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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 remains a strategic pillar for national energy security, yet it faces significant operational challenges as production fields mature. A critical issue is the exponential increase in produced water, which often surpasses the design limits of existing Produced Water Treatment Systems (PWTS). This research evaluates the investment feasibility of upgrading the PWTS capacity at a major gas processing facility where current water production has reached 3,110 BWPD, significantly exceeding the 2,000 BWPD design capacity. To address this, a hybrid framework was developed by integrating Technical and Economic Risk Assessments. Technical risks were quantified using Failure Mode and Effect Analysis (FMEA), involving 28 failure modes across seven primary equipment units. To mitigate the subjectivity of expert judgment, a Monte Carlo Simulation with 10,000 iterations was implemented, followed by a Risk Matrix to translate technical failures into quantifiable "Expected Costs." The Economic Risk Assessment was conducted via Cost-Benefit Analysis (CBA), incorporating these expected costs as avoided-loss benefits. The results identify an optimal upgrade capacity of 6,000 BWPD, which yields a Net Present Value (NPV) of USD 84.94 million, an Internal Rate of Return (IRR) of 80.88%, a Benefit-Cost Ratio (BCR) of 16.59, and a Payback Period (PP) of 24 months. Furthermore, sensitivity analysis underscores the project's robustness, demonstrating resilience against operational expenditure (OPEX) hikes of up to 50%, while establishing a critical production decline tolerance of -1.5% per day. This integrated methodology provides a robust, data-driven decision-making tool for managing high-risk energy infrastructure investments.

Keywords: Produced Water, Produced Water Treatment System (PWTS), Failure Mode and Effect Analysis (FMEA), Monte Carlo Simulation, Risk Matrix, Cost-Benefit Analysis (CBA), Sensitivity Analysis.

INTRODUCTION

The oil and gas sector remains a strategic pillar for Indonesia's economic resilience, contributing over IDR 110 trillion to state revenue in 2024 and creating a significant economic multiplier effect across supporting industries (Soesanto et al., 2025; Ditjen Migas, 2025). Central to this productivity is the Central Processing Plant (CPP), which manages complex hydrocarbon stabilization processes through systems such as gas-liquid separation, acid gas removal, and dehydration. However, as production fields reach maturity, facilities face an escalating challenge: the surge of produced water, a subsurface byproduct that requires rigorous management to maintain operational integrity and environmental compliance (Veil et al., 2004; Amakiri et al., 2022).

Operational assessments at a facility operated by PT XYZ have identified a profound "Design Capacity Gap." While the original Front-End Engineering Design (FEED) study projected a maximum water volume of only 366.90 BWPD by the sixteenth year of operation, actual production data in 2024 revealed a peak of 3,110 BWPD (PT XYZ, 2015). This surge, occurring just a decade into the plant's lifecycle, far exceeds the existing Produced Water Treatment System (PWTS) capacity of 2,000 BWPD. This discrepancy creates critical bottlenecks across primary equipment, including production separators, hydrocyclones, and injection pumps. Inadequate treatment allows residual oil and condensate to accumulate in storage tanks, elevating the risk of vapor leaks or potential explosions (Johnson et al., 2022). Currently, manual mitigation through vacuum truck handling is employed, yet this remains highly susceptible to human error and equipment unreliability, further destabilizing the facility's risk profile.

Addressing these technical and safety hazards necessitates a rigorous investment analysis that harmonizes engineering risk with financial viability (Kabyl et al., 2020). Conventional investment appraisals often overlook "intangible" engineering risks, focusing solely on direct returns. In contrast, this study adopts an integrative framework by quantifying technical failure probabilities into financial variables. Technical risk evaluation is conducted using Failure Mode and Effect Analysis (FMEA), which identifies potential failures based on severity, occurrence, detection, and dependency. To neutralize the inherent subjectivity of expert judgment, the study incorporates Monte Carlo Simulations utilizing a Triangular Distribution (Villalta et al., 2023). Through the application of a corporate Risk Matrix, these technical findings are transformed into "Expected Costs," providing a quantifiable financial input for a detailed Cost-Benefit Analysis (CBA).

The financial integrity of the proposed capacity upgrade is evaluated using indicators such as Net Present Value (NPV), Internal Rate of Return (IRR), Benefit-Cost Ratio (BCR), and Payback Period, accounting for both physical assets and intangible safety benefits (Harberger, 1991; Leiva Vilaplana et al., 2025). Furthermore, a Sensitivity Analysis is performed to gauge the project’s durability against production volatility and rising Operational Expenditure (OPEX). This research aims to identify the optimal upgrade capacity, theoretically recommended at 6,000 BWPD, to ensure the facility maintains both operational safety and long-term economic sustainability. By bridging the gap between stochastic technical risks and fiscal performance, this study provides a replicable, data-driven model for managing high-risk energy infrastructure investments.

