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Investment Analysis Upgrading Capacity of Produced Water Treatment System (PWTS) at a Gas Processing Facility

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Abstract
The oil and gas industry plays a strategic role in supporting national energy security. As production fields age, the volume of produced water increases, often exceeding the design capacity of the Produced Water Treatment System (PWTS) at PT XYZ's facilities. This condition disrupts smooth operations and poses potential safety risks. This study evaluates PWTS capacity upgrades from technical and economic perspectives. The Technical Risk Assessment employs Failure Mode and Effect Analysis (FMEA) and a Risk Matrix to evaluate equipment failure risks due to capacity limitations. The Economic Risk Assessment uses Cost-Benefit Analysis (CBA) to assess investment feasibility. Integrating these methods reveals that the optimum PWTS capacity is 6,000 BWPD, yielding a Net Present Value (NPV) of 84.83 million USD. Furthermore, Sensitivity Analysis confirms project feasibility with a production drop tolerance of up to -1.5% per day. This technical, economic, and sensitivity-based analysis forms a key component of risk management in investment decision-making.
Keywords: Produced Water, Produced Water Treatment System (PWTS), Failure Mode and Effect Analysis (FMEA), Risk Matrix, Cost-Benefit Analysis (CBA), Sensitivity Analysis.

INTRODUCTION

The oil and gas (Oil and Gas) sector plays a strategic role in supporting Indonesia's economic growth. As a country with significant oil and gas reserves, this sector contributes greatly as a source of domestic energy, a contributor to state revenue, and a driver of investment. The contribution of the upstream oil and gas sector will reach more than Rp 110 trillion to state revenue in 2024. Furthermore, investments worth USD 1 in this sector are estimated to create a chain economic impact of up to USD 1.6 in other supporting sectors.(Soesanto et al., 2025)(Düsseldorf Oil, 2025)(Düsseldorf Migas, 2021)

In order to meet domestic energy needs, the increase in oil and gas production is supported through the development of main facilities, such as the Central Processing Plant (CPP). CPP plays a vital role in processing natural gas from wells before distribution. This process involves a series of major systems, including Gas Liquid Separation, Acid Gas Removal System, TEG Dehydration, Acid Gas Conversion Unit, Thermal Oxidiser, Dew Point Control system, Condensate Stabilisation System, and Produced Water Treatment System (PWTS).

Produced water is a by-product of large volumes, which is formed from water that is trapped in (John A. Veil et al., 2004)subsurface formations and carried to the surface along with hydrocarbons. In line with field maturity, the volume of water produced tends to increase significantly, posing a serious challenge to treatment facilities.(Amakiri et al., 2022)

Design Capacity Gap: PT XYZ's actual daily production data throughout 2024 shows that the volume of water produced has reached a peak of 3,110 Barrel Water per Day (BWPD). This volume far exceeds the existing design capacity of the Produced Water Treatment System (PWTS) which is only 2,000 BWPD. This increase was confirmed by the petroleum engineering team as an indication of the formation of water in the subsurface formation. The main equipment of PWTS that was affected included production separators, hydrocyclones, degassing columns, produced water tanks, produced water booster pumps, produced water filters, and produced water injection pumps.

The current PWTS design capacity is determined based on the results of the Front End Engineering Design (FEED) study, which refers to the well production profile survey in the development phase (Figure 1.4). The study projects a maximum water volume of just 366.90 BWPD in its 16th year of operation. This condition contradicts the actual data, where the surge of water produced has occurred much earlier (about 10 years of operation) with much larger volumes.

The limited capacity of PWTS poses significant operational and safety risks. Inadequate management of produced water can disrupt the overall smooth operation of the facility, reduce equipment reliability, and trigger potential hazards due to high oil content accumulation in the produced water tank.

This suboptimal water management causes residual oil to be carried to the storage tank. As a result, facility safety risks arise, especially in the event of evaporation or leakage of tank components. Currently, mitigation is carried out through manual (Johnson et al., 2022)handling by operators using a vaccum truck to move the oil content back into the system. These methods are susceptible to human error and equipment unreliability, which ultimately increases the operational risk profile.

Therefore, the investment analysis of PWTS capacity building is very urgent to evaluate its feasibility from technical and economic aspects. This is in line with the framework that advocates the incorporation of technical risk assessment and economic risk assessment in investment decision-making.(Kabyl et al., 2020)

In this study, technical risk evaluation was carried out using Failure Mode and Effect Analysis (FMEA), while economic feasibility evaluation was conducted using Cost-Benefit Analysis (CBA). FMEA functions to identify and assess potential failure modes in PWTS equipment due to an increase in the volume of water produced. This assessment includes Severity (severity), Occurrence (likelihood of occurring), Detection (detection ability), and Dependency (relationship between systems). To quantify risk, the FMEA value is converted to Expected Cost using the Risk Matrix which is the standard of PT XYZ. The use of this Risk Matrix provides a measurable basis for translating subjectively assessed operational risks (expert judgement) into financial variables in CBA.

CBA is implemented to identify, analyze, and evaluate economic risks that affect investment eligibility, using key indicators such as Net Present Value (NPV), Internal Rate of Return (IRR), Benefit Cost Ratio (BCR), and Payback Period (PP). This economic assessment includes the dimensions of physical assets (Harberger,1991; Jenkins et al., n.d.; Leiva Vilaplana et al., 2025)tangible assets) and non-physical (intangible assets).(Elkemali , 2024)

Sensitivity Analysis is applied to test the resilience of investment projects to the volatility of key parameters. This analysis focuses on changes in the amount of gas and oil production, which directly affect the revenue and Net Present Value (NPV) value of each PWTS capacity alternative. The results of the sensitivity analysis aim to provide the minimum production limit required to maintain a positive company cash flow, considering the high uncertainty in production projections. This research offers significant benefits across technical, economic, and strategic dimensions. Technically, it identifies and mitigates operational risks arising from inadequate PWTS capacity, thereby enhancing facility reliability and process safety. Economically, the investment analysis recommends an optimal capacity of 6000 BWPD with strong financial indicators (NPV USD 84.83 million, IRR 80.77%, PP 24 months), ensuring project viability and added value. Additionally, the study supports environmental compliance through improved produced water management. The integrated methodological framework (FMEA, CBA, Sensitivity Analysis) provides a replicable approach for similar project evaluations, while the derived risk tolerance threshold (–1.5% daily production decline) offers a quantified basis for more informed and sustainable management decision-making.

