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East Kalimantan Gas System Hydrocarbon Accounting Robustness with Analytic Hierarchy Process (AHP)

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Abstract:

The study evaluates the robustness of a gas settlement method using the Analytical Hierarchy Process (AHP) to systematically prioritize multiple variables in complex multi-seller, multi-product, and multi-buyer conditions, affected by technical, contractual, and regulatory factors. Expert interviews identified critical variables such as inlet volume, Gross Heating Value (GHV), and operational dynamics across upstream, midstream, and downstream process. AHP calculations and Consistency Ratios validated expert judgments, deriving priority weights for each criterion and subcriterion. Testing scenarios revealed gaps in the lowest scoring scenario, leading to a proposed business solution for dynamic monitoring and integration of system disruptions into the settlement model. The study concludes that AHP-based methodologies provide a structured, transparent decision-making framework suited for complex, multi-stakeholder environments in the East Kalimantan System, advocating for continuous improvement and monitoring to maintain alignment with operational conditions. The analysis proposed a business solution to monitor the settlement method in a very tight manner and provide practical value to upstream stakeholders by understanding the condition that may disrupt the method.

Keywords: *Hydrocarbon Accounting, Analytical Hierarchy Process (AHP), Gas Commercialization, East Kalimantan System, Domestic Obligation Market, Operational Resilience, Oil and Gas Industry, Upstream Oil and Gas Industry.*

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1. Introduction

In 2023, Indonesia’s Gross Domestic Product (GDP) reached Rp20,892.4 trillion, according to Indonesia's Badan Pusat Statistik (BPS) (Indonesia Statistics, 2025). The upstream oil and gas industry, categorized under Mining and Quarrying—specifically petroleum, natural gas, and geothermal mining—contributed Rp521.1 trillion. Therefore, the mining of oil and gas and geothermal energy contributed to 2.5% of Indonesia’s total GDP.

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Pursuant to the Renstra IOG 4.0 (Rencana Strategis Indonesia Oil and Gas 4.0) or Strategic Plan of Indonesia Oil and Gas, launched by Special Task Force for Upstream Oil and Gas Business Activities (SKK Migas) in 2022, Indonesian upstream oil and gas production is considerably a target for national achievements (Nainggolan & Suarsana, 2019). The export value in the oil and gas production remains high; according to BPS, in 2023 Indonesia exported $916.6 million worth of petroleum while importing $11,142 million of crude/condensate for energy consumption. Meanwhile, natural gas was exported with an equivalent value of $3,515.8 million (Indonesia Statistics, 2025).

To enable gas transport, natural gas is condensed and liquified into Liquified Natural Gas (LNG). This liquified nature facilitates transport compared to pipeline gas. Currently, Indonesia has two upstream LNG producers: the Tangguh LNG Plant (operated by BP) and the Bontang LNG Plant (operated by PT Badak NGL under PT Pertamina). In 2023, the Bontang LNG Plant contributed $1,290.5 million to Indonesia's LNG export value, which accounted for 36.7% of the country's total exported natural gas (PT Badak NGL, 2024).

Domestically, in 2023 Indonesia produced 670.66 TBTU (Trillion British Thermal Units) of upstream LNG, with 37.7% sourced from the Bontang LNG Plant. Of the approximately 253.3 TBTU portion allocated to domestic use, 37.2%—equal to 95.3 TBTU—was directed to Domestic Buyers. This indicates that 14.2% of Bontang LNG's output was utilized to support domestic electricity supply in 2023, a figure expected to increase in 2024. For reference, 1 TBTU equals 293,083 kWh (Fachira & Kustanto, 2024).

In East Kalimantan, gas produced by different producers is commingled into one stream. However, as each producer is entitled only to what it produces, discrepancies between production and sales require an accurate, fair allocation system. This is where hydrocarbon accounting becomes critical: it allocates and reconciles hydrocarbons from production to sales (Nainggolan & Suarsana, 2019). The hydrocarbon accounting process in the East Kalimantan Gas System includes data collection, measurement, allocation, and negotiation to agree on accounting procedures among producers.