METHOD

Research Design and Data Collection

This study adopts an applicative quantitative approach to evaluate the feasibility of expanding Produced Water Treatment System (PWTS) capacity. The research is structured as a case study within a natural gas processing facility, focusing on optimizing equipment reliability amidst escalating production volumes.

Data collection was divided into primary and secondary sources. Primary data was gathered through structured questionnaires and expert judgment from a technical team comprising ten professionals with significant experience in production, maintenance, and process engineering (see Table 1). Secondary data involved PWTS equipment datasheets, 2024–2025 production history, and subsurface production projections.

Table 1. Technical Expert 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)

Technical Risk Assessment via Stochastic FMEA

This study employs a structured Failure Mode and Effect Analysis (FMEA) to evaluate operational vulnerabilities within the Produced Water Treatment System (PWTS). The primary objective is to prioritize risks stemming from the current capacity-demand imbalance observed in the facility. The assessment focuses on critical assets, including production separators, hydrocyclones, degassing column, produced water tank, produced water booster pumps, produced water filter, and produced water injection pumps.

FMEA Implementation Sequence

A systematic Failure Mode and Effect Analysis (FMEA) was conducted to map operational vulnerabilities across seven core equipment groups: production separators, hydrocyclones, degassing columns, storage tanks, booster pumps, filters, and injection pumps. The FMEA implementation followed a rigorous cycle of identifying failure modes (e.g., cavitation and internal corrosion), root causes (e.g., flow surges and sludging), and their subsequent effects on facility uptime.

To neutralize the inherent subjectivity of expert scores, a stochastic modeling approach using Monte Carlo Simulations is implemented with 10.000 iterations. This research utilizes a Triangular Distribution, which is the most effective model for quantifying risks when data is limited to minimum (a), maximum (b), and most-likely (c) estimates.

For each iteration, the parameter value X is generated from a random variable $U \in [0,1]$ using the following inverse transform equations:

For $0 \leq U < \frac{c-q}{b-a}$,

$$X = a + \sqrt{U(b-a)(c-a)}$$

For $\frac{c-a}{b-a} \leq U \leq 1$

$$X = b - \sqrt{(1-U)(b-a)(b-c)}$$

The simulated outputs for S, O, D and $D2$ are then multiplied to determine the Stochastic Risk Priority Number (RPN):

$$RPN_i = S_i x O_i x D_i x D2_i$$

Financial Integration: Risk Matrix and Expected Cost

Risk quantification was finalized by mapping simulated Severity and Occurrence scores onto a 5 x 5 Major Accident Hazard (MAH) Risk Matrix. This mapping translates qualitative engineering risks into quantitative financial variables. Severity scores were correlated with specific financial consequences (ranging from insignificant to catastrophic asset loss), while Occurrence scores were translated into annual failure probabilities.

LEVEL	PROBABILITY (LIKELIHOOD)				
	1 0% < X > 20% <10^-6 per year	2 20%< X <40% 10^-6 to 10^-4 per year	3 40%< X <60% 10^-4 to 10^-2 per year	4 60% < X <80% 10^-2 to 10^-1 per year	5 80%< X <100% >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

FMEA (O) Score	Matrix Level (1-5)	Matrix Categories	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)

In this framework, Severity represents financial consequences (asset loss), while Occurrence reflects annual failure probabilities. The resulting Expected Cost is subsequently utilized as a tangible cost variable within the Cost-Benefit Analysis (CBA), providing a robust, data-driven rationale for the PWTS capacity expansion.The resulting Expected Cost (E_{Cost}) focusing on Downtine and Asset Damage serves as a tangible and intangible cost variable in the Cost-Benefit Analysis (CBA), calculated as:

$$E_{Cost\ Downtime} = \sum_{i=1}^{n} (P_i \times L_i) + \sum_{i=1}^{n} (P_i \times AC_i)$$

Where P_i represents the annual probability of failure mode, L_i the cost of operational downtime, and AC_i the cost of phsical asset damage.

Economic Feasibility and Sensitivity Analysis

The financial model is constructed based on prevailing industrial parameters in the Indonesian upstream sector (Minister of Energy and Mineral Resources, 2025). Key assumptions include a Gas Price of USD 6.5/MMBTU, Oil Price of USD 67.92/BBL, and a Minimum Attractive Rate of Return (MARR) of 14%, aligned with the risk profile of critical gas processing systems (Ratna & Puspita, 2023). The investment appraisal utilized the CBA framework to compare total discounted costs (CAPEX and OPEX) against "Avoided Costs" (mitigated risks). Feasibility was measured using four key indicators: Net Present Value (NPV), Internal Rate of Return (IRR), Benefit-Cost Ratio (BCR), and Payback Period (PP).

