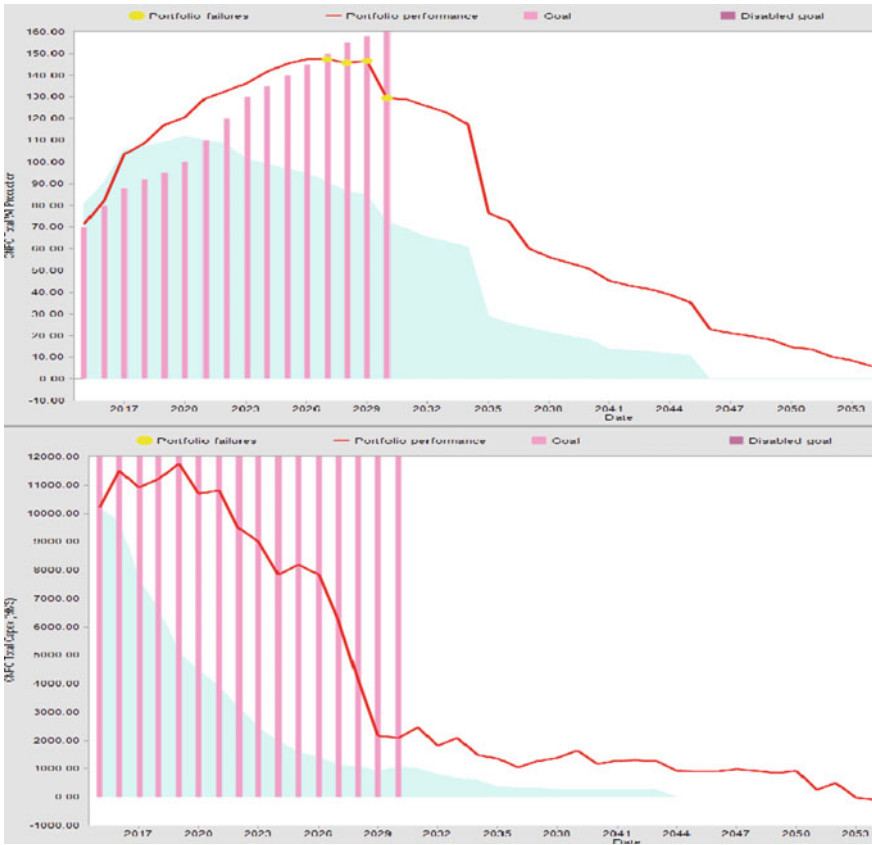**Fig. 4.** Comparison between the optimization results and the planning goals of scenario 2

Fig. 5. Comparison of portfolio optimization results and planning objectives for scenario 3

Table 3. Projects which need to sale partial equity or exit

Project name	Proposed sale of shares (%)	Year of sale
Project 4	100	2016
Project 9	100	2017
Project 14	100	2018
Project 22	30	2018
Project 28	100	2017
Project 30	40	2018

4. Scenario 4

On the basis of scenario 3, new projects with high valuation returns will be selected to incorporate into the investment optimization portfolio. The screening conditions are based on risk indicators, economic indicators such as internal rate of return and cash flow, relying on existing Sino-Kazakhstan natural gas and China-Kazakhstan crude oil energy pipelines, the conventional onshore oil and gas projects in the politically stable Central Asia–Russia region can be screened out. The new acquisition projects are shown in Table 4. It can be seen from Fig. 6 that by postponing construction of project, selling partial or all of the equity projects with poor economic returns and acquisition new projects with low risk and good returns, both production and investments constraints can be met.

Table 4. Proposal acquisition projects for scenario 4

Project Name	Proposal acquisitions (number)	Year of acquisition
Project 2	2	2022
Project 15	1	2019

5. Comparison of four scenarios

As can be seen from the production comparison of the four scenarios in Fig. 7, through the acquisition of new projects in the later period, only the production of scenario 4 meets the constraint conditions between 2016 and 2030. As can be seen from the comparison of the investments of four scenarios in Fig. 8, scenario 2, 3, 4 can meet the constraints, but scenario 4 will increase investment for new acquisitions from 2018 to 2022. Only scenario 4 meets the annual investment and production constraints.