This study aims to evaluate the technical and economic feasibility of upgrading the Produced Water Treatment System (PWTS) capacity at a gas processing facility, in response to the increasing volume of produced water that exceeds the existing design. Specifically, it seeks to identify equipment failure risks using Failure Mode and Effect Analysis (FMEA), assess investment viability through Cost-Benefit Analysis (CBA), and determine the optimal PWTS capacity to maintain operational safety and financial sustainability. The research provides practical benefits for facility managers and decision-makers by offering a data-driven framework for risk-informed investment planning, enhancing operational reliability, ensuring regulatory compliance, and supporting long-term economic performance. It also contributes methodologically by integrating technical risk assessment with economic analysis, presenting a replicable model for similar projects in the oil and gas sector.

METHOD

This study uses an applicative quantitative approach with the main objective of analyzing the feasibility of investment in PWTS capacity building. Technical risk assessment was carried out using Failure Mode and Effect Analysis (FMEA), the results of which were processed using PT XYZ's standard Risk Matrix to quantify risk.

The feasibility of the investment is analyzed using the Cost-Benefit Analysis (CBA) approach as part of the economic risk assessment. This analysis includes the evaluation of tangible assets and intangible assets, using financial indicators such as Net Present Value (NPV), Internal Rate of Return (IRR), Benefit-Cost Ratio (BCR), and Payback Period (PP).

Sensitivity analysis is also carried out to strengthen the management decision-making base. This approach aims to identify project feasibility thresholds (tipping points) and map the project's financial risks.

This research is applicable through a case study on the PWTS system of PT XYZ facilities, with a focus on optimizing equipment capacity to ensure the continuity of operations in a safe, reliable, and sustainable manner.

The research location is where the researcher conducts research and data collection. The research was conducted at the head office and gas field facilities operated by PT. XYZ.

The data used in this study includes questionnaire primary data for failure mode, cause of failure, and the effect of PWTS equipment failure according to the FMEA concept. Expert judgement assessment of FMEA (Severity, Occurrence, Detection, Dependency) parameters as technical risk quantification data. The teams involved in the discussion process are as follows:

Table 1. Technical Team

Position	Experience
Superitendent Production	>15 years old
Supervisor Production	8 – 10 years
Supervisor Maintenance	8 – 10 years
Field Process Engineer	8 – 10 years
Field Mechanical Engineer	8 – 10 years
Engineering Manager	>15 years old
Engineering Section Head	>10 years
Process Engineer	8 – 10 years
Integrity & Reability Engineer	8 – 10 years
Operator	3 – 5 years

Source: Expert judgment assessment and team composition data from PT XYZ (2025)

Secondary data: PWTS equipment datasheet, Produced water production data in 2024 and 2025, Petroleum engineering production projection data (sub-surface), Reference price (shopping list) and historical Capital Expenditure (CAPEX) data from PT XYZ, Budgeting of service/material provider proposals, References to related journals.

Technical Risk Assessment with FMEA

FMEA is a systematic and data-based method that aims to identify, evaluate, and prioritize the risk of failure based on a combination of the impact of equipment failure (Severity), Occurrence Probability, Detection Capability and Dependency. Increased water volume can have a significant impact on the reliability of the operation of key equipment in a PWTS system, such as production separators, hydrocyclones, degassing columns, produced water storage tanks, water booster & injection pumps, and filters. Therefore, the FMEA approach was chosen to assess technical risks in a structured manner and serve as the basis for the justification of investments.

FMEA Implementation Order

The steps to implement FMEA in this study are as follows:

1) PWTS system analysis

Analysis of the PWTS system at the gas processing facility of PT. XYZ, based on Process Flow Diagram (PFD) and Piping & Instrument Diagram (P&ID).

2) Identify failure mode

At this stage, the possibility of failure that can occur for all major equipment such as overflow, corrosion, cavitation, performance degradation, or the possibility of increased pressure is analyzed.

3) Identify the failure cause

Examine the root causes such as increased flowrate, slugging, imperfect separation, changes in fluid viscosity, decreased tool efficiency, inadequate capacity design.

4) Failure effects analysis

Assess the direct impact on facility operations, such as: potential downtime, equipment damage, and increased maintenance time.

5) Risk assessment

Each failure mode is evaluated with the following parameters: Severity (S): Impact on operations and safety, Occurrence (O): Frequency of potential failures, Detection (D): The ability of the system to detect failures before impact, Dependency (D2): The degree of interconnectedness between equipment in the system. Score range: 1-10, obtained through the results of the technical team assessment as expert judgment.

6) Risk Priority Number (RPN)

$$\mathrm{RPN} = \mathrm{SxOxDxD2}$$

The higher the RPN value, the higher the urgency of mitigation needed.

Quantifying Risk with Risk Matrix

Quantify risk by converting Severity and Occurrence scores into Consequences and Probability on the Risk Matrix in accordance with the Major Accidenc Hazard (MAH) PT XYZ. The 5 x 5 risk matrix used reflects the level of consequences and probability of risk.

LEVEL	PROBABILITY (LIKELIHOOD)				
	1	2	3	4	5
	0% < X > 20%	20%< X <40%	40%< X <60%	60% < X <80%	80%< X <100%
	<10^-6 per year	10^-6 to 10^-4 per year	10^-4 to 10^-2 per year	10^-2 to 10^-1 per year	>1 per year
5 (Catastrophic)	5	10	15	20	25
4 (Significant)	4	8	12	16	20
3 (Moderate)	3	6	9	12	15
2 (Minor)	2	4	6	8	10
1 (Insignificant)	1	2	3	4	5

Figure 1. Risk Matrix Major Accident Hazard (MAH) PT XYZ

Source: PT XYZ Major Accident Hazard (MAH) Risk Matrix Standard (2025)

Convert FMEA Severity and Occurrence scores as follows:

Table 2. Severity conversion score

FMEA(S) Score	Matrix Level (1-5)	Matrix Categories	Impact Description	Cost per incident
9.01 - 10.00	5	Catastrophic	Huge Production/Asset Loss (>$5 Million)	USD 10,000,000.00
7.01 - 9.00	4	Significant	Large Production/Asset Losses (USD Millions)	USD 5,000,000.00
5.01 - 7.00	3	Moderate	Moderate Losses (Hundreds of Thousands USD)	USD 500,000.00
3.01 - 5.00	2	Minor	Small Losses (Thousands of USD)	USD 100,000.00
1.00 - 3.00	1	Insignificant	Very Small/Insignificant Losses	USD 25,000.00

Source: Adapted from PT XYZ Risk Matrix guidelines and FMEA conversion framework (2025)

Table 3. Occurrence conversion score

Skor FMEA (O)	Level Matriks (1-5)	Category Matrix	Probability/Frequency	Quantitative Value
9.01 - 10.00	5	Frequent Occurrences	> 1 per year	2
7.01 - 9.00	4	May Happen	10^-3 to 10^-1 per year	0.1
5.01 - 7.00	3	Sometimes It Happens	10^-4 to 10^-3 per year	0.001
3.01 - 5.00	2	Rare	10^-6 to 10^-4 per year	0.0001
1.00 - 3.00	1	Very Rare	<10^-6 per year	0.000001

Source: Adapted from PT XYZ Risk Matrix guidelines and FMEA conversion framework (2025)

The risk of equipment failure in the form of a consequence x probability results in an expected cost which will be used as one of the tangible cost values in CBA.