Finally, a Sensitivity Analysis was executed to evaluate project resilience against hydrocarbon production volatility (-0.5% to -5%) and OPEX escalation (+5% to +50%). This stress test pinpointed the "tipping points" of the investment, ensuring the proposed capacity upgrade remains sustainable under fluctuating market and subsurface conditions.

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.

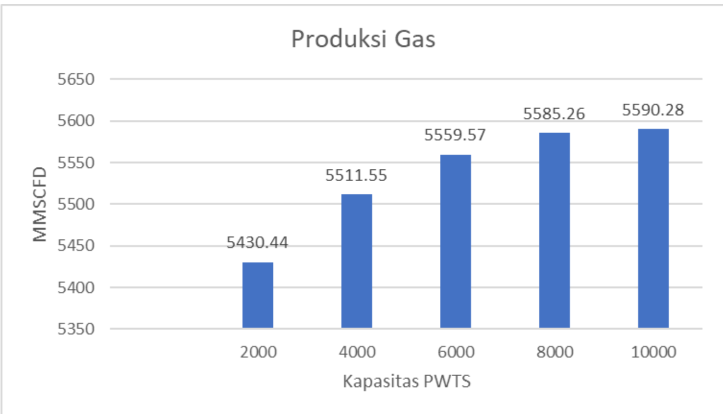


Figure 2. Total projected gas production

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.

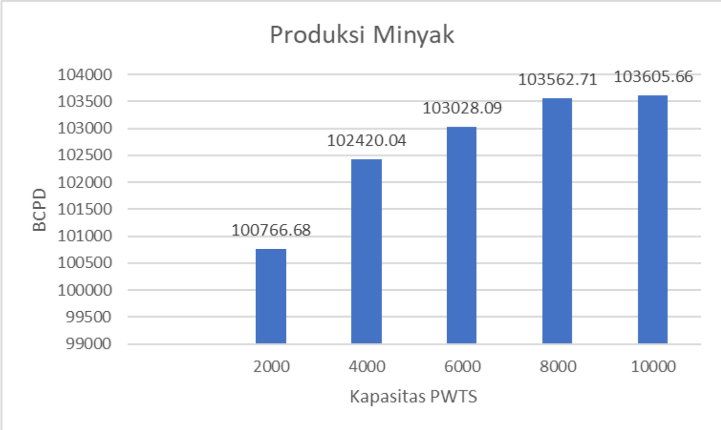


Figure 3. Total oil production projections

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.

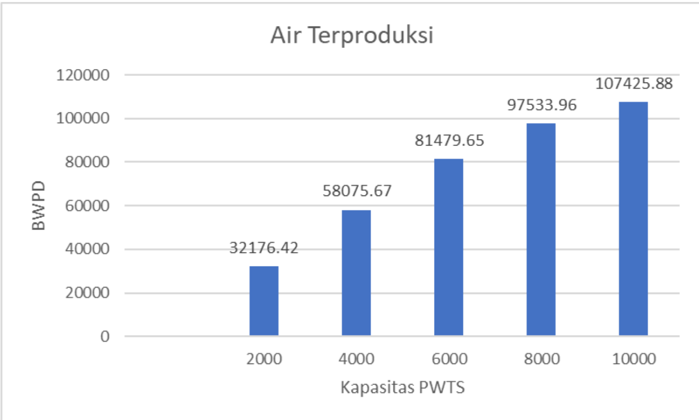


Figure 4. Total projected water produced

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.

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

PWTS Capacity	Forecast Production		Incremental Production		Incremental Production (ΔI per year)	
	Total Gas Rate, MMSCFD (2024 - 2047)	Total Condensate Rate, BCPD (2024 - 2047)	Gas (MMSCFD)	Condensate (BCPD)	Gas (MMSCFD)	Condensate (BCPD)
2000 BWPD (eksisting)	5,430.44	100,766.68	-	-	-	-
4000 BWPD	5,511.55	102,420.04	81.11	1,653.36	3.38	68.89
6000 BWPD	5,559.57	103,028.09	129.13	2,261.40	5.38	94.23
8000 BWPD	5,585.26	103,562.71	154.82	2,796.02	6.45	116.50