Through the sale of poor efficiency projects, the after-tax cash flow of scenario 3 and 4 are significantly higher than scenario 1 and 2 (Fig. 9). The net cash flow of scenario 4 has decreased slightly during the period 2018–2023, and this is due to the fact that the new acquisition projects require capital investment. With the normal development of the projects in the later period, the cash flow will gradually increase.

As can be seen from the indicator bubble chart in Fig. 10, the investment of scenario 3 is the smallest due to selling the poor-performing assets, and after-tax net present value is better than scenario 1 and 2. By optimizing portfolio methods, the cumulative equity production and cumulative net present value of scenario 4 are the largest, and investment fund is saved compared to the original plan.
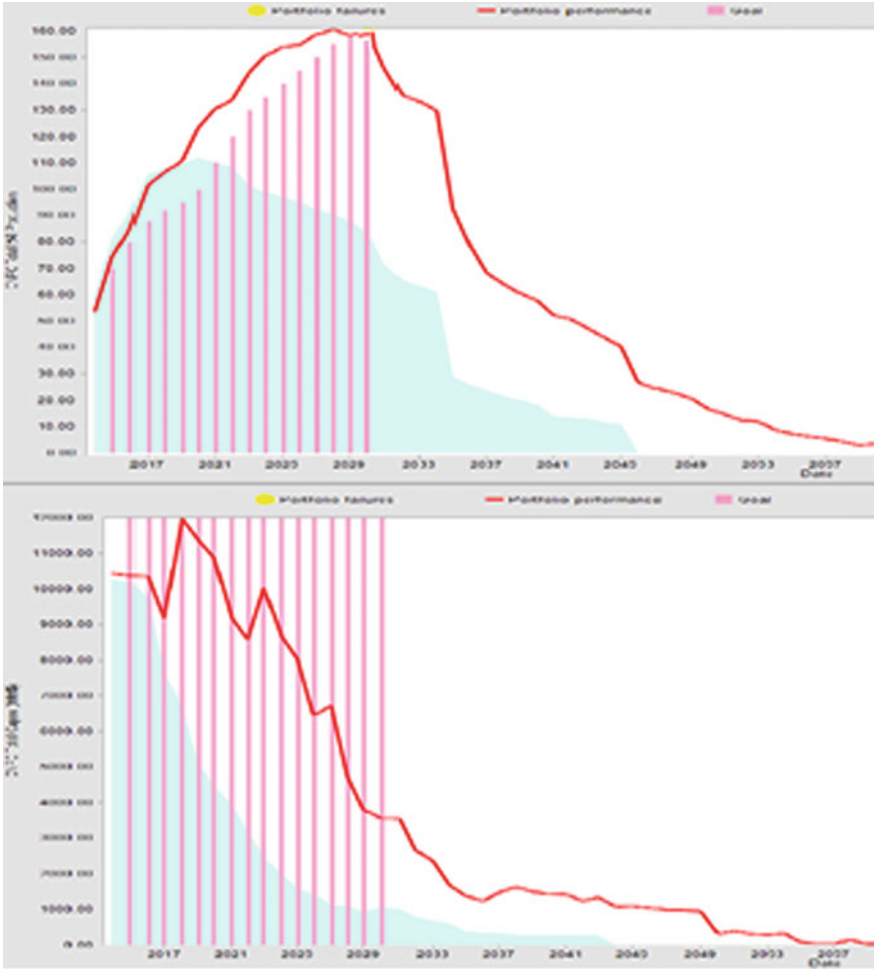
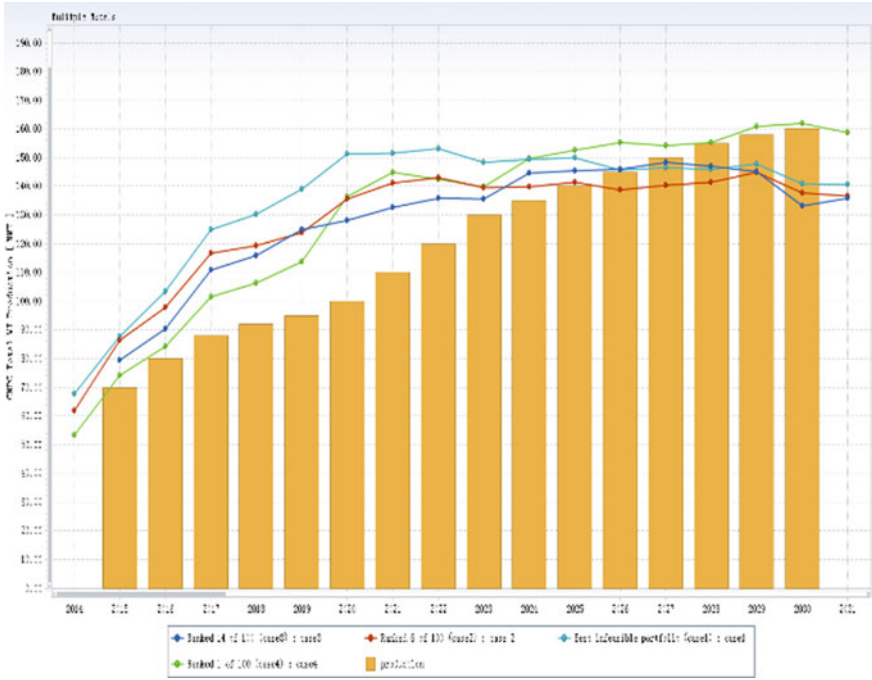**Fig. 6.** Comparison of portfolio optimization results and planning targets for scenario 4
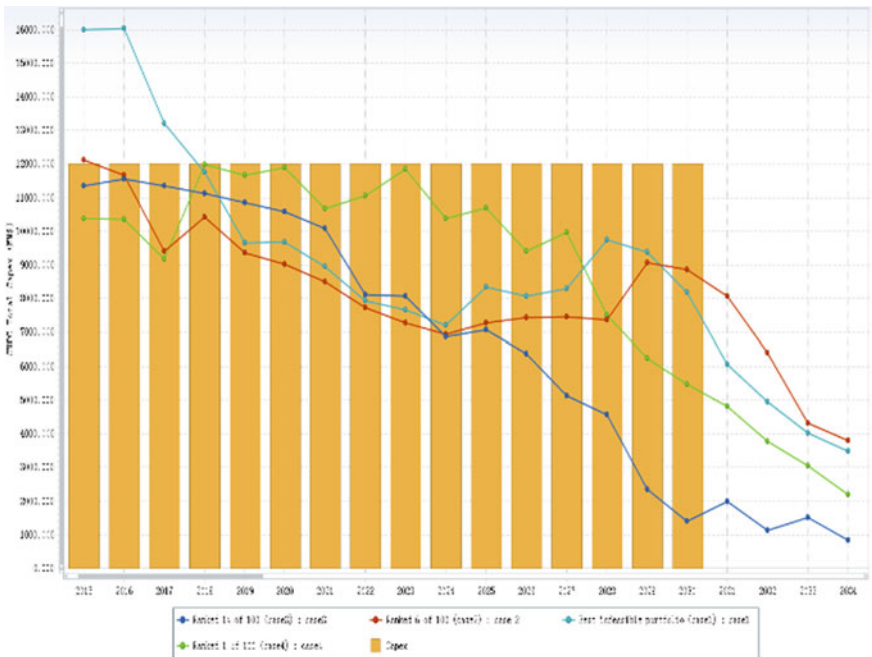
Fig. 7. Production comparison of four scenarios