FMEA and CBA integration

The validated FMEA results are further used as the basis for justifying the investment needs in the CBA approach, namely: Equipment with the highest RPN value is prioritized for capacity upgrades or modified as part of the investment, Mitigation costs (CAPEX and OPEX) are calculated based on technical recommendations from FMEA results, Economic benefits are calculated from a reduction in potential production losses, reduced downtime, and further damage avoidance. Thus, the results of the technical risk assessment (FMEA) as a justification for investment in increasing PWTS capacity, as well as strengthening data-based investment decisions and measurable risk analysis.

Economic Risk Assessment with CBA

The economic risk analysis in this study was carried out using the Cost-Benefit Analysis (CBA) method as a framework for evaluating the feasibility of investing in increasing the capacity of Produced Water Treatment System (PWTS) equipment. The CBA approach systematically compares the total cost and total benefit of the discounted project. Economic risk evaluation is carried out in three main stages: (1) Cost and benefit analysis (tangible and intangible assets), (2) Quantification of annual risk (Expected Cost) as Avoided Cost, and (3) Calculation of investment eligibility.

Cost and Benefit Analysis (Tangible & Intangible Asset)

Investment feasibility takes into account all costs and benefits. Costs are broken down into Capital Expenditure (CAPEX) and Operational Expenditure (OPEX), which include tangible assets (physical equipment) and non-physical costs (e.g., training and engineering fees). The Intangible Benefit of the investment in capacity building is measured based on the Avoided Cost, namely Downtime Avoidance and Asset Damage Avoidance.

Quantification of Annual Risk (Expected Cost)

Expected Cost (E_{cost}) is the value of the expected annual financial loss due to the potential risk of failure of PWTS equipment. E_{cost} serves as a quantitative basis for calculating Investment Benefits, which is defined as Avoided Cost. The calculation of E_{cost} is based on a Risk Matrix that converts the FMEA parameters as follows: Annual failure rate (X): obtained from mapping the Occurrence (O) FMEA score to the frequency of events per year. Consequence cost (total C): obtained from mapping the FMEA Severity (S) score to total financial losses per incident, i.e. total C = $C_{downtime} + C_{damage}$. The annual expected cost formula is,

$$E_{cost} = X \text{ x } C_{total}$$

Investment Feasibility Calculation

In calculating the feasibility of investment in this study, some of the assumptions used are as follows: Gross Heating Value (GHV): 1050, Plan operating time: 350 days/year, Gas Price: USD 6.5/ MMBTU, Oil/Condensate Price: USD 67.92/ Barrel, MARR: 14%, Depreciation: 25%, Tax: 22%, Operating Inflation: 5%/ year, Financing scheme: 30% (Equity), 70% (Loan) with Interest of 7%/year. Gas and oil prices based on the Ministry of Energy and Mineral Resources of the Republic of Indonesia, the oil price used in this study is USD 67.92 /BBL and the gas price is USD 6.5 /MMBTU.(Minister of Energy and Mineral Resources of the Republic of Indonesia, 2025a, 2025b)

According to the hurdle rate (MARR), the average optimal oil and gas project in Indonesia is 10.91% - 15.42%. In this study, the hurdle rate (MARR) was used at 14%, considering that the PWTS system is one of the main systems in gas treatment facilities.(Ratna & Puspita, 2023)

Investment feasibility is measured by the following NPV, IRR, BCR, and PP indicators:

1) Net Present Value (NPV)

NPV is used to measure the difference between the total benefits to be received and the total costs incurred, after both are discounted to the present value. This concept takes into account that the value of money today is higher than the value of money in the future, because of the existence of alternative investment opportunities. The NPV formula is as follows:

$$NPV = \sum_{t=1}^{T} \frac{B_t - C_t}{(1+r)^t} - C_0$$

Where:

B_t = (benefit) in t year

C_t = Operational cost in t year

r = Discount level (MARR)

C_0 = Investment cost

T = Project age (year)

The NPV acceptance criteria in assessing investment feasibility are based on the nominal value shown from the calculation results. The acceptance indicators are as follows: NPV > 0, then the investment is financially feasible, the NPV < 0, then the investment is not financially feasible, NPV has become a popular measuring tool because of its simplicity and reliability in measuring the future value of an investment. NPV is compiled based on cash flow consisting of cash in and cash out, which is calculated by taking into account the element of uncertainty, namely interest rate. NPV describes the projected amount of cash in the future, but is valued based on the current value of money (Dai et al., 2022) .

2) Internal Rate of Return (IRR)

One method to evaluate the feasibility of an investment is to look at the magnitude of the interest rate. When the NPV value is equal to zero, the interest rate that occurs is referred to as the internal rate of return (IRR). Cash flow at NPV = 0 can provide information about the IRR expressed in percentages per time period. The IRR formula is as follows:(Dai et al., 2022)

$$0 = \mathrm{NPV} = \sum_{t=1}^{T} \frac{C_t}{(1 + \mathrm{IRR})^t} - C_0$$

Where:
C_t = Net cash inflow in t year
C_0 = Investment year
IRR = Internal rate of return
T = Project age (year)

3) Benefit Cost Ratio (BCR)

BCR is an alternative measure for assessing the feasibility of an investment, where the value of benefits and costs is compared so that the value of BCR is in the range between 0 to 1. The BCR method pays attention to the aspects of benefits obtained as well as the costs that must be incurred. The BCR formula is as follows:(Dai et al., 2022)

$$\mathrm{BCR} = \frac{\mathrm{Benefit}}{\mathrm{Cost}}$$

The criteria for determining the feasibility of investment using the BCR method are as follows: BCR ≥ 1, then the investment is considered feasible, BCR < 1, then the investment is considered unfeasible.

4) Payback Period (PP)

The analysis of investment feasibility should be displayed in several investment indicators in addition to the cash flow component. One of the indicators that can be presented is in the form of a period of return on investment. The payback period must be measured when the cash flow has reached a break-even point or initial return on capital (break even point). The PP formula is as follows:(Dai et al., 2022)

$$\mathrm{PP} = \frac{\text{Initial Investment}}{\text{Annual Cash Flow}}$$

The shorter the duration of the PP, the sooner the project can return the initial investment so that it is considered safer or profitable.