10000 BWPD	5,590.28	103,605.66	159.84	2,838.97	6.66	118.29

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

Months	Average of Gas Production (MMSCFD)	Average of Produced Water Production (BWPD)	Maximum Produced Water Production (BWPD)	Average of Condensate Production (BPD)
Jan	306.22	1178.09	2963.34	7336.36
Feb	322.45	1364.31	2617.33	7671.56
Mar	324.57	1631.62	2748.59	7680.98
Apr	325.20	1267.93	1582.05	7786.69
May	306.66	1252.58	1587.98	7200.52
Jun	309.65	1588.95	2405.69	7295.26
Jul	329.99	1891.77	3110.10	7701.45
Aug	332.94	2133.58	3024.12	7747.25
Sep	323.06	2448.89	3054.21	7518.73
Oct	161.05	386.25	1057.61	3665.84
Nov	331.73	1037.03	1431.07	7782.79
Dec	321.97	1101.09	1572.18	7446.18

Source: PT XYZ production records (2024)

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

Months	Average of Gas Production (MMSCFD)	Average of Produced Water Production (BWPD)	Maximum Produced Water Production (BWPD)	Average of Condensate Production (BPD)
Jan	272.49	1113.69	1492.29	6269.05
Feb	303.29	1369.06	1979.87	7041.65
Mar	298.13	1521.13	2424.09	6903.59
Apr	290.84	1620.47	2729.37	6681.53
May	311.52	1725.16	2105.17	7152.31
Jun	300.08	1823.85	2455.76	6838.45
Jul	330.27	1960.14	2427.91	7517.93
Aug	322.31	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.

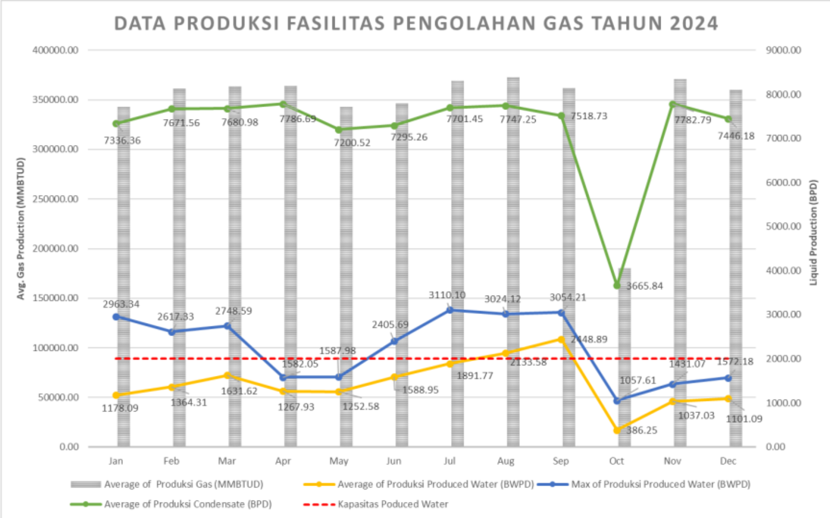


Figure 5. 2024 production chart
Source: Author’s visualization based on PT XYZ production data (2024)

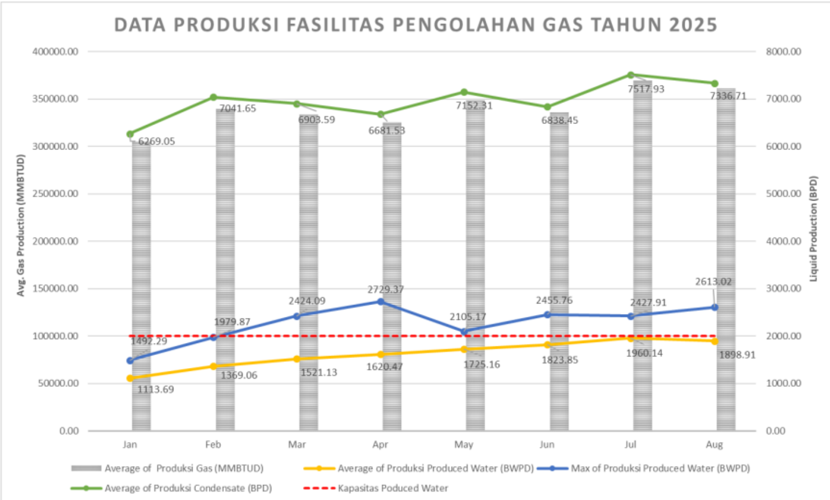


Figure 6. Production chart of 2025
Source: Author’s visualization based on PT XYZ production data (2024)

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.

Technical Risk Assessment with FMEA method

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.

