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Research Paper

Multidimensional Scaling - Based Framework for Assessing the Sustainability of Communal Wastewater Treatment System

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Abstract

This study evaluates the sustainability of a communal wastewater treatment plant (CWWTP) in Pohjentrek Village, Pasuruan City, Indonesia, by integrating across five dimensions, technical, social, economic, environmental, and institutional using Multi-Dimensional Scaling (MDS), complemented by leverage and Monte Carlo analyses to identify critical attributes and validate model robustness. The results show that the social and environmental dimensions achieved a very sustainable status, with index values of 82.71 and 82.40, respectively. These findings reflect strong community acceptance of the communal wastewater treatment system and recognition of its environmental benefits, particularly in reducing potential groundwater contamination in densely populated residential areas. In contrast, the technical (67.38), economic (74.02), and institutional (72.10) dimensions were classified as sufficiently sustainable, indicating that the system remains operational but exhibits several structural vulnerabilities. Technical sustainability is constrained by effluent quality that has not yet consistently met regulatory standards and by the absence of routine effluent monitoring. While economic sustainability remains highly dependent on limited household contributions due to the absence of other funding source. Institutional sustainability largely relies on the commitment of local managers. The reliability of the sustainability assessment is supported by low stress values (0.14–0.15), high coefficients of determination ($R^2 = 0.94–0.95$), and Monte Carlo deviations below 5%, indicating a stable and statistically robust MDS configuration. Importantly, the sustainability classification reflects the aggregated performance across multiple dimensions rather than relying solely on individual indicators such as effluent compliance. This study contributes to the literature on sanitation sustainability by providing a validated, attribute-level sustainability diagnosis that integrates system performance with multidimensional analysis. The findings highlight the identification of sensitive attributes and priority interventions, enabling more targeted and effective management strategies for improving the sustainability of communal wastewater treatment systems.

Keywords

Communal Wastewater Treatment Plant (CWWTP), Monte Carlo Analysis, Multi-Dimensional Scaling (MDS), Leverage Analysis, Sustainability Assessment

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1. INTRODUCTION

The objectives of Sustainable Development Goals (SDGs) number 6 is reinforced by Indonesia's national development agenda through the National Medium-Term Development Plan, which targets equitable access to sanitation and hygiene services and the elimination of open defecation practices by 2030. Domestic wastewater management represents a critical environmental and public health challenge, particularly in densely populated urban and peri-urban areas. Nearly 80% of clean water used by households is discharged as wastewater (Widyarani et al., 2022), which contributes to environmental pollution and increases the risk of waterborne diseases such as diarrhea (Hasugian, 2025). Inadequate sanitation systems therefore not only degrade environmental quality but also threaten community health, highlighting the need for more effective and sustainable wastewater management approaches.

In response to these challenges, the development of centralized domestic wastewater management systems at the communal scale (CWWTPs), has emerged as a practical and context-appropriate solution. Communal WWTPs offer a relatively affordable and technically feasible approach to reducing pollutant loads while promoting community involvement in planning, construction, and operation. Previous studies have shown that community-based wastewater treatment systems can enhance social acceptance and environmental protection when supported by effective management and institutional arrangements (Nurmiyanto et al., 2023). As such, communal WWTPs play a strategic role in supporting the achievement of national sanitation targets and SDG 6, especially in areas where individual on-site systems are not feasible by improving the water quality (Obaideen et al., 2022).