Sensitivity Analysis

Sensitivity analysis was used to assess the impact of changes in oil and gas production on the investment feasibility indicators, namely NPV, IRR, and PP for each PWTS capacity alternative. This approach is part of economic risk assessment, which aims to provide a quantitative basis for management in investment decision-making. Sensitivity Analysis Steps: Establish the baseline of oil and gas production capacity (2000 BWPD – base case), Conduct systematic variation of CAPEX and OPEX values, with a general range of variation of -0.5%, -1%, ..., -5% of the baseline value. Recalculate the investment feasibility indicators of NPV, IRR, and PP for each combination of production capacity change scenarios. Analyze the sensitivity of the results to find out the tipping point at which the project remains or is no longer feasible.

RESULTS AND DISCUSSION

Production Data and PWTS Capacity Projection

This study uses production forecast data prepared by the subsurface team until 2047, as well as actual production data throughout 2024 to the second quarter (Q2) of 2025. These data include the volume of gas, oil, and produced water production.

1. Production Forecast

Projected production of gas, oil, and water produced is analyzed according to the duration of the work facility operation agreement. The high production uncertainty influenced by reservoir conditions and well operation patterns require forecasts to be prepared based on the Produced Water Treatment System (PWTS) installed capacity approach. The production forecast simulation is presented in five PWTS capacity scenarios: 2000 BWPD (existing), 4000 BWPD, 6000 BWPD, 8000 BWPD, and 10000 BWPD.

A) Gas Production

Projected gas production production for the period 2024 to 2047, based on five PWTS capacity scenarios, is shown in Figure 2.

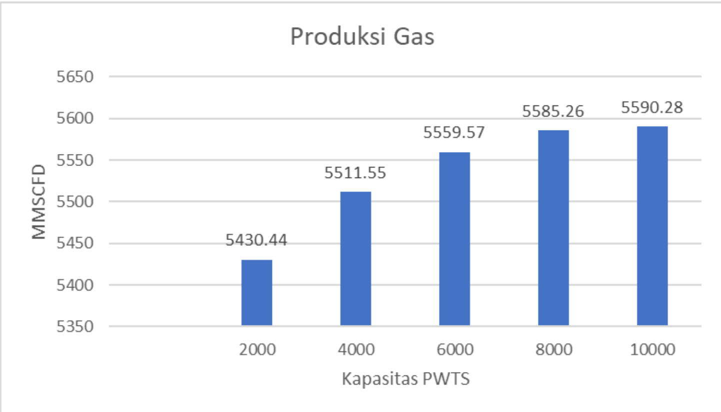

Figure 2. Total projected gas production

Source: Author's visualization based on subsurface team production forecast data (2024–2047), PT XYZ

B) Oil Production

Projected oil production production for the period 2024 to 2047, based on five PWTS capacity scenarios, is shown in Figure 3.

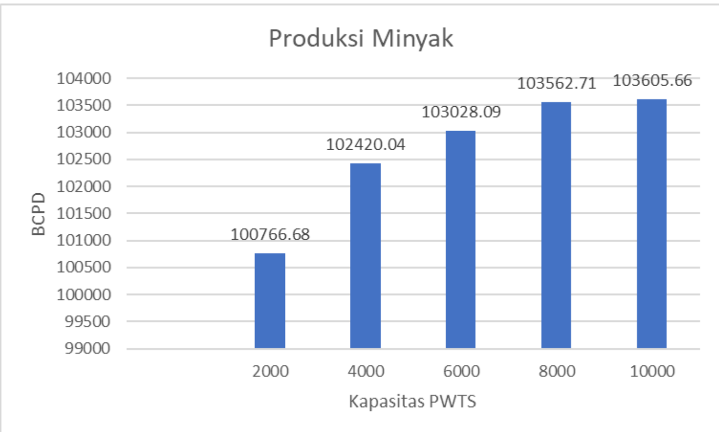

Figure 3 Total oil production projections

Source: Author's visualization based on subsurface team production forecast data (2024–2047), PT XYZ

C) Water produced

The projected water produced for the period 2024 to 2047, based on five PWTS capacity scenarios, is shown in Figure 4.

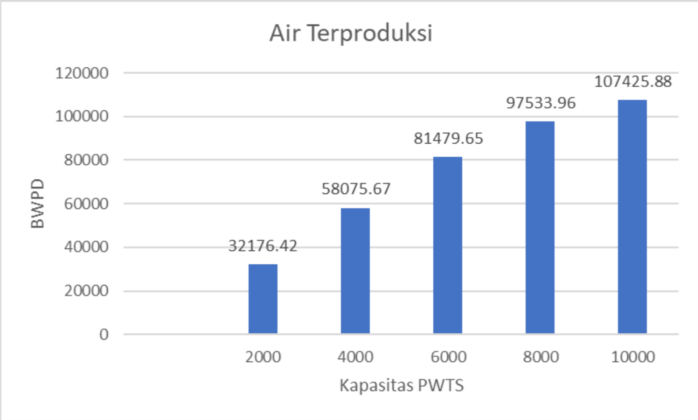

Figure 4. Total projected water produced

Source: Author's visualization based on subsurface team production forecast data (2024–2047), PT XYZ

Data on the incremental volume of gas, oil, and water production from 2024 to 2047 for each PWTS capacity scenario is the main reference in the calculation of Cost-Benefit Analysis (CBA). The incremental data is summarized in Table 4.1.

Table 4. Incremental production of gas, oil and water produced

Kapasitas PWTS	Forecast Produksi						Incremental	
	Max Gas Rate, MMSCFD (2024 - 2047)	Max Condensate Rate, BCPD (2024 - 2047)	Max Water Rate, BWPD (2024 - 2047)	Total Gas Rate, MMSCFD (2024 - 2047)	Total Condensate Rate, BCPD (2024 - 2047)	Max Water Rate, BWPD (2024 - 2047)	Gas (MMSCFD)	Condensate (BCPD)
2000 BWPD (eksisting)	332.00	7,306.39	1,969.72	5,430.44	100,766.68	32,176.42	-	-
4000 BWPD	332.00	7,300.85	3,997.73	5,511.55	102,224.88	58,075.67	81.11	1,458.20
6000 BWPD	332.00	7,297.74	5,933.33	5,559.57	102,957.51	81,479.65	129.13	2,190.82
8000 BWPD	332.00	7,306.07	7,963.77	5,585.26	103,603.76	97,533.96	154.82	2,837.08
10000 BWPD	332.00	7,297.22	9,763.01	5,590.28	103,616.53	107,425.88	159.84	2,849.84

Source: Subsurface team production forecast data (2024–2047), PT XYZ

2. Actual Production Data

Actual production data throughout 2024 and production data until August 2025. These data show fluctuations in water production over time. Production data can be seen in the following table:

Table 5. Actual production data for 2024

Bulan	Sum of Feed Gas (MMSCFD)	Average of Produksi Gas (MMSCFD)	Average of Produksi Gas (MMBTUD)	Average of Produksi Produced Water (BWPD)	Max of Produksi Produced Water (BWPD)	Average of Produksi Condensate (BPD)
Jan	9896.48	306.22	343211.30	1178.09	2963.34	7336.36
Feb	9765.57	322.45	361402.36	1364.31	2617.33	7671.56
Mar	10472.94	324.57	363271.48	1631.62	2748.59	7680.98
Apr	10172.03	325.20	363932.60	1267.93	1582.05	7786.69
May	9901.42	306.66	343174.61	1252.58	1587.98	7200.52
Jun	9668.05	309.65	346606.25	1588.95	2405.69	7295.26
Jul	10641.18	329.99	369378.85	1891.77	3110.10	7701.45
Aug	10734.31	332.94	372676.77	2133.58	3024.12	7747.25
Sep	10099.88	323.06	361724.80	2448.89	3054.21	7518.73
Oct	5239.49	161.05	180197.54	386.25	1057.61	3665.84
Nov	10400.76	331.73	371132.53	1037.03	1431.07	7782.79
Dec	9394.63	321.97	360212.11	1101.09	1572.18	7446.18

Source: PT XYZ production records (2024)

Table 6. Actual production data for 2025 (January – August)

Bulan	Sum of Feed Gas (MMSCFD)	Average of Produksi Gas (MMSCFD)	Average of Produksi Gas (MMBTUD)	Average of Produksi Produced Water (BWPD)	Max of Produksi Produced Water (BWPD)	Average of Produksi Condensate (BPD)
Jan	8807.70	272.49	304851.77	1113.69	1492.29	6269.05
Feb	8850.43	303.29	339438.25	1369.06	1979.87	7041.65
Mar	9637.69	298.13	333639.51	1521.13	2424.09	6903.59
Apr	9090.56	290.84	325591.73	1620.47	2729.37	6681.53
May	10054.95	311.52	348805.57	1725.16	2105.17	7152.31
Jun	9385.84	300.08	336020.79	1823.85	2455.76	6838.45
Jul	10670.16	330.27	369777.01	1960.14	2427.91	7517.93
Aug	10420.13	322.31	361156.95	1898.91	2613.02	7336.71

Source: PT XYZ production records (2024)

The data in the table above shows fluctuations in the production of gas, oil, and water produced in line with reservoir conditions and operating patterns. These fluctuations indicate that at certain times, the volume of water produced exceeds the design capacity of existing equipment. Figure 5 and Figure 6 are actual production graphs.

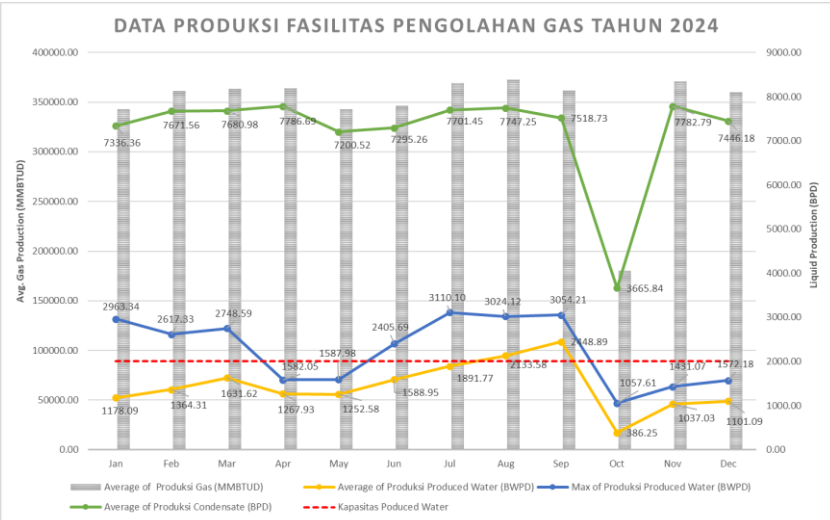

Figure 5. 2024 production chart

Source: Author's visualization based on PT XYZ production data (2024)

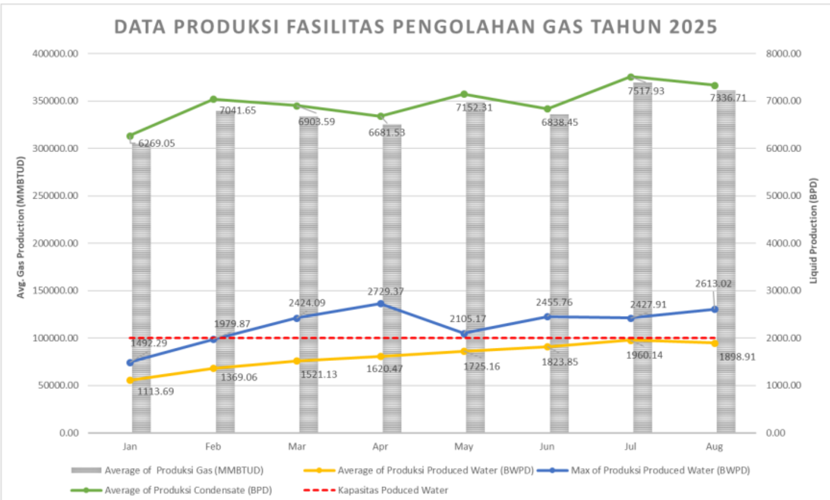

Figure 6. Production chart of 2025

Source: Author's visualization based on PT XYZ production data (2024)

In the graph above, the monthly cumulative gas production is shown with bars. Oil and water production are shown in a graph. The blue line shows the maximum water production in each month, which at a certain time has exceeded the design capacity of the main equipment of PWTS indicated by the red line. Based on production data, in July 2024 the maximum production of water produced will reach 3110 BWPD. Meanwhile, maximum production throughout 2025 reached 2729 BWPD in April.

1.2. Technical Risk Assessment with FMEA method

Technical risk assessment is carried out to determine the risk assessment of PWTS' main equipment if the production of water exceeds capacity with the FMEA method. Discussions were conducted with the technical team which included the operation and maintenance teams.

1. FMEA Questionnaire

Risk assessment in the form of failure mode, cause of failure and effect of failure questionnaires was determined from the results of discussions and opinions by the technical team. The results of the questionnaire were collected for further analysis at the risk assessment stage of PWTS's main equipment.