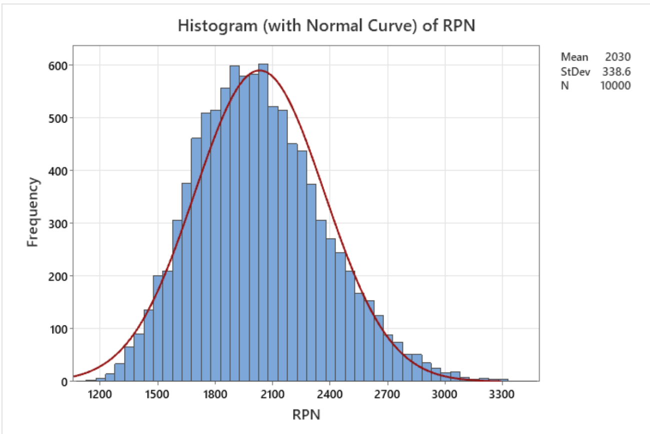
The results of the assessment showed three equipment with the highest risk, namely Hydrocyclone, Produced Water Booster Pump, and Produced Water Injection Pump see in

Table 7. These three appliances have the potential to be a critical point for increasing the capacity of water produced.

Table 7. Critical Failure Mode

Equipment	Failure Mode No	FMEA	Expert Judgement											RPN (SxOxDxD2)
			1	2	3	4	5	6	7	8	9	10	Average	
Hydrocyclone	2.2	S	9	8	8	7	8	7	8	8	7	7	7.70	1893.83
		O	5	6	6	5	6	6	7	6	6	8	6.10	
		D	6	5	7	6	7	6	6	7	7	7	6.40	
		D2	6	8	7	5	5	6	6	6	7	7	6.30	
Produced Water Booster Pump	5.2	S	8	8	8	7	8	8	8	7	8	8	7.80	1306.50
		O	5	5	4	4	5	6	6	6	5	4	5.00	
		D	5	4	7	4	5	5	7	4	5	4	5.00	
		D2	6	8	7	5	6	7	7	7	8	6	6.70	
Produced Water Injection Pump	7.1	S	7	8	8	7	8	6	6	8	7	7	7.20	1467.18
		O	6	6	5	6	4	5	5	6	6	6	5.50	
		D	5	5	6	6	6	5	6	5	6	7	5.70	
		D2	7	6	6	7	7	6	6	7	7	6	6.50	

To address expert subjectivity, a Monte Carlo simulation (10,000 iterations) with a triangular distribution was executed. For the hydrocyclone (FM-2.2), the simulation revealed a mean RPN of 2029.50, which is 135.67 points higher than the conventional deterministic assessment of 1893.83 in Figure 7. Furthermore, the simulation identified a maximum RPN potential of 3443.62, exposing extreme risk scenarios that typical static models overlook. These results confirm that under current conditions, the system is highly susceptible to "cascade failures," where separator carry-over leads to hazardous hydrocarbon accumulation in atmospheric storage tanks.



Statistics

Variable	N	N*	Percent	Mean	SE Mean	StDev	Minimum	Q1	Median	Q3
RPN	10000	0	100	2029.50	3.38591	338.591	1120.33	1784.38	2002.56	2246.50

Variable	Maximum	Range	Mode	N for Mode
RPN	3443.62	2323.30	*	0

Figure 7. FMEA Monte Carlo Simulation – Hydrocyclone FM 2.2
Source: Author's visualization based on FMEA Monte Carlo Simulation (2024)

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)

1. 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 8.

Table 8. CAPEX for upgrading PWTS equipment

No	Deskripsi	Opsi-1	Opsi-2	Opsi-3	Opsi-4
		Total 4000 bwpd (peningkatan kapasitas 2000 bwpd)	**Total 6000 bwpd (peningkatan kapasitas 4000 bwpd)**	**Total 8000 bwpd (peningkatan kapasitas 6000 bwpd)**	**Total 10000 bwpd (peningkatan kapasitas 8000 bwpd)**
A	**CAPEX Tangible Asset**				
1	Project Management Team	279,363.03	279,363.03	279,363.03	279,363.03
2	Engineering	311,025.29	311,025.29	311,025.29	311,025.29
3	Procurement				
3.1	Main Equipment				
	- Hydrocyclone Package	1,623,174.19	1,834,587.10	2,046,000.00	2,142,622.58
	- Water Booster Pump	98,946.77	98,946.77	197,893.55	238,584.26
	- Water Injection Pump	471,900.00	471,900.00	943,800.00	1,137,863.48
	- Degassing Column	-	210,731.03	210,731.03	210,731.03
	- Produced Water Filter	39,290.32	52,258.06	104,516.13	128,000.00
3.2	Bulk Piping Material	340,190.19	340,101.42	441,795.23	484,874.19
3.3	Bulk Instrumentation Material	209,347.74	418,586.39	543,747.94	596,768.19
3.4	Bulk Electrical Material	418,695.48	209,293.16	271,873.94	298,384.13