Historically, when gas composition was more uniform, settlement was based on mmscf (volume)—the "pay for production" method. Currently, due to compositional variations, settlements are based on energy output in mmbtu—known as the "pay for energy produced" method (Prakoso et al., 2019). Given the complexity of these arrangements, it is essential to analyze the robustness of the current settlement system.

To evaluate this, the Analytic Hierarchy Process (AHP) will be applied, a method capable of handling both quantitative and qualitative variables affecting decision-making (Saaty, 1980; Saaty, 2008). AHP has been successfully implemented in hydrocarbon and energy decision-making frameworks in previous studies, such as LNG strategy formulation (Fachira & Kustanto, 2024), upstream project prioritization

(Affandi & Novani, 2022, 2023), and gas system optimization (Fairuz et al., 2022). This thesis will identify key influencing variables using AHP, assess the current settlement system, and propose improvements for increased robustness.

2. Theoretical Background

Analytic Hierarchy Process (AHP): The Analytic Hierarchy Process (AHP) is a structured decision-making technique developed by Thomas L. Saaty in the 1970s. This method provides a systematic framework for analyzing complex decisions involving both quantitative and qualitative factors through pairwise comparisons and expert judgment (Saaty, 2008). AHP allows the measurement of interdependent variables and helps in identifying priorities in decision-making.

Its application has extended across various domains such as business, energy, healthcare, and transportation (Saaty & Vargas, 1981), as well as in strategic decision-making processes (De Felice et al., 2016). For example, Affandi & Novani (2022, 2023) applied AHP in evaluating oil production scenarios at PT Pertamina Hulu Rokan. Similarly, AlHashmi et al. (2021) demonstrated how AHP can support sustainable procurement strategies in the oil and gas sector. Al Mohannadi et al. (2023) further highlighted AHP's role in enhancing organizational resilience in the energy industry.

Lestari et al. (2018) combined the Fuzzy AHP approach to select alternatives in oil and gas projects, while Fairuz et al. (2022) applied AHP to determine logistical site selection in upstream operations. Goepel (2018) developed AHP-OS, an online tool that allows for efficient multi-criteria analysis. This tool will be particularly relevant to this study, supporting the identification of variables that influence the robustness of settlement models in hydrocarbon accounting.

By applying AHP within the context of hydrocarbon accounting in upstream gas systems—especially in multi-seller and multi-buyer scenarios with commingled gas flows—this research offers a structured and replicable decision-making framework. As shown in previous studies by Affandi & Novani (2022, 2023), this approach enables the integration of expert judgment into complex operational decision-making.

LNG Marketing: The natural gas value chain, particularly the LNG sector, is characterized by a high degree of operational complexity due to the diversity of gas sources and contractual arrangements. Prakoso et al. (2019), in their study presented at the 14th Offshore Mediterranean Conference, explored a multi-seller/multi-buyer LNG system with commingled gas streams of varying specifications. Their findings underscore the importance of stakeholder coordination and gas quality compatibility in establishing a robust and fair settlement model.

Fachira & Kustanto (2024) analyzed the commercialization strategy of LNG in the global market using a case study of PPTETS. Their study emphasized internal and external factors affecting LNG sustainability, including market trends, pricing structures, contract flexibility, and supply-demand dynamics.

Hydrocarbon Accounting: In open-access gas pipeline systems such as the East Java Gas Pipeline (EJGP), hydrocarbon accounting is a critical issue. Nainggolan & Suarsana (2019) developed a verification methodology using Flow Quantity Assurance software and third-party audits to address discrepancies between calculated and actual gas volumes. Their work highlights how transparent verification protocols are essential to avoid disputes and inaccuracies in entitlement calculations, especially in open-access gas transportation systems.

Framework of the Research: This study expands the application of AHP into the domain of hydrocarbon accounting within upstream gas systems in Indonesia, specifically in the East Kalimantan Gas System. While AHP has been widely used for energy planning and infrastructure decisions (De Felice et al., 2016), its use in prioritizing settlement-related variables in commingled gas systems involving multiple sellers and buyers remains limited in existing literature.

