Risk-Based Analysis of Joint Operation (JO) Model in Managing Waste Management Facility at Refuse-Derived Fuel (RDF) Plant Bantar Gebang to Improve RDF Performance

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ABSTRACT: *The operational performance of the Bantar Gebang Refuse-Derived Fuel (RDF) Plant faces challenges related to product quality and production quantity. Average moisture content increased from 35.26% in 2024 to 42.33% in 2025, while RDF production in 2024 reached only 63.29% of the daily target. This study aims to identify the aspects and indicators of Joint Operation (JO) stages, assess priority risks, examine the relationships among JO stages, risks, JO strategies, and RDF performance, and develop a risk-based JO model. A mixed-methods approach was employed, combining document analysis, expert validation involving seven experts, a survey involving 97 respondents, Partial Least Squares–Structural Equation Modeling (PLS-SEM), and a focus group discussion (FGD) involving three experts. The study identified 13 JO aspects measured by 17 indicators, 20 JO strategy indicators, and 19 priority risks. All four hypothesized relationships were positive and statistically significant, with path coefficients ranging from 0.359 to 0.722. The resulting model consists of three phases: Pre-JO, JO Formation, and Implementation and Monitoring, supported by nine risk-control matrices. RDF performance was assessed through a single latent construct incorporating indicators of product quality and production quantity. Since the proposed JO model has not been implemented, its effectiveness in improving actual facility performance requires further evaluation using operational data.*

KEYWORDS - *Joint Operation (JO), risk management, Refuse-Derived Fuel (RDF), RDF performance, PLS-SEM, waste-to-energy*

I. Introduction

Urban waste management has shifted from a collect-and-dump approach toward waste reduction and recovery of material value [1]. The Bantar Gebang Integrated Waste Processing Site was designed to receive 2,000 tons of waste per day, but the waste from Special Capital Region of Jakarta entering the site now reaches 6,500 – 7,000 tons per day [2]. One response is the RDF Plant, which converts waste into an alternative fuel that can replace coal, including in the cement industry [3], [4]. A study in Bantar Gebang RDF Plant shows that RDF can reduce waste generation and extend the service life of the site [5].

The Bantar Gebang RDF Plant is designed to process 2,000 tons of waste per day with a target of 700 tons of RDF per day. However, 2024 production was only 443 tons per day (63.29% of the target). Average RDF moisture content rose from 35.26% (2024) to 42.33% (2025), while the calorific value fell from 3,293.24 to 3,014.17 kcal/kg [6]. For comparison, SNI 9313:2024 sets a maximum moisture content of 22% for RDF used in the cement industry [7].

RDF performance is influenced by interrelated technical, operational, and managerial factors. Feedstock characteristics, particularly moisture content and heterogeneous composition, affect the

drying process and the resulting product quality. Processing technology, equipment capacity, maintenance, and process control also determine the effectiveness of sorting, shredding, drying, and blending operations [8], [9]. When the feed rate is not aligned with the capacity of the drying system, material residence time may decrease, limiting moisture removal and affecting the quality of the resulting RDF.

The management of an RDF facility also involves multiple stakeholders, including the government as the asset owner or facility manager, prospective business partners, waste suppliers, and RDF users or offtakers. Differences in responsibilities, risk allocation, payment arrangements, and performance expectations may create coordination challenges. Therefore, the management of an existing RDF facility requires an arrangement that considers not only operational capabilities but also the initial condition of the assets, the characteristics of incoming waste, and the responsibilities of each party.

Joint Operation (JO) between the government and a business entity can be considered as an alternative governance arrangement because it enables the parties to combine resources, technical capabilities, and operational experience. Public–private partnerships (PPPs) have been implemented in municipal waste management and related sectors [11], [12]. However, partnership arrangements do not automatically ensure successful performance. Technical, financial, regulatory, environmental, and social risks need to be identified, allocated to parties according to their ability to manage them, and controlled through contractual provisions and performance monitoring [10], [13].

This study does not assume that the absence of a JO arrangement is the direct cause of the observed RDF performance problems. Instead, JO is examined as a potential governance arrangement that may provide a clearer framework for responsibility allocation, operational management, risk control, and performance monitoring in an existing RDF facility.

Previous studies have examined waste-to-energy (WtE) and PPP risks [10], [14], risk and benefit allocation [13], and RDF production and quality [8], [9]. However, an integrated framework connecting JO stages, operational indicators, risks, JO strategies, and RDF performance remains insufficiently addressed, particularly for an RDF facility that is already operating.

This study aims to: (1) identify the main aspects of JO formation and implementation; (2) determine indicators for JO stages and JO strategies; (3) identify and assess priority risks; (4) analyze the relationships among JO stages, risks, JO strategies, and RDF performance; and (5) develop a risk-based JO model for the Bantar Gebang RDF Plant.

The study focuses on JO in the post-construction or operational stage rather than the entire PPP cycle from initial construction. Its contribution is the integration of JO stages, risk assessment, management strategies, and RDF performance into a framework that translates identified risks into responsibility allocation, mitigation measures, proposed contractual provisions, and monitoring indicators.