Despite these advantages, the sustainability of communal WWTPs remains a complex issue influenced by technical performance, social acceptance, financial capacity, institutional arrangements, and environmental impacts. Several research have reported on WWTPs sustainability from different perspectives. Sunaryo and Soewondo (2024) examined the determinants of community participation and sustainability in a community-based sanitation program in Temanggung Regency using Partial Least Squares Structural Equation Modeling (PLS-SEM). Their study focused on modeling relationships among latent variables affecting community participation rather than evaluating treatment system performance or environmental outcomes. Brontowiyono et al. (2022) assessed sustainability using a structured scoring and indexing approach; however, the framework did not explicitly integrate empirical treatment performance data or conduct statistical validation to examine attribute sensitivity influencing sustainability outcomes. Similarly, (Cecilia et al., 2023) applied a multi-criteria decision analysis (MCDA) approach to evaluate sustainability across technical, managerial, economic, institutional, environmental, and social dimensions based on stakeholder perceptions. While this approach provided valuable insights into perceived system strengths and weaknesses, it did not link measured operational performance to a composite sustainability index or assess attribute-level sensitivity and model robustness. This study addresses that gap by combining empirical treatment performance data with Multi-Dimensional Scaling (MDS), leverage analysis, and Monte Carlo simulation to produce a robust, attribute-sensitive sustainability diagnosis that directly informs targeted operational improvements for communal WWTPs.

Research by Mahendra et al. (2018) evaluated wastewater management sustainability using MDS based primarily on expert judgment reflecting conditions in Jakarta. Although the study produced a composite sustainability index, the assessment relied largely on expert perceptions rather than empirical operational data from a specific treatment facility. Susanthi et al. (2023) also utilized MDS to assess the sustainability of communal wastewater treatment systems and subsequently developed management strategies using SWOT analysis. While this study shares methodological similarities with the present research, the analysis was mainly oriented toward strategic planning at the managerial level and did not explicitly incorporate empirical operational performance into the sustainability assessment. Nurmiyanto et al. (2023) developed a Sustainability System Index (SSI) framework using an MDS-based approach to compare sustainability conditions across multiple systems. However, the analysis focused primarily on composite index construction and comparative evaluation rather than examining attribute-level sensitivity or validating sustainability classifications under data uncertainty. Accordingly, a methodological gap remains in linking field-based performance with a statistically validated, attribute-sensitive sustainability assessment at the facility level. This study addresses that gap by integrating treatment performance analysis with Multi-Dimensional Scaling (MDS), leverage analysis, and Monte Carlo simulation to produce a robust and operationally grounded sustainability evaluation framework. By combining performance-based data with multidimensional sustainability analysis, this approach enables the identification of sensitive attributes and priority interventions that can support more targeted and effective management improvements for communal wastewater treatment systems.

2. EXPERIMENTAL SECTION

2.1 Study Area

This research was conducted from September – October 2025 at the Pohjentrek WWTP, Pasuruan City, which is one of the areas with a high risk of wastewater sanitation. The location of the communal wastewater treatment plant is in RT 01 RW 04, Pohjentrek Village, Pasuruan City, at coordinates 7°41'50.84"S and 112°52'14.697" E as seen in Figure 1. The beneficiaries of the communal wastewater treatment plant consist of the communities in RT 01 and RT 02 RW 04, Pohjentrek, Pasuruan City. This study used total sampling, consisting of 64 house connections and managers of the communal wastewater treatment plant. Figure 1 presenting the study area and service area of Pohjentrek CWWTP.

2.2 Methods

The validity and reliability tests for the questionnaires were conducted using IBM SPSS Ver. 29 software and administered to 30 respondents. The validity test used the bivariate correlate method with Pearson Product Moment correlation to assess the relationship between the score for each question item and the total score at the same aspect. Questionnaire items were declared valid if the correlation coefficient value was positive and significant ($r > 0.361$ and sig. 5%). Reliability testing was carried out using the Cronbach's Alpha method to measure internal consistency between statement items, with a criterion of $\alpha > 0.60$ indicating good reliability.