Therefore, this research contributes a novel perspective to both AHP methodology and its relevance in the evolving governance of the energy sector by integrating expert-driven prioritization into operational and financial decision-making in complex gas trading environments.

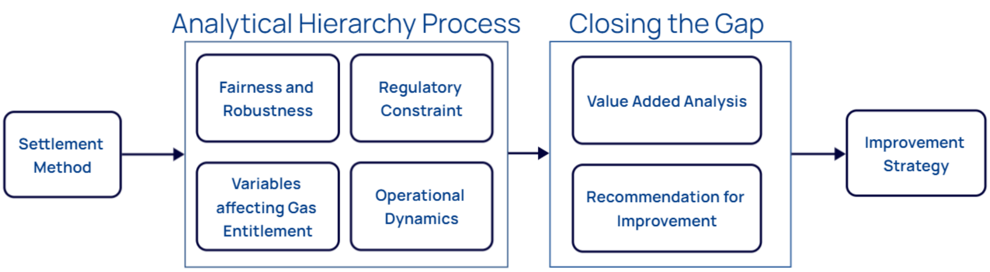

Figure 1. Conceptual Framework of the Research

3. Methodology

Given the complexity of the gas settlement system and its reliance on multiple operational, contractual, and regulatory variables, the Analytical Hierarchy Process (AHP) was selected as the primary analytical method. The first phase of analysis involved expert interviews to identify and validate key variables impacting settlement robustness, including upstream production volume, gross heating value (GHV), operational reliability, and domestic consumption requirements. Qualitative responses were synthesized into quantifiable variables in the form of criteria and subcriteria. The interview will also yield various alternatives, in which such alternatives shall be tested against the AHP. It must be noted that while expert input ensures contextual depth, it may have potential bias due to limited sample size and subjective experience of key experts.

Subsequently, after figuring out the criteria and subcriteria, expert surveys were conducted to form the basis of the AHP hierarchy. The resulting matrices were processed using standard AHP techniques, including column normalization, calculation of priority vectors through row averages, and consistency checks to ensure logical coherence (Consistency Index and Consistency Ratio). Aggregation of multiple expert inputs was calculated using the geometric mean to yield a unified matrix for each level of analysis. This methodology ensured that subjective expert insights were translated into objective, numerical weights, that accurately reflect relative importance among the key variables identified previously.

Following the calculation of global weights for each subcriterion, the study proceeded to evaluate potential alternatives, tested against the AHP. Alternatives were assessed based on their performance, and the least of all performance will be the one in needs of improvement. This scoring scale is derived from operational data normalization. Weighted scores were calculated by multiplying the subcriterion scores by their respective global weights. The total scores for each alternative were then summed to generate a final prioritization, identifying which settlement method offered the greatest robustness, fairness, and compliance with operational objectives.

This approach aligns with the research framework, which emphasizes systematic variable prioritization, expert-driven analysis, and structured decision-making. The use of AHP not only ensures methodological transparency but also facilitates sensitivity analysis and scenario testing in future research. By embedding expert knowledge into the settlement evaluation process quantitatively, this study offers a repeatable model for similar multi-criteria decision-making challenges within the energy sector.

4. Empirical Findings/Result

Comparative Analysis of Interview Results

Table 1. Comparison Result of Expert Interviews

Topic	Expert AH	Expert AP	Expert DP
GHV Impact	Views that GHV affects LNG target margins.	Views that GHV is one of the contributing factors in settlement variables.	Discusses its influence on processing plant operations.
Settlement Benchmark	Refers to PSC and DMO.	Aligns with AH on PSC but suggests to find additional benchmarks.	No benchmark. Suggests to see oil settlement in Alaska Basin.
LPG Processing	Notes LPG production is constrained by minimum feed capacity.	Views that LPG Processing is tied into economic feasibility concerns.	Less emphasis on LPG; more on gas allocation.
HCA Model Fairness	Stresses need for resilience in HCA model.	Notes that current model is sufficient.	Highlights fairness but questions scalability.
Robustness	Views that current method is robust enough.	Views that current method is robust enough without any changes.	Views that current method is quite robust but needs heavy monitoring.