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II. Literature Review

2.1 RDF Production and RDF Performance

RDF is produced from the combustible fraction of waste through processes such as sorting, shredding, drying, and blending. Its performance is influenced by feedstock characteristics, processing technology, equipment capacity, and process control [8]. RDF product quality is generally assessed through parameters such as moisture content, calorific value, particle size, ash content, and the concentration of certain chemical elements [9]. Moisture content affects the energy available during combustion, calorific value indicates the energy potential of the fuel, and particle-size consistency contributes to product uniformity.

Quality and quantity are related but distinct dimensions of RDF facility performance. Increasing the amount of waste processed does not necessarily result in a higher quantity of RDF that meets the required specifications, particularly when the processing and drying capacities are limited. Accordingly, this study uses RDF Performance (Y) as a single latent variable measured directly through indicators representing two aspects: RDF Product Quality, comprising moisture content, calorific value, and size homogeneity; and RDF Production Quantity, represented by RDF output in tons per

day. This operational distinction prevents production quantity from being interpreted as a direct measure of product quality

2.2 Joint Operation and Public–Private Partnership

JO is a cooperation arrangement between two or more parties to carry out operational activities based on agreed contributions, responsibilities, rights, and obligations. PPP literature identifies risk management, contract management, success and failure factors, economics and finance, and performance management as major themes [16]. Governments may pursue additional capital, operational efficiency, and value for money, while private parties may seek investment opportunities, risk sharing, and profit [17].

In waste management, partnership arrangements require coordination among public authorities, private operators, communities, waste suppliers, and product users. Collaborative governance emphasizes stakeholder involvement and collaboration processes to support shared goals [22].

Experiences from other countries provide relevant lessons. In the Czech Republic and Slovakia, partner evaluation and periodic monitoring are important considerations in municipal waste management [18]. In Poland, regulatory arrangements support cooperation between local governments and private parties in RDF-related activities [4]. Social acceptance is an important consideration in waste management cooperation in Moscow [19]. In China, risk allocation and benefit distribution have been examined in PPP projects [13], while studies in Thailand have highlighted the importance of waste quality and technical requirements in the development of MSW and RDF power plants [9]. PPP risk-management strategies may also include exit provisions, performance evaluation, and transparent compensation mechanisms [20].

In Bantar Gebang, the RDF Plant is managed by the Jakarta Provincial Government's Environment Agency (EA) through its existing institutional arrangement. Under proposed JO arrangement, a business partner may undertake operational and maintenance activities within an agreed scope, while the government retains its responsibilities as the public authority and asset owner. The cooperation arrangement therefore needs to account for the initial condition of existing assets, current operational performance, feedstock characteristics, equipment capacity, and RDF offtake arrangements. Responsibilities should be allocated according to the agreed scope of work and each party's ability to control the relevant risks

2.3 Risk Management in Cooperation Projects

Risk management involves identifying, analyzing, evaluating, and controlling uncertainties that may affect project objectives. Cooperation projects may experience difficulties when risk-management procedures are weak, while their effectiveness depends partly on available resources and organizational capacity [21]. Relationships among risks in WtE projects are complex [10], and risk perceptions may differ between government and private stakeholders [15].

In this study, risks related to RDF facility cooperation are classified into seven categories: technical and operational, technology, financial and economic, regulatory, environmental, social, and collaboration risks.

Risk allocation should consider each party's ability to control the source of a risk [13]. Risks arising from the condition of existing assets cannot necessarily be assigned entirely to a new business partner. Conversely, risks caused by the partner's actions within its agreed scope of work may be allocated to that partner. Risk sharing should therefore consider the initial condition of the facility, the cause of the risk, the scope of work, and the ability of each party to control the relevant risk.

For an existing RDF facility, the distinction between pre-existing risks and risks arising during JO implementation is particularly important. This distinction prevents a party from being held responsible for conditions beyond its contractual control and provides a basis for more transparent risk allocation

2.4 JO Strategy

JO strategy refers to the management actions used to support cooperation implementation and facility performance. Based on the literature and the operational context of RDF facilities, the strategies in this study are grouped into six

dimensions: technology and innovation; human resources and organizational capacity; finance; regulation and institutions; feedstock quality and RDF process; and environment and sustainability [8], [9], [21].

Collaborative governance requires stakeholder involvement and coordination to support shared objectives [22]. Environmental management also requires attention to emissions and residual waste generated by waste-processing activities [3], [23].

In the Bantar Gebang RDF Plant context, JO strategies need to address both the administrative requirements of cooperation and the technical and operational conditions that determine RDF performance. These strategies include technology adaptation to local waste characteristics, workforce competence, equipment maintenance, financial arrangements, feedstock quality control, process optimization, and environmental management.