2. PWTS Equipment Risk Assessment

Of the 10 questionnaire assessments by the technical teams for Severity (S), Occurrence (O), Detection (D), and Dependency (D2) were used for the RPN assessment. The RPN value is calculated from (S × O × D × D2). The results of the 10-person technical team risk assessment can be seen in Appendix-1.

Based on the total RPN value, the risk assessment is categorized into Low risk with an RPN value of <800, Medium with an RPN value of 800 – 1500, High with an RPN value of >1500. Equipment failure mode identified has the potential to result in downtime and asset damage to gas treatment facilities. The FMEA Severity and Occurrence Assessment is quantified by converting the score to Consequences and Probability on the Risk Matrix.

The results of the assessment showed three equipment with the highest risk, namely Hydrocyclone, Produced Water Booster Pump, and Produced Water Injection Pump. These three appliances have the potential to be a critical point for increasing the capacity of water produced.

3. Risk Mitigation

From the risk assessment above, further mitigation is needed so that the PWTS system can operate optimally. Mitigation is carried out on equipment with medium and high risk. Mitigation in the form of tangible is carried out by adding equipment capacity included in CAPEX, as well as condition monitoring equipment included in OPEX. In addition, mitigation is also carried out on intangible factors in the form of training for technicians and operators, ensuring that human resources have reliable competencies to operate PWTS equipment.

Economic Risk Assessment with CBA method

The CBA analysis was conducted to evaluate the financial feasibility of investing in PWTS capacity building. This evaluation includes the calculation of Capital Expenditure (CAPEX), Operational Expenditure (OPEX), Intangible Cost, as well as economic feasibility indicators such as Net Present Value (NPV), Internal Rate of Return (IRR), Benefit Cost Ratio (BCR), and Payback Period (PP)

4. Capital Expendix (CAPEX)

The CAPEX calculation is based on the value of the investment required for the capacity increase of PWTS equipment. The CAPEX analysis is divided into two main aspects: Tangible Asset: Includes the cost of procurement of main equipment (hydrocyclone, degassing column, booster pump, injection pump, and filter), bulk material procurement, as well as project management, engineering, and construction process costs. Intangible Asset: Includes investment costs for the development of new SOPs and upgrades to the control philosophy of PWTS operations.

This analysis aims to evaluate the scenario of increasing PWTS capacity to 4000 BWPD, 6000 BWPD, 8000 BWPD, and 10000 BWPD. CAPEX is summarized in Table 4.7.

Table 7. CAPEX equipment capacity increase

No	Deskripsi	Opsi-1 Total 4000 bwpd (peningkatan kapasitas 2000 bwpd)	Opsi-2 Total 6000 bwpd (peningkatan kapasitas 4000 bwpd)	Opsi-3 Total 8000 bwpd (peningkatan kapasitas 6000 bwpd)	Opsi-4 Total 10000 bwpd (peningkatan kapasitas 8000 bwpd)
A	**CAPEX Tangible Asset**				
1	Project Management Team	Rp 4,330,127,000	Rp 4,330,127,000	Rp 4,330,127,000	Rp 4,330,127,000
2	Engineering	Rp 4,820,892,000	Rp 4,820,892,000	Rp 4,820,892,000	Rp 4,820,892,000
3	Procurement				
3.1	Main Equipment				
	- Hydrocyclone Package	*1 x 2000 BWPD*	*2 x 2000 BWPD*	*2 x 3000 BWPD*	*2 x 4000 BWPD*
		Rp 25,159,200,000	Rp 28,436,100,000	Rp 31,713,000,000	Rp 33,210,650,000
	- Water Booster Pump	*1 x 2000 BWPD*	*2 x 2000 BWPD*	*2 x 3000 BWPD*	*2 x 4000 BWPD*
		Rp 1,533,675,000	Rp 1,533,675,000	Rp 3,067,350,000	Rp 3,698,056,000
	- Water Injection Pump	*1 x 2000 BWPD*	*2 x 2000 BWPD*	*2 x 3000 BWPD*	*2 x 4000 BWPD*
		Rp 7,314,450,000	Rp 7,314,450,000	Rp 14,628,900,000	Rp 17,636,884,000
	- Degassing Column		*1 x 5000 BWPD*	*1 x 5000 BWPD*	*1 x 5000 BWPD*
		Rp -	Rp 3,266,331,000	Rp 3,266,331,000	Rp 3,266,331,000
	- Produced Water Filter	*1 x 2000 BWPD*	*2 x 2000 BWPD*	*2 x 3000 BWPD*	*2 x 4000 BWPD*
		Rp 609,000,000	Rp 810,000,000	Rp 1,620,000,000	Rp 1,984,000,000
3.2	Bulk Piping Material	Rp 5,272,948,000	Rp 5,271,572,000	Rp 6,847,826,000	Rp 7,515,550,000
3.3	Bulk Instrumentation Material	Rp 3,244,890,000	Rp 6,488,089,000	Rp 8,428,093,000	Rp 9,249,907,000
3.4	Bulk Electrical Material	Rp 6,489,780,000	Rp 3,244,044,000	Rp 4,214,046,000	Rp 4,624,954,000
3.5	Bulk Civil Material	Rp 258,612,000	Rp 405,506,000	Rp 526,756,000	Rp 578,119,000
4	Construction & Installation	Rp 13,475,755,000	Rp 13,381,683,000	Rp 17,382,942,000	Rp 19,077,934,000
5	Comissioning & Start-up	Rp 1,764,144,000	Rp 1,622,022,000	Rp 2,107,023,000	Rp 2,312,477,000
	Total	**Rp 74,273,473,000**	**Rp 80,924,491,000**	**Rp 102,953,286,000**	**Rp 112,305,881,000**
		USD 4,791,836.97	**USD 5,220,934.90**	**USD 6,642,147.48**	**USD 7,245,540.71**
B	**CAPEX Intangible Asset**				
1	Development SOP	Rp 1,205,223,000	Rp 1,205,223,000	Rp 1,205,223,000	Rp 1,205,223,000
2	Upgrade Control philosophy	Rp 192,836,000	Rp 192,836,000	Rp 192,836,000	Rp 192,836,000
	Total	**Rp 1,398,059,000**	**Rp 1,398,059,000**	**Rp 1,398,059,000**	**Rp 1,398,059,000**
		USD 90,197.35	**USD 90,197.35**	**USD 90,197.35**	**USD 90,197.35**
C	**Total CAPEX**	**USD 4,882,034.32**	**USD 5,311,132.26**	**USD 6,732,344.84**	**USD 7,335,738.06**

Source: Author's compilation based on vendor proposals and historical CAPEX data, PT XYZ

5. Operational Expendditur (OPEX)

The operational costs analyzed in this study are existing operational costs and operational costs for increasing the capacity of PWTS equipment with capacities of 4000 BWPD, 6000 BWPD, 8000 BWPD, and 10000 BWPD.