The experts are working in the upstream oil and gas industry, and have hands-on experience in working on the current and past settlement methods. The research will focus on the upstream areas, considering the input of the model comes from upstream productions.

Criteria and Subcriteria of AHP Model

Based on the interview above, the AHP model is defined as per follows:

1. Upstream Production:
   a. Inlet East Kalimantan System (Quantity) in mmscf
   b. Gross Heating Value ("GHV") in mmbtu/mmscf
   c. Upstream Operations (Operations, maintenance, turnaround, etc.)
2. Domestic Consumption:
   a. Domestic Demand in mmscf
   b. Domestic Operations (Buyer's operations, maintenance, turnaround, etc.)
   c. Domestic Quality Needed (GHV, in mmbtu/mmscf)
3. Downstream Processing:
   a. PT Badak's Minimum GHV (mmbtu/mmscf)
   b. PT Badak's minimum inlet volume (mmscf)
   c. PT Badak's Operations (Operations, maintenance, turnaround, etc.)

Scenario(s)
Based on the interviews, three Experts also pointed out the likely scenarios that can be used as alternatives in the AHP model. Three alternatives (scenarios) are also chosen by the interviewees, under the time frame of approximately 5 years ahead in the future. These scenarios serve as the alternatives in the AHP evaluation and are defined as follows:

Scenario 1 – Do Nothing
This scenario assumes a continuation of the current operational boundaries without any major interventions. Gas production is expected to follow a natural decline curve, and no additional infrastructure or field development is introduced. The objective of this scenario is to serve as a baseline for comparison, reflecting the settlement system's performance under a "business-as-usual" approach.

Scenario 2 – New Field(s) Onstream
This scenario assumes the current system will have new and fresh production, from various field(s). While natural decline still occurs in old assets, additional volumes from new developments are expected to offset part of this decline. The scenario tests the settlement model's adaptability to upstream expansion and evaluates the robustness of the settlement method.

Scenario 3 – System Disruption
In this scenario, it is assumed that significant changes occur to the physical system, driven by large capital expenditures (CAPEX). Examples include the construction of new pipelines, expansion of processing facilities, or new tie-ins. These changes are expected to disrupt current gas flow patterns, potentially requiring a reconfiguration of settlement method to mirror the operational conditions.

The summary of the AHP Model can be seen in the following Figure.