2.5 Conceptual Framework and Hypotheses

This study examines the relationships among four constructs: JO stages (X1), risks (X2), JO strategies (X3), and RDF performance (Y). JO stages represent the aspects that need to be considered in planning, forming, and implementing the cooperation. Risks represent uncertainties associated with the cooperation and operation of the RDF facility. JO strategies represent management actions used to address identified risks and support facility operations. RDF performance is represented by a single latent variable measured using indicators of RDF product quality and production quantity.

The research hypotheses are formulated as follows:

- H1: JO stages (X1) influence JO strategy (X3).
- H2: Risk (X2) influences JO stages (X1).
- H3: Risk (X2) influences JO Strategy (X3).
- H4: JO strategy (X3) has a positive relationship with RDF performance (Y).

The positive direction of H2 and H3 reflects the proposed relationship between the assessment of identified risks and the consideration of risk-related requirements in JO planning and strategy development. It does not imply that an increase in actual risk improves cooperation or facility performance. The interpretation of these relationships is limited to the operational meaning of the risk construct and the perceptions captured by the questionnaire.

2.6 Research Gap and Contribution of this Study

Previous studies have examined various aspects of public-private partnerships (PPPs) in waste management and waste-to-energy projects, including partnership implementation, risk identification, risk allocation, and management strategies. Afful et al. (2024) examined PPP implementation in municipal solid waste management, highlighting the importance of institutional arrangements and stakeholder involvement [11]. Ghimire et al. (2024) investigated stakeholders' risk perceptions in waste-to-energy PPP projects [15], while Cheng et al. (2023) analyzed the interrelationships among risks in waste-to-energy incineration projects [10]. These studies provide important insights into the risks and management challenges associated with collaborative waste management projects.

Other studies have focused on risk allocation and strategies for managing PPP projects. Wang et al. (2023) examined risk allocation and benefit distribution in construction waste recycling PPP projects [13]. Gad et al. (2024) discussed risk allocation and technological innovation in waste-to-energy PPPs [14], while Jiang et al. (2024) examined risk management strategies from the perspective of infrastructure project vulnerabilities [20]. In addition, Adu Gyamfi et al. (2024) highlighted the influence of resource management on PPP risk management [21], and Mwesigwa et al. (2024) emphasized the role of community engagement and commitment in the sustainability of PPP projects [26].

Despite these contributions, several research gaps remain relevant to the management of RDF facilities. First, previous studies have generally examined PPP arrangements, risk factors, or risk management strategies as separate research focuses. An integrated framework connecting JO stages, operational risks, JO strategies, and RDF performance remains insufficiently addressed, particularly for an RDF facility that is already operating.

Second, the operational characteristics of RDF facilities require specific consideration. RDF performance is influenced by feedstock composition, moisture content, processing technology, equipment capacity, and operational management. Although previous studies have discussed RDF production and technological considerations [8], these operational requirements have not been sufficiently integrated into a risk-based JO management framework for an existing facility.

Third, the relationships among cooperation arrangements, risk considerations, management strategies, and RDF performance require further empirical examination. Existing studies provide insights into risk perception, risk allocation, and PPP management, but these aspects need to be integrated into a model specifically designed for the operational management of an existing RDF facility.

To address these gaps, this study develops a risk-based JO model for the Bantar Gebang RDF Plant. The study integrates four main constructs: JO stages (X1), risks (X2), JO strategies (X3), and RDF performance (Y). The relationships among these constructs are empirically examined using Partial Least Squares–Structural Equation Modeling (PLS-SEM). The findings are subsequently synthesized into a management model consisting of three phases: Pre-JO, JO Formation, and Implementation and Monitoring.

The main contribution of this study is the integration of JO stages, risk assessment, management strategies, and RDF performance into a single risk-based JO framework. Unlike studies that primarily focus on PPP risk identification or allocation, this study translates identified priority risks into responsibility allocation, mitigation strategies, proposed contractual provisions, and monitoring indicators. The model is intended to support operational cooperation planning in existing RDF facilities by clarifying responsibility boundaries, addressing operational risks, and establishing performance monitoring arrangements.

III. Methodology

3.1 Research Design

This study employed a mixed-methods approach using a case study of the Bantar Gebang RDF Plant. The research combined document analysis, expert validation, Delphi assessment, questionnaire surveys, PLS-SEM, and an FGD. The research was organized into five stages corresponding to the five research questions (RQ).

The five research stages, each answering one research question (RQ), are summarized in Table 1.

Table 1. Research Design by Research Question

RQ	Research Question	Instrument and Analysis	Output
1	What are the main aspects of JO formation?	Document analysis; face and content validation by seven experts	13 JO stage aspects
2	What indicators measure each aspect and JO strategy?	Indicator development and content validation	17 JO stage indicators (X1) and 20 JO strategy indicators (X3)
3	What are the priority risks?	Delphi with five experts; probability × impact assessment by 97 respondents; validation by five experts	19 priority risks
4	How are JO stages, risks, JO strategies, and RDF performance related?	Likert-scale questionnaire involving 97 respondents; PLS-SEM	Structural model and hypothesis tests H1–H4
5	How can a risk-based JO model be developed?	FGD involving three experts	Three-phase JO model and nine risk-control matrices

3.2 Research Location and Respondents

The study was conducted at the Bantar Gebang RDF Plant. Experts and respondents were selected based on their knowledge, experience, or

involvement in JO, waste management, project management, risk management, or RDF operations.