3.5	Bulk Civil Material	16,684.65	26,161.68	33,984.26	37,298.00
4	Construction & Installation	869,403.55	863,334.39	1,121,480.13	1,230,834.45
5	Comissioning & Start-up	113,815.74	104,646.58	135,936.97	149,192.06
	Total	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	78,000.00	78,000.00	78,000.00	78,000.00
2	Upgrade Control philosophy	12,000.00	12,000.00	12,000.00	12,000.00
	Total	USD 90,000.00	USD 90,000.00	USD 90,000.00	USD 90,000.00
C	Total CAPEX	USD 4,881,836.97	USD 5,310,934.90	USD 6,732,147.48	USD 7,335,540.71

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

2. 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 9. Gas treatment facility operating costs

	Description	Total Cost
A	**OPEX (Exsisting)**	
1	Direct Cost (Operation & Maintenance)	19,500,000.00
2	Indirect Cost	3,900,000.00
3	Turn Around Cost (per 3 tahun)	9,677,419.35
	Total	**USD 33,077,419.35**

Source: PT XYZ financial and operational reports (2024)

B) Operational costs of upgrading equipment capacity

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

Table 10. Operational costs of PWTS upgrading capacity

No	Description	Option-1	Option-2	Option-3	Option-4
		Total 4000 bwpd (upgrading capacity 2000 bwpd)	Total 6000 bwpd (upgrading capacity 4000 bwpd)	Total 8000 bwpd upgrading capacity 6000 bwpd)	Total 10000 bwpd (upgrading capacity 8000 bwpd)
A	**OPEX Tangible Asset**				
1	Labor				
1.1	Operator	47,096.77	47,096.77	47,096.77	47,096.77
1.2	Technician	70,645.16	70,645.16	70,645.16	70,645.16
2	Spare part kit material:				
	- Hydrocyclone Package	32,463.48	36,691.74	40,920.00	42,852.45

	- Water Booster Pump	14,842.02	14,842.02	29,684.03	35,787.64
	- Water Injection Pump	28,314.00	28,314.00	56,628.00	68,271.81
	- Degassing Column	-	12,643.86	12,643.86	12,643.86
	- Produced Water Filter	3,143.23	4,180.65	8,361.29	10,240.00
3	Consumable material	29,033.05	34,689.50	45,538.23	50,151.42
	Total	**USD 225,537.71**	**USD 249,103.70**	**USD 311,517.35**	**USD 337,689.11**
B	**OPEX Intangible Asset**				
1	Training Operator & Technician	20,645.16	20,645.16	20,645.16	20,645.16
2	Insurance	97,636.74	106,218.70	134,642.95	146,710.81
	Total	**USD 118,281.90**	**USD 126,863.86**	**USD 155,288.11**	**USD 167,355.98**
C	**Total OPEX**	**USD 343,819.61**	**USD 375,967.56**	**USD 466,805.46**	**USD 505,045.09**

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 11. Expected Cost per year

No	Risk	Effect	Expected Cost
1	Downtime	Loss of Production	USD 10,785,684.00
2	Asset Damage	Perbaikan peralatan	USD 41,000.00

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. Table 12 is a summary of the assessment of investment analysis.

Table 12. Investment analysis summary

Parameter	Unit	PWTS Capacity				
		2000 BWPD (Base Case) (MM USD)	4000 BWPD (MM USD)	6000 BWPD (MM USD)	8000 BWPD (MM USD)	10000 BWPD (MM USD)
CAPEX			USD 4.88	USD 5.31	USD 6.73	USD 7.34
Total Revenue		USD 14,470.80	USD 14,703.86	USD 14,833.01	USD 14,907.09	USD 14,920.10
Total OPEX		USD 1,210.53	USD 925.99	USD 927.06	USD 996.49	USD 997.86
Incremental Net Operating Income (NOI)			USD 506.77	USD 634.86	USD 639.50	USD 651.15
Loan (70%)	70%		USD 3.66	USD 3.98	USD 5.04	USD 5.49
Depreciation			USD 3.66	USD 3.98	USD 5.05	USD 5.50