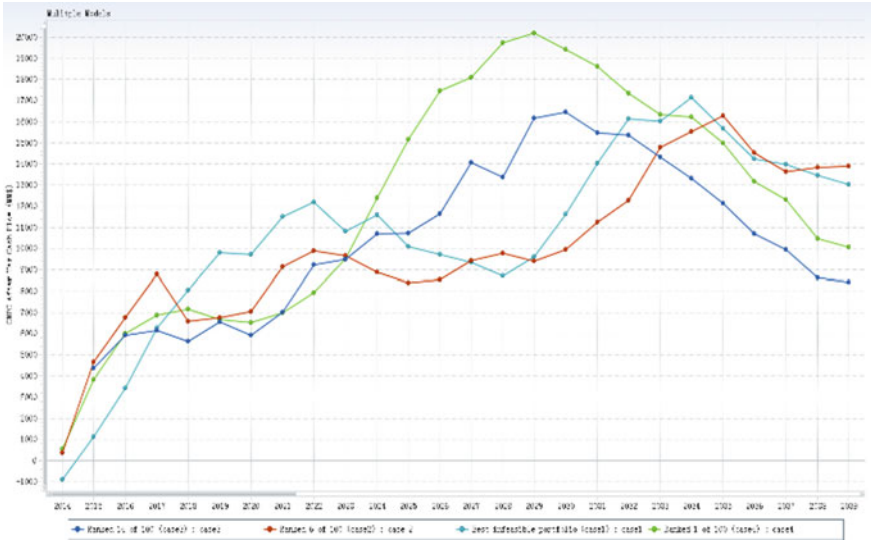**Fig. 8.** Investment comparison of four scenarios

Fig. 9. Comparison of net cash flows for optimized portfolio of four scenarios
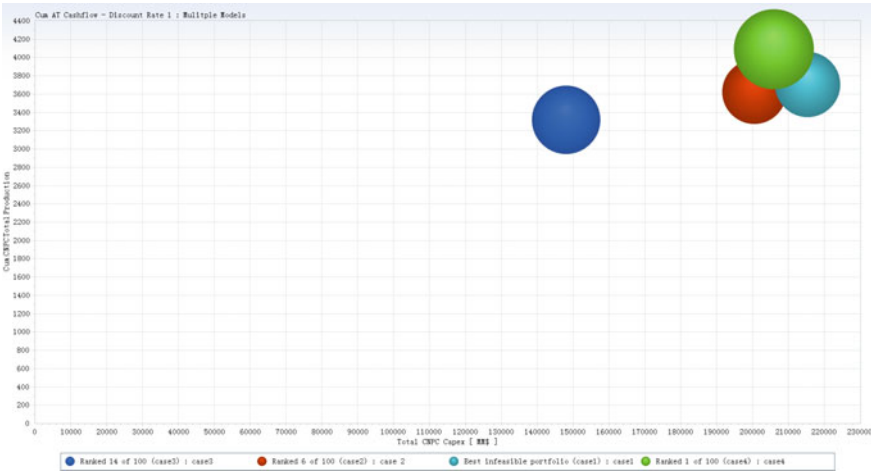

Fig. 10. Comparison of investment, production, and net present value of investment portfolios under the four scenarios

5   Conclusion

1. Learned from the theory of project management, based on the project management models and evaluation methods of other major foreign oil companies, the basic flow of overseas oil and gas project portfolio optimization was determined by analyzing the characteristics of overseas oil and gas production and operation.

2. Through the analysis of multiple technical, economic, and risk indicators of the projects, a multi-objective optimization combinatorial mathematical model has been established, and this model comprehensively considers the factors such as production, investment, internal rate of return, risk, and net present value. Four optimized portfolio cases were separately analyzed, through postponing the construction of some projects, selling the part of working interests or quitting whole projects, purchasing some new projects, the multi-objectives of the planning were ultimately achieved. Evaluation results and recommendations for overseas oil and gas project investment optimization provide certain decision support.

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