Seven experts participated in the validation of JO aspects and indicators. Five experts participated in the Delphi process and subsequent validation of priority risks. For the general respondent survey, 100 questionnaires were returned. Of these, 97 were included in the analysis, while three were excluded following the homogeneity screening criteria applied in the study. The resulting 97 questionnaires were used for risk assessment and PLS-SEM analysis.

The exclusion of three questionnaires should be interpreted as a data-screening decision rather than a non-response. The specific homogeneity test procedure and exclusion thresholds should be reported in the final methodological record to ensure that the screening process can be replicated.

3.3 Identification of JO Aspects, Indicators, and Risks

JO aspects were identified from relevant documents, regulations, and literature, then validated by experts. The experts assessed the clarity and relevance of the proposed aspects and indicators. The operational indicators for JO stages and JO strategies were developed and validated using the same procedure.

Risks were identified based on the JO stage indicators and previous studies. The Delphi process involved five experts, and risk factors were retained when the consensus level reached at least 75%. Risk levels were assessed by respondents using probability and impact scores.

$$R = P \times I \quad (1)$$

where (R) is the risk score, (P) is the probability score, and (I) is the impact score. High-category risks were subsequently reviewed by five experts using a minimum approval threshold of 80% to determine the final priority risks.

3.4 PLS-SEM Analysis

The relationships among JO stages (X1), risks (X2), JO strategies (X3), and RDF performance (Y) were analyzed using Partial Least Squares–Structural Equation Modeling (PLS-SEM) in SmartPLS.

RDF performance was specified as one latent variable (Y), with indicators directly assigned to the construct. The indicators represented two operational aspects: RDF product quality, including moisture content, calorific value, and size homogeneity; and RDF production quantity, measured by RDF output in tons per day. The study therefore treats product quality and production quantity as distinct indicator domains within the same latent construct, rather than modeling them as separate higher-order constructs.

The measurement model was evaluated using outer loadings, Average Variance Extracted (AVE), Cronbach's alpha, composite reliability, and the Heterotrait–Monotrait ratio (HTMT). The structural model was assessed through variance inflation factor (VIF), coefficient of determination (R^2), effect size (f^2), and path coefficients. Bootstrapping was used to examine the significance of the hypothesized relationships at a significance level of 0.05. A hypothesis was considered statistically supported when the t-statistics exceeded 1.96 and the p-value was below 0.05.

The interpretation of the measurement model must follow the actual measurement specification used in SmartPLS. In particular, the retention of indicators with outer loadings below the recommended threshold should be evaluated in relation to the construct specifications, indicator relevance, and the complete measurement-model results.

3.5 Development and Validation of the Risk-Based JO Model

The initial model was developed by synthesizing the findings from RQ1 to RQ4. The model was subsequently evaluated through an FGD involving three experts representing facility management, academia, and project-management practice. The discussion assessed the model phases, division of responsibilities, risk allocation, mitigation strategies, proposed contractual provisions, and monitoring indicators.

The FGD was used to evaluate and refine the proposed model based on operational considerations and stakeholder experience. The resulting model is therefore presented as a recommended management

framework and not as evidence of an already implemented JO arrangement.

IV. Results and Discussion

4.1 RDF Performance at The Bantar Gebang RDF Plant

Operational data show that RDF quality worsened from 2024 to 2025 (Table 2). Moisture content increased and calorific value decreased, while the share of RDF meeting the size requirement was still below the 95% minimum. In terms of quantity, 2024 production was 443 tons per day (63.29% of the 700 tons per day target).

Table 2. Average RDF quality at the Bantar Gebang RDF Plant, 2024–2025

Parameter	2024	2025	Change
Moisture content (%)	35.26	42.33	Increased
Calorific value (kcal/kg)	3,293.24	3,014.17	Down 8.47%
Size conformity (%)	56.99	46.85	Decreased

Production quantity is presented separately from the product quality parameters. The 2024 RDF output of 443 tons per day represents 63.29% of the 700 tons per day target.

These operational conditions should be understood as an interconnected management and process challenge. Incoming waste characteristics, equipment condition, operator capacity, maintenance, and coordination with offtakers may affect the facility's ability to achieve its targets. Wet and heterogeneous feedstock increases the drying load. When the feed rate is not aligned with the capacity of the drying system, the residence time of material in the dryer may decrease, reducing the effectiveness of moisture removal.

The operational data provide the context for developing a JO model that addresses actual facility conditions. However, these data do not establish that the absence of JO directly caused the observed performance problems.