Tax (22%)	22%		USD 106.04	USD 131.65	USD 142.13	USD 145.86
Equity Cash Flow After Tax			USD 400.74	USD 503.21	USD 497.38	USD 505.30
NPV		USD (10.83)	USD 78.91	USD 84.94	USD 87.03	USD 84.60
IRR			86.87%	80.88%	65.87%	60.99%
BCR			16.47	16.59	15.47	15.46
PP	(Bulan)		23	24	27	28

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

As summarized in Table 4.11, the 6,000 BWPD option offers the best balance between Capital Expenditure (USD 5.31 Million) and financial returns, yielding an NPV of USD 84.94 Million, an IRR of 80.88%, and a Benefit-Cost Ratio (BCR) of 16.59. The investment achieves a rapid Payback Period of 24 months. While higher capacities (8,000 and 10,000 BWPD) show slightly higher NPVs, they suffer from diminishing returns in IRR and longer payback durations.

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.

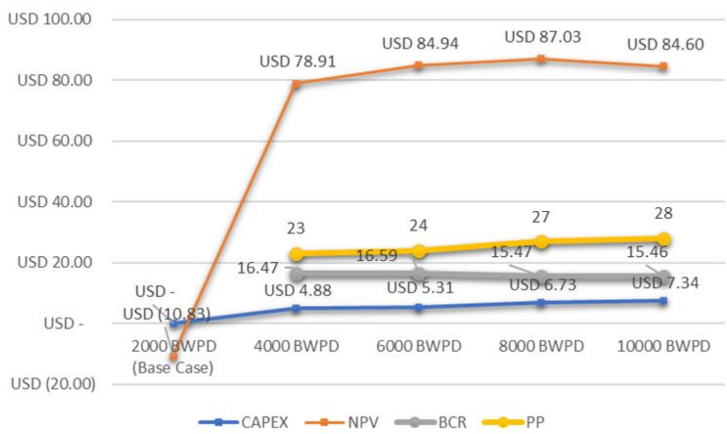


Figure 8. NPV Project

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

Sensitivity Analysis

Sensitivity analysis was conducted to determine the financial "tipping points" of the optimal 6,000 BWPD scenario. In Figure 9, the project demonstrated remarkable resilience against Operational Expenditure (OPEX) escalation, maintaining profitability up to a 45% increase, where the NPV remains positive.

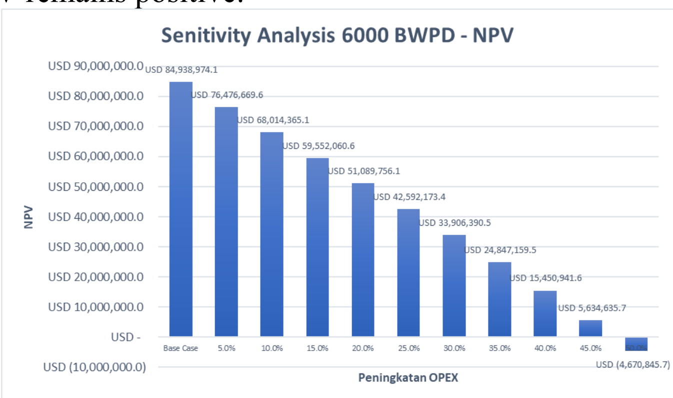


Figure 9. OPEX Escalation Sensitivity Analysis

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

However, the investment is highly sensitive to production volatility. The analysis identifies a critical production decline tolerance of -1.5% per day. In Figure 10, a decline beyond 2% (equivalent to a loss of ±6.6 MMSCFD of gas) would drive the NPV into negative territo. This highlights that while cost control is important, maintaining reservoir stability and equipment uptime is the most critical factor for the project's economic sustainability.

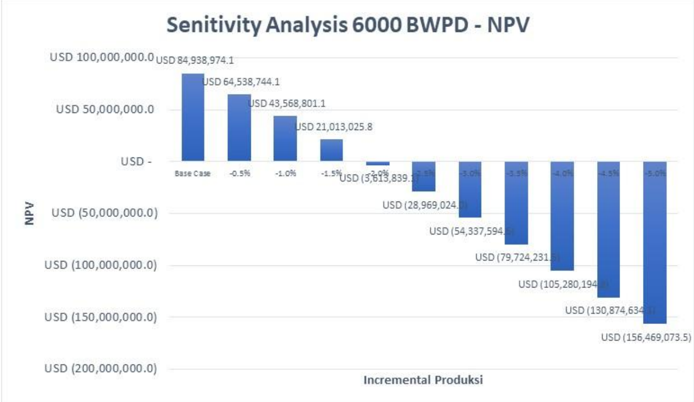


Figure 10. Production Decline Sensitivity Analysis

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

CONCLUSION

This study highlights a critical capacity gap in the existing Produced Water Treatment System (PWTS), where peak water surges—reaching 3,110 BWPD—regularly exceed design limits by over 50%. Through FMEA and Monte Carlo simulations, the Hydrocyclone, Produced Water Booster Pump, and Injection Pump were identified as the highest-risk components, with stochastic modeling exposing extreme risk scenarios that deterministic methods often overlook. To ensure operational stability, the Degassing Column and Filtration units must also be scaled to support the 6,000 BWPD threshold.