Data collection was carried out by distributing closed questionnaires to all beneficiaries and managers of the communal wastewater treatment plant in RT 01 and RT 02, totaling 64 people representing their respective households. The total number of beneficiaries is 64 households who actively participating in the management of the communal wastewater treatment plant. In this study, respondents were

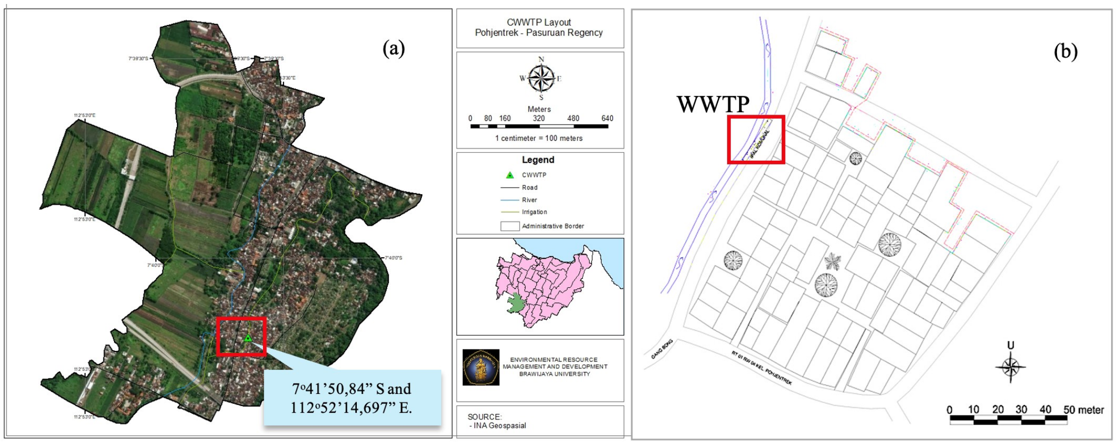

Figure 1. (a) Study Area and (b) Service Area of Pohjentrek WWTP – Pasuruan City

selected from this population. Since the analysis approach involves reconstruction based on a normal distribution, a minimum sample size of 30 respondents is required to ensure adequate representativeness (Majdina et al., 2024). The assessment was conducted on 33 attributes in five aspects of sustainability arranged in an ordinal scale, "Strongly Disagree (1)", "Disagree (2)", "Unsure (3)", "Agree (4)", or Strongly Agree (5)". The results were then converted into numerical data based on the field sampling results. The scoring reflects respondents' perceptions and field conditions related to the performance and management of the communal wastewater treatment plant. The use of an ordinal scale allows qualitative conditions to be systematically quantified and incorporated into the multidimensional analysis. Tabel 1 shows. the aspects and attributes that influence CWWTP sustainability status.

The sustainability analysis of communal wastewater treatment plants was conducted using the Multidimensional Scaling (MDS) method with the RAP (Rapid Appraisal) approach based on software Ms. Excel add-ins. The scores were then normalized and transformed into a dissimilarity matrix, which served as input for the ordination process using the Rapfish software. This analysis produces both a graphical ordination and a sustainability index derived from the multidimensional configuration of the assessed attributes. Each dimension of sustainability (technical, social, economic, environmental, and Institutional) was analysed based on attributes that had been given ordinal scores. The ordination results produced a sustainability index value with the categories of not sustainable (0–25), less sustainable (25–50), sufficiently sustainable (50–75), and highly sustainable (75–100). The MDS output includes statistical indicators such as the coefficient of determination (R^2) and stress values, which are used to evaluate the reliability of the ordination model. The R^2 value represents the proportion of variance explained by the model, where higher values approaching 1 indicate a better representation of the data structure. Meanwhile, the stress value measures the goodness-of-fit between the multidimensional configuration and the original data matrix. An acceptable model is indicated by an R^2 value greater than 0.50 and a stress value below 0.20, with lower stress values reflecting a more accurate and reliable MDS ordination (Kahirun et al., 2025). Monte Carlo simulation was performed at a 95% confidence interval and 25 iterations to test the stability and accuracy of the analysis results. The results of the Monte Carlo analysis will be compared with the MDS analysis. The difference between the two values is considered adequate if it is less than 5% (Ismail et al., 2025).