4.2 JO Aspects and Indicators

The study identified 13 JO aspects measured by 17 indicators. The aspects were identified from documents, regulations, and literature, and subsequently validated by experts. The number of indicators exceeds the number of aspects because certain aspects require more than one measurement. For example, feasibility studies are assessed through technical, financial, environmental, and social considerations. Aspect 11, administrative and legal compliance, was broadened from the initial focus on tax identification to include administrative, legal, and tax requirements. This adjustment reflects the need to assess the broader administrative readiness of the parties involved in the cooperation.

Table 3. JO Stages and Operational Indicators

No.	Aspect	Number of indicators	Main indicator
1	Project selection	1	Prequalification and two-stage qualification procedure
2	Public consultation	2	Community participation; transparency of information
3	Feasibility study	4	Technical, financial, environmental, and social analyses
4	Risk allocation	1	Identification of risks among stakeholders
5	Form of cooperation	1	Type of JO consistent with regulations
6	Business entity qualification	1	Administrative and technical requirements met
7	JO *lead firm*	1	Experienced consortium leader
8	JO contract	1	Clear rights and obligations of the parties

No.	Aspect	Number of indicators	Main indicator
9	Concession period	1	Duration of the JO determined
10	JO responsibilities	1	Clear division of tasks among parties
11	Administrative and legal compliance	1	Administrative, legal, and tax requirements met
12	JO implementation	1	RDF Plant operates according to target capacity and plan
13	Performance monitoring of the business entity	1	Monitoring according to contract provisions

The 13 aspects describe the stages and institutional requirements that need to be considered in planning, forming, and implementing the cooperation. The 17 indicators provide operational measures for evaluating these aspects.

4.3 JO Strategy Indicators

The study identified 20 JO strategy indicators grouped into six dimensions: technology and innovation; human resources and organizational capacity; finance; regulation and institutions; feedstock quality and RDF process; and environment and sustainability.

The technology and innovation dimension includes technology selection and operation and maintenance efficiency. Human resources and organizational capacity cover competence, technical training, and partner experience. Financial strategies include financing schemes, profit and risk sharing, and budget monitoring. Regulation and institutional strategies include RDF quality compliance, permits, and contract monitoring. Feedstock quality and RDF process strategies include moisture and size control, sorting, drying, shredding, and blending. Environment and sustainability strategies include emission and residue management.

JO aspects and JO strategies are treated as separate constructs because they serve different functions. JO aspects describe the stages and requirements of cooperation, whereas JO strategies describe management actions intended to support JO implementation and facility operations. This distinction prevents the cooperation process from being conflated with the strategies used to manage its operational performance.

4.4 Priority Risks

Of the 28 initial risk factors, one risk factor concerning asset transfer was removed during content validation and the Delphi process. The remaining 27 risks were assessed by 97 respondents. The assessment classified 23 risks as high and four as medium. No risks were classified as low. Following further validation by five experts, 19 risks were designated as priority risks.

Four high-category risks were not retained as priority risks after expert validation: payment delays, high investment cost, investor change, and unclear waste-management boundaries. Their exclusion indicates that they did not meet the final expert-validation criteria; it does not mean that these risks can never occur.

Table 4. Priority Risk Categories

Category	Number	Priority Risks
Technical and operational	5	Facility location; operation and maintenance; construction and implementation; facility design; operational management capacity
Technology	2	Inappropriate RDF technology selection; technical readiness and system integration
Financial and economic	2	Revenue uncertainty; market and RDF price uncertainty

Category	Number	Priority Risks
Regulatory	3	Policy and administrative changes; political and legal uncertainty; delays in government decisions
Environmental	3	Air, water, and soil pollution; leachate; public health impact
Social	3	Community opposition; land-use conflict; low public awareness
Collaboration	1	Conflicts of interest among stakeholders

The seven detailed categories are retained as the basis for risk identification. For the development of the JO model, these categories are consolidated into three broader groups to facilitate risk allocation and control: (1) technical and operational risks, including technology-related risks; (2) financial, policy, and political risks, including financial and regulatory risks; and (3) environmental, social, and institutional risks, including collaboration-related risks. This consolidation is intended to organize risk-control arrangements and does not alter the original identification of the 19 priority risks.

4.5 PLS-SEM Results

The PLS-SEM analysis examined the relationships among JO stages (X1), risks (X2), JO strategies (X3), and RDF performance (Y).

The reported measurement model results for X1, X2, and X3 showed AVE values of 0.549, 0.535, and 0.594, respectively. Cronbach's alpha ranged from 0.944 to 0.966, while composite reliability ranged from 0.951 to 0.968. HTMT values ranged from 0.599 to 0.818. VIF values ranged from 1.000 to 2.088.

The reported results indicate that the AVE values for X1, X2, and X3 exceeded 0.50, while the reported reliability coefficients were within the range presented in the analysis. The HTMT values ranged from 0.599 to 0.818, and the VIF values ranged from 1.000 to 2.088.