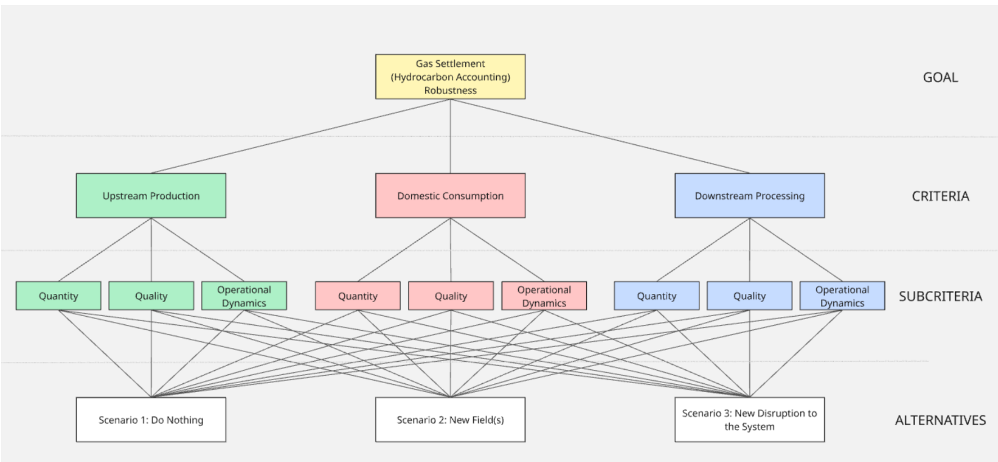

Figure 2. The AHP model of East Kalimantan Gas System Hydrocarbon Accounting

In this study, the hierarchy consists of three main criteria, i.e., Upstream Production, Domestic Consumption, and Downstream Processing, with nine subcriteria (three of each) such as Quantity (inlet volume), Quality (GHV), and Operational Dynamics. Through expert input via pairwise comparisons, AHP quantifies the relative importance (weights) of each criterion and subcriterion. During the calculation, it is also important to ensure consistency by checking the consistency ratio (CR) of expert judgments, thereby validating the robustness of the weight calculations. AHP allows the combination of both qualitative assessment and quantitative factors into a structured hierarchy with weights.

Based on the respondents of the survey, the criteria's weights (the global criteria) can be seen in Table 2.

Table 2. Aggregate Matrix of the three Criteria

Criteria	Upstream	Domestic	Downstream	**Weights**
Upstream	1.00	6.58	6.58	76.68%
Domestic	0.15	1.00	1.00	11.66%
Downstream	0.15	1.00	1.00	11.66%

The result of criteria's weights as depicted above is consistent with the Expert Interviews, because all three of them emphasized the importance of the upstream producers' side. Without any upstream production as the input to the system, there will be no domestic supply and/or downstream processing at PT Badak. This also reflects the importance of upstream production to provide inflow to the domestic consumption and downstream activities, making it the logical priority in the system robustness.

The first criteria, the Upstream Production, yields consistency of the respondents, and almost a balance of importance between quality and quantity. The result of the 'almost' balance of quality vs quality were expected, as the priority may differ based on the perspectives of the respondent, of which part they work on. For example, for a production engineer, quantity of the gas will be their Key Performance Indicator, whilst for a commercial analyst, the quality of gas will determine higher or lower revenue. The aggregate matrix can be seen in the Table 3.

Table 3. Aggregate Matrix of "Upstream Production" Criteria

Upstream Production	Quantity	Quality	Operations	**Weights**
Quantity	1.00	1.37	31.59	56.75%
Quality	0.73	1.00	23.08	41.46%
Operations	0.03	0.04	1.00	1.80%

The second criteria, the Domestic Consumption, also yields consistency of the respondents, and a sense of importance for quantity in the Domestic Consumption. The prioritization is more homogenous compared with the Upstream Production criteria, as the demand from Domestic Consumption will significantly change the entitlement in the Downstream Processing section. However, aligning with Expert interviews, the quality needed by Domestic Consumption is not capped, thus the gas quality is not prioritized, as can be seen in the aggregate matrix in the Table 4.

Table 4 Aggregate Matrix of "Domestic Consumption" Criteria

Domestic Consumption	Quantity	Quality	Operations	**Weights**
Quantity	1.00	3.51	12.32	73.20%
Quality	0.28	1.00	3.51	20.86%
Operations	0.08	0.28	1.00	5.94%

The third criteria, the Downstream Processing, yields almost a balance of importance between quality and quantity, similar to the upstream side. However, the end result yielded the prioritization of quality, as already emphasised, due to the operational constraint of the refinery capable of producing LNG. Without achieving specific GHV, the refinery will be unable to operate, let alone producing LNG. The aggregate matrix can be seen in the Table 5.

Table 5. Aggregate Matrix of "Downstream Processing" Criteria

Downstream Processing	Quantity	Quality	Operations	**Weights**
Quantity	1.00	0.73	23.08	41.46%
Quality	1.37	1.00	31.59	56.75%
Operations	0.04	0.03	1.00	1.80%

Figure 3 depicted the total local and global weights, calculated after having the above data.