A) Operating costs of gas processing facilities (existing)

Existing operational costs include direct costs, indirect costs, and non-routine operational costs of turn-round activities.

Table 1. Gas treatment facility operating costs

	Deskripsi	Total Cost
A	**OPEX**	
1	Direct Cost (Operation & Maintenance)	Rp 302,250,000,000
2	Indirect Cost	Rp 60,450,000,000
3	Turn Around Cost (per 3 tahun)	Rp 150,000,000,000
	Total	**Rp 512,700,000,000**
		USD 33,077,419.35

Source: PT XYZ financial and operational reports (2024)

B) Operational costs of equipment capacity increase

Tangible operational costs for equipment capacity increase include labor costs, spare parts, consumable materials. Intangible operational costs include training and insurance.

Table 2. Operational costs of PWTS capacity building

No	Deskripsi	Opsi-1 Total 4000 bwpd (peningkatan kapasitas 2000 bwpd)		Opsi-2 Total 6000 bwpd (peningkatan kapasitas 4000 bwpd)		Opsi-3 Total 8000 bwpd (peningkatan kapasitas 6000 bwpd)		Opsi-4 Total 10000 bwpd (peningkatan kapasitas 8000 bwpd)	
A	**OPEX Tangible Asset**								
1	Labor								
1.1	Operator	Rp	730,000,000	Rp	730,000,000	Rp	730,000,000	Rp	730,000,000
1.2	Technician	Rp	1,095,000,000	Rp	1,095,000,000	Rp	1,095,000,000	Rp	1,095,000,000
2	Spare part kit material:								
	- Hydrocyclone Package	Rp	503,184,000	Rp	568,722,000	Rp	634,260,000	Rp	664,213,000
	- Water Booster Pump	Rp	230,051,250	Rp	230,051,250	Rp	460,102,500	Rp	554,708,400
	- Water Injection Pump	Rp	438,867,000	Rp	438,867,000	Rp	877,734,000	Rp	1,058,213,040
	- Degassing Column	Rp	-	Rp	195,979,860	Rp	195,979,860	Rp	195,979,860
	- Produced Water Filter	Rp	48,720,000	Rp	64,800,000	Rp	129,600,000	Rp	158,720,000
3	Consumable material	Rp	450,012,225	Rp	537,687,228	Rp	705,842,553	Rp	777,346,973
	Total	**Rp**	**3,495,834,475**	**Rp**	**3,861,107,338**	**Rp**	**4,828,518,913**	**Rp**	**5,234,181,273**
		USD	**225,537.71**	**USD**	**249,103.70**	**USD**	**311,517.35**	**USD**	**337,689.11**
B	**OPEX Intangible Asset**								
1	Training Operator & Technician	Rp	320,000,000	Rp	320,000,000	Rp	320,000,000	Rp	320,000,000
2	Insurance	Rp	1,513,430,640	Rp	1,646,451,000	Rp	2,087,026,900	Rp	2,274,078,800
	Total	**Rp**	**1,833,430,640**	**Rp**	**1,966,451,000**	**Rp**	**2,407,026,900**	**Rp**	**2,594,078,800**
		USD	**118,285.85**	**USD**	**126,867.81**	**USD**	**155,292.06**	**USD**	**167,359.92**
C	**Total OPEX**	**USD**	**343,823.56**	**USD**	**375,971.51**	**USD**	**466,809.41**	**USD**	**505,049.04**

Source: Author's analysis based on operational budgeting data, PT XYZ

Expected Cost

Expected Cost is used to quantify the risks that have been identified in the FMEA analysis. Expected Cost represents the potential financial loss derived from the risk of downtime and high asset damage if there is no increase in the capacity of PWTS equipment (Base Case – 2000 BWPD). This Expected Cost calculation integrates the risk value (RPN) and the potential monetary losses that may arise, thus functioning as a risk management component that must be considered in the investment feasibility analysis.

Table 3. Expected Cost per year

No	Potensi Risiko	Efek	Total Cost
1	Downtime	Loss of Production	USD 10,785,684.00
2	Asset Damage	Perbaikan peralatan	USD 24,350.00

Source: Author's calculation based on FMEA and Risk Matrix analysis, PT XYZ

Investment Analysis

Based on the projected data and costs that have been analyzed, a feasibility analysis of the project was carried out to increase the capacity of PWTS equipment. Investment analysis to determine the optimal equipment capacity to be applied in gas processing facilities. Investment analysis is in Appendix-2. Table 4.11 is a summary of the assessment of investment analysis.

Table 4. Investment analysis summary

Parameter	Unit	2000 BWPD (Base Case) (MM USD)	4000 BWPD (MM USD)	6000 BWPD (MM USD)	8000 BWPD (MM USD)	10000 BWPD (MM USD)
CAPEX			USD 488	USD 331	USD 673	USD 734
Total Revenue		USD 14,470.80	USD 14,703.86	USD 14,833.01	USD 14,907.09	USD 14,920.10
Total OPEX		1,209.98	USD 925.99	USD 927.06	USD 996.49	USD 997.86
Incremental Net Operating Income (NOI)			USD 506.24	USD 634.32	USD 638.97	USD 650.62
Loan (70%)	70%		USD 3.66	USD 3.98	USD 3.04	USD 3.49
Depreciation			USD 3.66	USD 3.98	USD 3.05	USD 3.50
Tax (22%)	22%		USD 105.93	USD 131.54	USD 142.02	USD 145.75

Parameter	Unit	2000 BWPD (Base Case) (MM USD)	4000 BWPD (MM USD)	6000 BWPD (MM USD)	8000 BWPD (MM USD)	10000 BWPD (MM USD)
Equity Cash Flow After Tax			USD 400.31	USD 502.79	USD 496.96	USD 504.88
NPV		USD (@0.81)	USD 78.80	USD 84.83	USD 36.92	USD 4.49
IRR			36.75%	30.77%	65.18%	60.91%
BCR			16.47	16.59	15.47	15.46
PP	Bulan		23	24	41	48

Source: Author's analysis based on CBA and financial projections (2025)

The comparison of the total revenue from each PWTS capacity to the total operational costs is presented in Figure 7.