Twelve of the 27 risk indicators had outer loadings below 0.70 but were retained because of their conceptual relevance and the reported AVE value for the risk construct, which remained above 0.50. However, AVE alone should not be used as the sole justification for retaining indicators with low outer loadings. The final paper should report on the individual loading values and explain the retention decision in accordance with the actual measurement specification of the risk construct.

Table 5. Hypothesis Testing Results

Hypothesis	β	t	p	f^2	Decision
H1	0.533	4.220	< 0.001	0.436 (large)	Supported
H2	0.722	12.714	< 0.001	1.088 (large)	Supported
H3	0.359	2.800	0.005	0.198 (medium)	Supported
H4	0.710	12.308	< 0.001	1.016 (large)	Supported

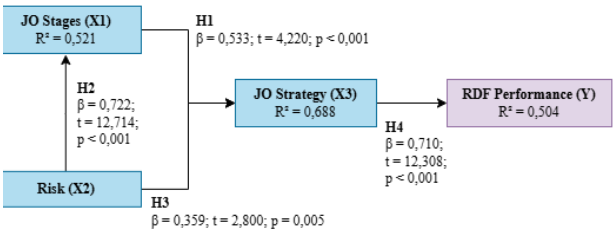


Fig. 1 Results of the PLS-SEM Structural Model Test

All four hypothesized relationships were positive and statistically significant. The largest path coefficient was observed for the relationship between risks and JO stages (β = 0.722), followed by the relationship between JO strategies and RDF performance (β = 0.710).

The positive relationship between risks and JO stages indicates that higher risk-assessment scores were associated with higher scores for JO stages in the respondent data. This result should not be interpreted as evidence that increasing actual risk improves JO arrangements. Rather, it reflects the statistical association between the risk construct and

the construct representing JO stages, within the operational definitions used in the questionnaire.

The relationship between JO stages and JO strategies was also positive and significant (β = 0.533). This finding indicates that more systematic consideration of JO stages was associated with stronger JO strategy assessments. Similarly, the relationship between risks and JO strategies was positive and significant (β = 0.359), indicating an association between risk assessments and the strategies considered relevant to addressing operational and cooperation-related uncertainties.

JO strategies had a positive and significant relationship with RDF performance (β = 0.710). This finding suggests that respondents who assigned higher scores to JO strategies also tended to assign higher scores to RDF performance indicators. Since RDF performance was assessed through respondent perceptions in the PLS-SEM model, this relationship does not demonstrate that the strategies have already improved actual moisture content, calorific value, size homogeneity, or RDF production quantity.

The structural model is expressed in the following equations, where ε is the error term:

$$X1 = 0.722\ X2 + \varepsilon_1 \quad (2)$$

$$X3 = 0.533\ X1 + 0.359\ X2 + \varepsilon_2 \quad (3)$$

$$Y = 0.710\ X3 + \varepsilon_3 \quad (4)$$

The R^2 values were 0.521 for X1, 0.688 for X3, and 0.504 for Y. This means that the model explains 52.1% of the variance in JO stages, 68.8% of the variance in JO strategies, and 50.4% of the variance in respondents' assessments of RDF performance.

The R^2 value for RDF performance represents the proportion of variance explained in the latent construct as measured by the questionnaire indicators. It should not be interpreted as the proportion of actual technical improvement in RDF quality or production quantity.

The PLS-SEM findings provide empirical evidence of the relationships among the four constructs and serve as one input for developing the proposed JO model. They do not establish causal effects or demonstrate that the proposed JO arrangement has already improved the facility's operational performance.

4.6 Development of the Risk-Based JO Model

The initial model was developed from the results of RQ1–RQ4 and refined through an FGD involving three experts representing facility management, academia, and project-management practice. The final model consists of three phases: Pre-JO, JO Formation, and Implementation and Monitoring (Fig. 2).

The Pre-JO phase ensures the readiness of the existing facility before the cooperation arrangement is established. This phase includes project selection, public consultation, feasibility assessment, risk identification, initial asset assessment, and evaluation of current operational performance. An independent performance test is recommended before the JO contract is established. The test provides an objective baseline of the existing facility's operational condition and actual performance. Local waste characterization, including moisture content and waste composition, should also be conducted to establish realistic performance targets and identify the operational requirements of the facility.

The JO Formation phase covers the determination of the cooperation arrangement, partner qualification, selection of the lead firm, division of responsibilities, risk allocation, financing arrangements, and contract drafting. The contract should establish clear performance indicators based on independent testing and local feedstock characteristics. It should also include provisions addressing regulatory changes, laboratory testing, technology suitability, responsibility boundaries, financing mechanisms, and profit and risk sharing. The allocation of responsibilities needs to distinguish pre-existing asset conditions from modifications or work undertaken by the partner within the agreed JO scope.

The Implementation and Monitoring phase covers facility operation, implementation of mitigation strategies, control of RDF quality and quantity, performance monitoring, contract evaluation, and risk handling throughout the cooperation period.

Monitoring should cover operation and maintenance efficiency, staff training, moisture and size control, process performance, emission management, and residue handling. Periodic

technology and feedstock evaluations should be conducted to identify operational disruptions and determine corrective actions. Quality and quantity targets should be linked to the agreed characteristics of the incoming waste and the verified capacity of the facility.