Economic evaluation through Cost-Benefit Analysis (CBA) confirms that the 6,000 BWPD expansion is the most optimal investment, providing a robust Net Present Value (NPV) of USD 84.94 Million, an IRR of 80.88%, and a 24-month payback period. While the project demonstrates high financial resilience against OPEX escalations of up to 45%, it remains sensitive to reservoir performance. A production decline exceeding 1.5% to 2% per day serves as the critical "tipping point" that could jeopardize the project's economic viability. Consequently, management must prioritize equipment uptime and reliability to minimize unplanned downtime and safeguard the project's high returns.

REFERENCE

Amakiri, K. T., Canon, A. R., Molinari, M., & Angelis-Dimakis, A. (2022). Review of oilfield produced water treatment technologies. In *Chemosphere* (Vol. 298). Elsevier Ltd. https://doi.org/10.1016/j.chemosphere.2022.134064

Dai, H., Li, N., Wang, Y., & Zhao, X. (2022). *The Analysis of Three Main Investment Criteria: NPV IRR and Payback Period*.

Ditjen Migas. (2021, November 30). *Jadi Salah Satu Pilar Ekonomi, Industri Migas Takkan Ditinggalkan*. https://migas.esdm.go.id/post.

Ditjen Migas. (2025, May 22). *Peran Penting Industri Migas Wujudkan Ketahanan Energi Nasional*. https://migas.esdm.go.id/post.

Elkemali, T. (2024). Intangible and Tangible Investments and Future Earnings Volatility. *Economies*, *12*(6). https://doi.org/10.3390/economies12060132

Harberger, A. C. (1991). *COST-BENEFIT ANALYSIS FOR INVESTMENT DECISIONS*. https://www.researchgate.net/publication/242736382

Jenkins, G. P., Kuo, C.-Y., & Harberger, A. C. (n.d.). *COST-BENEFIT ANALYSIS FOR INVESTMENT DECISIONS, CHAPTER 1: THE INTEGRATED ANALYSIS OF INVESMENT PROJECTS*.

John A. Veil, Markus G. Puder, Deborah Elcock, Robert J. Redweik, Jr., & Argonne National Laboratory. (2004). *A White Paper Describing Produced Water From Production of Crude Oil , Natural Gas, and Coal Bed Methane*.

Johnson, D., Clark, N., Heltzel, R., Darzi, M., Footer, T. L., Herndon, S., & Thoma, E. D. (2022). Methane emissions from oil and gas production sites and their storage tanks in West Virginia. *Atmospheric Environment: X*, *16*. https://doi.org/10.1016/j.aeaoa.2022.100193

Kabyl, A., Yang, M., Abbassi, R., & Li, S. (2020). A risk-based approach to produced water management in offshore oil and gas operations. *Process Safety and Environmental Protection*, *139*, 341–361. https://doi.org/10.1016/j.psep.2020.04.021

Leiva Vilaplana, J. A., Yang, G., & Ackom, E. (2025). From investment to net benefits: A review of guidelines and methodologies for cost–benefit analysis in the electricity sector. In *Energy Research and Social Science* (Vol. 124). Elsevier Ltd. https://doi.org/10.1016/j.erss.2025.104052

Menteri Energi Dan Sumber Daya Mineral Republik Indonesia. (2025a). *Keputusan Menteri Energi Dan Sumber Daya Mineral Republik Indonesia No. 76.K/2025*.

Menteri Energi Dan Sumber Daya Mineral Republik Indonesia. (2025b). *Keputusan Menteri Energi Dan Sumber Daya Mineral Republik Indonesia No. 90.K/2025*.

Ratna, N., & Puspita, E. (2023). An Analytic Network Process (ANP) Approach to Refining the Hurdle Rate by Factoring in Project Risk Premium: A Case Study of Indonesia National Oil Company 1, 2. In *PM World Journal: Vol. XII*. An Analytic Network Process. www.pmworldjournal.com

Soesanto, E., Raihan, A., & Angga, S. (2025). *Pengaruh Kebijakan Pemerintah terhadap Keberlanjutan Industri Migas di Era Transisi Energi*. 15–24. https://doi.org/10.61132/konstruksi.v3i1.680