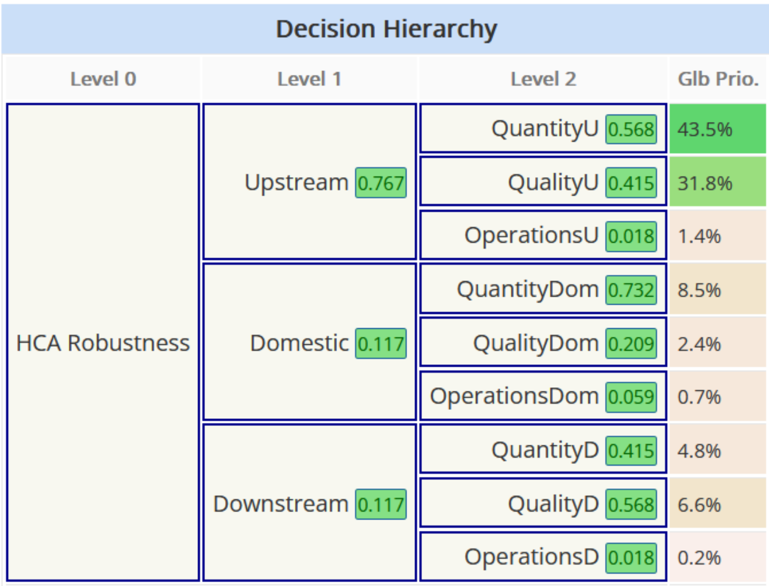

Figure 3 The weights of AHP model of East Kalimantan Gas System Hydrocarbon Accounting

The Decision Hierarchy depicted above is also consistent with the stakeholders' interests, i.e., gas settlement from the upstream side, in which without such input, no settlement method will be necessary.

Moving forward, the scenario likeliness and best option against robustness is calculated by using the respondents' responses for each subcriteria.

Decision Hierarchy						
Level 0	Level 1	Level 2	Glb Prio.	Do Nothing	New Field(s)	New Disruption to System
HCA Robustness	Upstream 0.767	QuantityU 0.568	43.5%	0.679	0.248	0.073
		QualityU 0.415	31.8%	0.652	0.272	0.077
		OperationsU 0.018	1.4%	0.637	0.268	0.095
	Domestic 0.117	QuantityDom 0.732	8.5%	0.378	0.290	0.331
		QualityDom 0.209	2.4%	0.378	0.290	0.331
		OperationsDom 0.059	0.7%	0.390	0.330	0.280
	Downstream 0.117	QuantityD 0.415	4.8%	0.397	0.499	0.104
		QualityD 0.568	6.6%	0.316	0.588	0.095
		OperationsD 0.018	0.2%	0.147	0.767	0.087
			1.0	59.6%	29.7%	10.7%

Figure 4. The weights of AHP model alternatives of East Kalimantan Gas System Hydrocarbon Accounting

Participant	Do Nothing	New Field(s)	New Disruption to System	CR_{max}
Group result	**59.6%**	**29.7%**	**10.7%**	**6.3%**
AD Dewanto	59.7%	29.4%	10.9%	8.9%
SS Saviega	60.2%	28.5%	11.2%	5.6%
SL Leonardo	58.1%	31.5%	10.3%	9.8%
LN Nugroho	59.5%	30.1%	10.4%	14.1%
AS Swissanto	59.4%	30.6%	10.0%	9.8%
AIP Prakoso	62.7%	26.5%	10.8%	9.8%
inkco20	58.9%	30.5%	10.6%	6.8%

Figure 5. The consistency of AHP model alternative testing of the East Kalimantan Gas System Hydrocarbon Accounting

Based on the above, the final AHP results reveal that the most robust alternative is the "Do Nothing" scenario, which scored the highest overall priority at 59.6%, followed by "New Field(s)" at 29.7%, and lastly "New Disruption to the System" at only 10.7%. This suggests that under the current settlement structure, the system performs most consistently and reliably when no significant changes, either in infrastructure or upstream development, are introduced.

Notably, the "New Disruption to the System" scenario yields the lowest score among most subcriteria, particularly under the Upstream and Downstream sides, indicating that large CAPEX-induced changes pose a higher risk to system stability, whilst such disruption may not have significant effect on Domestic Consumption.