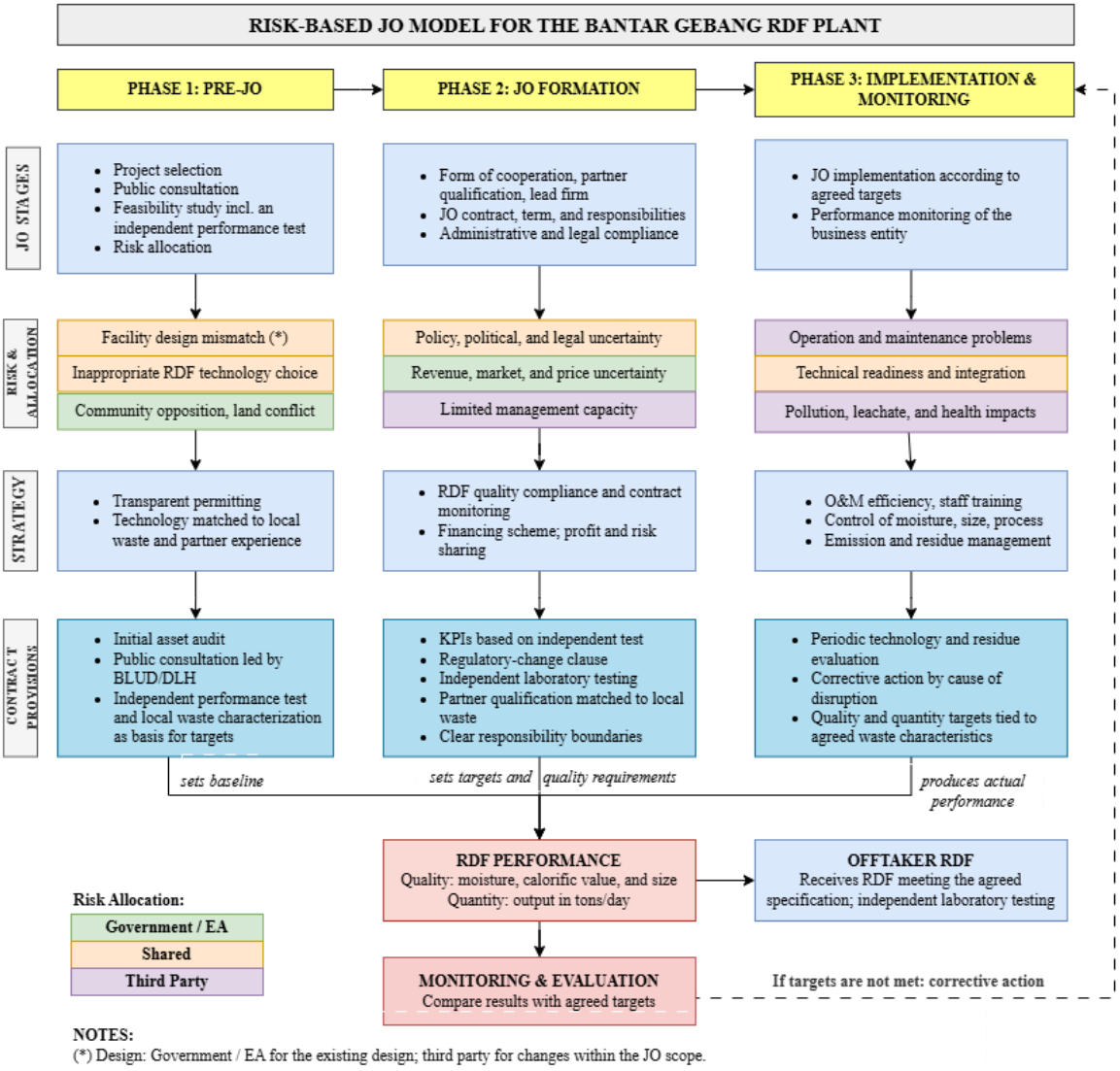


Fig. 2 Risk-Based JO Model for The Bantar Gebang RDF Plant

The 19 priority risks are organized into three groups: technical and operational; financial, policy, and political; and environmental, social, and institutional risks. Each group is supported by three matrices: risk allocation, mitigation strategies, and proposed contractual provisions with monitoring indicators. This produces nine risk-control matrices in total.

The risk allocation matrix identifies whether a risk is assigned to the government or EA, the third party, or shared between the parties. The mitigation matrix identifies actions to prevent or reduce the likelihood and impact of the risks. The contractual provision matrix translates these arrangements into proposed clauses and monitoring indicators.

The risk-control arrangements should consider the source of each risk and the ability of the parties to control it. For example, operation and maintenance problems arising from activities within the partner's agreed operational scope may be allocated to the third party. The corresponding mitigation measures may include preventive maintenance, operator training, routine inspection, and maintenance planning. Contractual provisions may require the partner to maintain equipment and submit periodic equipment-conditioning and maintenance reports. Monitoring indicators may include equipment availability, downtime, maintenance completion, and production performance.