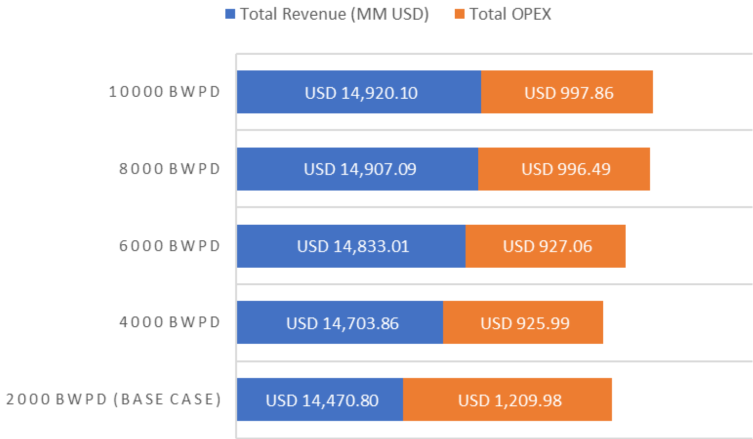

Figure 7. Revenue vs operating costs

Source: Author's analysis based on CBA results (2025)

Based on Figure 7, it can be seen that increasing PWTS capacity significantly increases total revenue, while total operating costs (OPEX) are relatively controlled in all upgrade scenarios.

To determine the most optimal PWTS capacity increase scenario, Figure 8 presents a comparison between the investment value (CAPEX) and the Net Present Value (NPV) of the project.

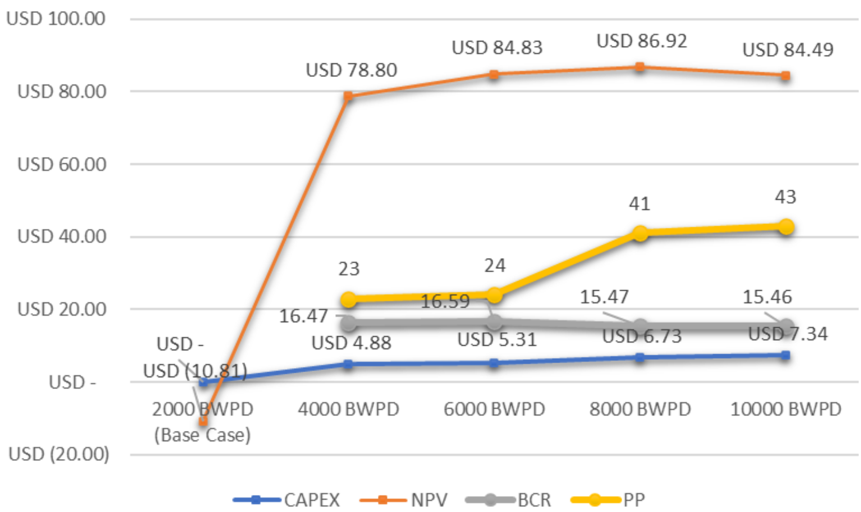

Figure 8. NPV Project

Source: Author's analysis based on investment evaluation (2025)

The capacity of PWTS 8000 BWPD is the most optimal capacity. This is confirmed from the investment value of USD 5.31 million resulting in an NPV of USD 84.83 million, IRR of 80.77%, BCR with a value of 16.59, and PP for 24 months.

Sensitivity Analysis

Sensitivity analysis is carried out as part of risk management to determine the project's tolerance limit to changes in the main variable, namely production capacity fluctuations. This analysis modeled the effect of a decrease in incremental production capacity ranging from -0.5% to -5%. The results of the sensitivity analysis for the optimal investment scenario of 6000 BWPD are presented in Figure 4.8.

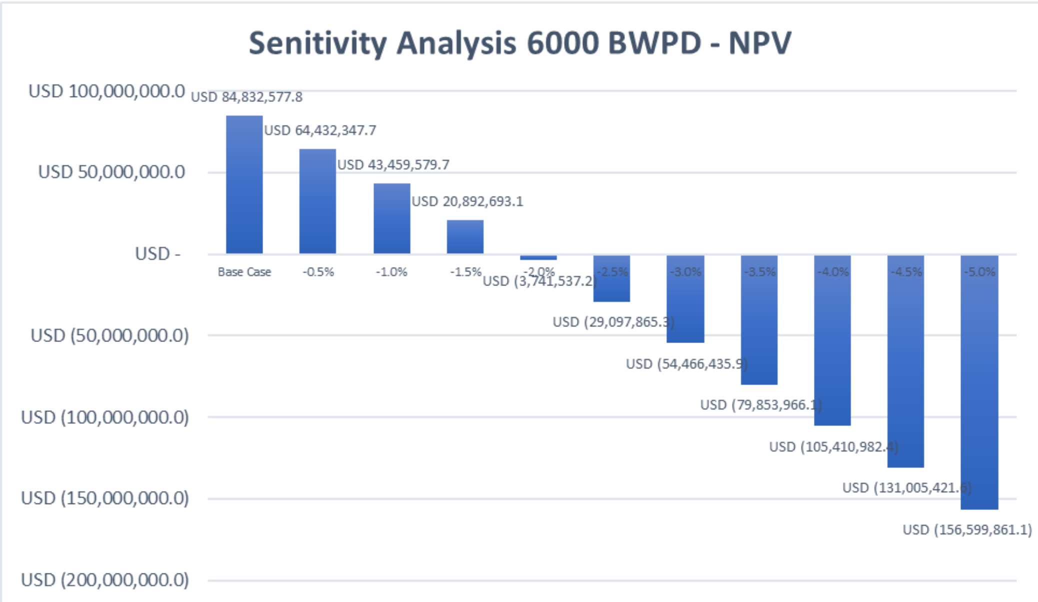

Figure 9. Sensitivity analysis PWTS 6000 BWPD

Source: Author's sensitivity analysis based on production decline scenarios (2025)

Based on Figure 4.8, the 6000 BWPD capacity increase project proved to be sensitive to production declines. NPV reached a negative value of USD -3.7 million when there was a decrease in production of -2% per day (equivalent to the loss of gas production ±6.6 MMSCFD and oil ±127 BOPD). Thus, the maximum tolerance limit for project cash flow to remain positive is at a decrease in production of -1.5% per day.

CONCLUSION

The actual produced water volume periodically exceeds PWTS equipment capacity, with FMEA and Risk Matrix identifying Hydrocyclone, Produced Water Booster Pump, and Produced Water Injection Pump as highest-risk items; Degassing Column and Produced Water Filter were also prioritized due to capacity constraints at the optimal 6,000 BWPD scale. Cost-Benefit Analysis (CBA) confirms this upgrade as the most viable option, delivering an NPV of 84.83 million USD, IRR of 80.77%, BCR of 16.59, and a 24-month Payback Period. Sensitivity Analysis establishes a 2% daily production drop (6 MMSCFD gas and 127 BOPD oil loss) as the risk threshold for negative NPV, guiding decision-making. For future research, exploring advanced automation and real-time monitoring systems (e.g., IoT-integrated sensors) could enhance predictive maintenance and further mitigate risks beyond static capacity upgrades.

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