5. Discussion

The business solution proposed as a result of this AHP-driven analysis is a close coordinated monitoring system aimed at ensuring the East Kalimantan Gas System operates with minimal disruption. This approach is recommended for both the current and subsequent years. Through this monitoring mechanism, any changes or disturbances in the gas transmission system must be communicated transparently and collaboratively among stakeholders. Such communication ensures fair resolution mechanisms aligned with prevailing laws and regulations, while also considering the technical feasibility of gas operations.

This recommendation aligns with the findings of Nainggolan & Suarsana (2019), who stressed the importance of transparent verification mechanisms in hydrocarbon accounting to avoid discrepancies in open-access pipeline systems such as EJGP. Their work demonstrated how third-party audits and mass balance verification protocols can significantly enhance accountability and fairness in entitlement calculations.

Moreover, the implementation of this monitoring framework may encounter challenges due to varying interests among counterparties and regulatory limitations. As noted by Al Mohannadi et al. (2023), organizational resilience in the oil and gas sector depends not only on strategy but also on stakeholder engagement and governance coordination. Therefore, relationship-building between stakeholders becomes a crucial enabler of effective monitoring.

This coordinated approach is expected to support timely and accurate settlement periods, offering advantages for all parties. Timely revenue realization promotes financial stability and enhances the sector's reputational capital, which is vital for long-term sustainability (Fachira & Kustanto, 2024).

The broader implications of this strategy point toward the need for a "restructured" settlement method—one that is both analytically rigorous and operationally flexible. By leveraging AHP as a prioritization tool (Saaty, 2008; Saaty & Vargas, 1981), this research introduces a structured, expert-driven framework for selecting and ranking key variables in the settlement process. At the same time, this framework allows room for periodic recalibration, especially in response to external factors such as changes in gas heating value (GHV), domestic market demand, or upstream supply disruptions.

The importance of designing commercial arrangements that adapt to physical and operational changes in the pipeline is echoed in the work of Prakoso et al. (2019), who emphasized the need for settlement models to account for commingled gas systems involving multi-sellers and multi-buyers. These complexities require dynamic mechanisms to maintain fairness and operational reliability across all parties.

For instance, changes such as lower GHV thresholds under PT Badak NGL's operational terms or the construction of additional pipelines that affect flow dynamics must be factored into the commercial framework to ensure alignment with actual system behavior. As suggested by Affandi & Novani (2022, 2023), the use of AHP in field development decisions provides a structured means to integrate technical and commercial judgments into a single evaluative process—an approach that is equally valid in settlement recalibration.

Thus, the business solution acts as a "gap-closing" framework between the current settlement methodology and the desired future state. It balances operational realities with commercial fairness while embedding stakeholder input into each step of the decision-making process. By doing so, the framework enhances transparency, reduces the risk of disputes, and supports the long-term sustainability of Indonesia's gas governance systems.

6. Conclusions

This study demonstrated that the Analytical Hierarchy Process (AHP) is an effective tool for prioritizing key variables in a complex, multi-stakeholder environment such as gas settlement systems. Through expert interviews and structured survey analysis, the research identified critical variables, including the gas quantity (inlet volume), gas quality (GHV), and operational dynamics. The application of AHP enabled a transparent derivation of weights, which were then used to evaluate the robustness of existing and alternative future scenarios.

The research recommended: 1) a close monitoring to the current settlement method to ensure fairness and robustness of the method, and 2) meet and discuss with relevant stakeholders in the event system disruption may occur.

The findings confirm what the Experts conveyed, that Upstream Production variables carry the most significant influence, considering that without any upstream production, the gas settlement will not exist, and as such, Domestic Consumption cannot be met and Downstream Processing would not process anything. Therefore, alignment of the operational conditions and the mathematical model for the entitlement calculations become significant and variables detected shall provide insight to enhance fairness and regulatory alignment. The research also highlights AHP tool as an effective method to embed expert knowledge into quantitative frameworks to support decision-making.

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