The FGD produced several main refinements as follows:

1) Independent performance testing. An independent performance test should be conducted before the contract is established because actual production is below the feasibility study target. The results provide a basis for assessing the initial condition and determining agreed performance targets.
2) Technology suitability. Technology selection should consider local waste characteristics, particularly moisture content and heterogeneous composition. During the site visit, an imported shredder was observed to be not yet fully adapted to Jakarta's wet and heterogeneous waste. This observation is presented as a finding from the site visit and expert discussion, not as a verified statement about the manufacturer's original design specifications.
3) Responsibility boundaries for existing assets. The model distinguishes the condition of existing assets from modifications or changes made by the partner during the JO. For example, in relation to design risk, the government or EA is responsible for the existing design, while the third party is responsible for design changes within the agreed JO scope.
4) RDF offtake arrangements. RDF offtake arrangements should clearly regulate pickup schedules, volume, storage capacity, emergency storage areas, and procedures for handling delays. RDF pricing should consider product quality and the agreed testing mechanism. Penalties should be linked to failures within the control of the party concerned.
5) Public consultation and complaints. The EA should lead public consultation, while the third party should handle complaints arising from its operational activities. This allocation is consistent with the importance of community involvement in PPP sustainability [11], [26].

These refinements demonstrate how the FGD translated the initial model into more specific management and contractual considerations. The changes address the conditions of an existing RDF facility, especially the need to establish an objective baseline, adapt technology to local waste, clarify responsibility boundaries, and manage RDF offtake.

4.7 Development of the Risk-Based JO Model

The final model integrates the results of the five research questions. The 13 JO aspects and 17 indicators provide the basis for organizing the cooperation stages. The 20 JO strategy indicators provide the management actions required to support the facility. The 19 priority risks inform responsibility allocation, mitigation measures, and contractual provisions. The PLS-SEM findings provide empirical evidence of the relationships among JO stages, risks, strategies, and RDF performance. Finally, the FGD refines the model by incorporating operational and institutional considerations.

The relationship between the research findings and the model components can be summarized as follows:

Table 6. Research Finding

Research Finding	Implication For the JO Model
Risks (X2) → JO stages (X1)	Risk identification and consideration are incorporated into the Pre-JO stage and responsibility planning
JO stages (X1) → JO strategies (X3)	JO stages provide the basis for developing management strategies during JO Formation
Risks (X2) → JO strategies (X3)	Priority risks are translated into mitigation strategies and control measures
JO strategies (X3) → RDF performance (Y)	Operational strategies are directed toward the agreed quality and quantity performance indicators

The model should be regarded as a recommended management framework for the Bantar Gebang RDF Plant, rather than a universally applicable contract form. Its implementation requires adjustment to the results of facility evaluation, prevailing policy, partner readiness, and agreements among the parties. Its effectiveness can only be established through implementation and subsequent evaluation using actual operational and contractual data.

V. Conclusion

This study developed a risk-based JO model for the Bantar Gebang RDF Plant by integrating institutional, technical, operational, and risk-control considerations. The study identified 13 JO aspects measured by 17 indicators, 20 JO strategy indicators grouped into six dimensions, and 19 priority risks classified into seven categories.

The PLS-SEM results showed positive and statistically significant relationships among all four hypothesized paths. The relationship between risks and JO stages had the largest coefficient ($\beta = 0.722$), followed by the relationship between JO strategies and RDF performance ($\beta = 0.710$). The model explained 52.1% of the variance in JO stages, 68.8% of the variance in JO strategies, and 50.4% of the variance in respondents' assessments of RDF performance.

The main contribution of this study is the integration of JO stages, risk assessment, management strategies, and RDF performance into a three-phase model consisting of Pre-JO, JO Formation, and Implementation and Monitoring. The model is supported by nine risk-control matrices covering risk allocation, mitigation strategies, proposed contractual provisions, and monitoring indicators. It also incorporates important considerations for an existing RDF facility, including independent performance assessment, existing asset conditions, local feedstock characteristics, RDF offtake arrangements, and responsibility boundaries.

This study has several limitations. First, RDF performance in the PLS-SEM model was assessed through respondents' perceptions rather than actual technical measurements before and after JO implementation. Therefore, the study does not demonstrate that the proposed model has already improved RDF product quality or production quantity. Second, the model was evaluated through an FGD involving three experts and has not yet been tested through actual JO implementation, operational data, or financial simulation. Third, the study focuses on one RDF facility, so its application to other facilities requires adjustment to local technology, feedstock, institutional, and regulatory conditions.

Future research should evaluate the model through actual JO implementation and compare RDF moisture content, calorific value, size homogeneity, and production quantity before and after implementation. Further research should also develop financial simulations, evaluate the allocation of operational and financial risks, and translate the proposed risk-control matrices into detailed contractual provisions.

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