Domestic wastewater quality testing was conducted one time at the inlet and outlet points of CWWTP. Sample were taken using grab sampling at 7.00 am, representing the peak flow rate of community activity and then analyzed at accredited laboratory of DLH Pasuruan Regency. The sampling procedures referred to SNI 8995:2021 standard on water test sampling methods for physical and chemical testing and SNI 9063:2022 on water and wastewater test sampling methods for microbial parameter. The analyzed parameters included pH, BOD, COD, TSS, and Fecal Coliform were compared to domestic wastewater quality standards based on Regulation of the Indonesian Minister of Environmental Number 11 of 2025.

3. RESULTS AND DISCUSSION

3.1 Sustainability Status

The sustainability assessment of Pohjentrek WWTP indicates varying levels of performance across the five evaluated dimensions. The social and environmental aspects achieved the highest sustainability indices, with scores of 82.71 and 82.40, respectively, placing both dimensions in the very sustainable category. The technical, economic, and institutional aspects were classified as sufficiently sustainable, with indices ranging from 67.38 to 74.02. The Kite Model illustrating a slightly imbalanced sustainability profile, where

Table 1. Aspects and Attributes That Influence Sustainability Status

Aspects	Attributes
Technical Aspect	T1. System reliability;
	T2. Physical condition of facilities and infrastructure;
	T3. Service coverage;
	T4. Operational ease;
	T5. System capacity;
	T6. WWTP performance;
	T7. Regular maintenance of WWTP units.
Social Aspect	S1. Community participation;
	S2. Community acceptance;
	S3. Understanding the function of communal wastewater treatment plants;
	S4. Community awareness;
	S5. Trust in the management group;
	S6. Sharing of responsibilities;
	S7. Changes in community behavior.
Economic Aspect	F1. Willingness to Pay;
	F2. Affordability of contributions;
	F3. Appropriateness of contributions;
	F4. Operational and maintenance costs;
	F5. Regularity of contribution payments;
	F6. Other funding;
	F7. Financial reports.
Environ mental Aspect	E1. Impact on the environment;
	E2. Diseases caused by wastewater pollution;
	E3. Effluent quality;
	E4. Water body pollution;
	E5. Prevention of raw water source pollution.
Institutional Aspect	I1. Organizational structure;
	I2. Duties and responsibilities of the organization;
	I3. Mechanism for selecting managers;
	I4. Regular meetings;
	I5. Operators;
	I6. Active managers;
	I7. Government support.

Source: (Mahendra et al., 2018; Nurmiyanto et al., 2023; Sunaryo and Soewondo, 2024; Sumanto et al., 2025; Sembuil et al., 2022).

the expansion toward the social and environmental axes contrasts with the more constrained technical, economic, and institutional dimensions. This asymmetric pattern highlights the interdependence among sustainability aspects and underscores the need for targeted technical and institutional improvements to achieve a more balanced and resilient communal wastewater management system. The assessment of the sustainability status of the Pohjentrek WWTP - Pasuruan City results in Table 2 and kite model of sustainability index shown in Figure 2.

Table 2. Sustainability Status of the Pohjentrek WWTP – Pasuruan City

Sustainability Aspect	Sustainability Index	Sustainability Status
Technical	67.38	Sufficiently sustainable
Social	82.71	Highly sustainable
Economic	74.02	Sufficiently sustainable
Environmental	82.40	Highly sustainable
Institutional	72.10	Sufficiently sustainable

Source: Analysis Result, 2025

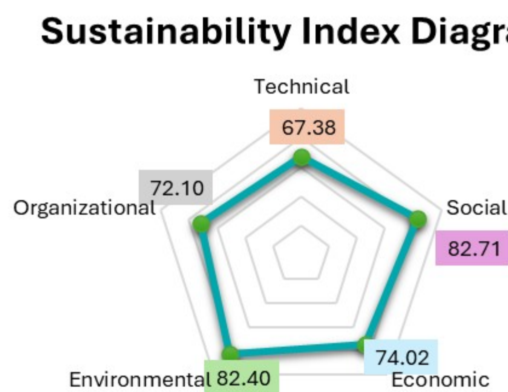

Figure 2. Kite Model of Sustainability Index Pohjentrek WWTP – Pasuruan City

Multi-Dimensional Scaling (MDS) results demonstrate a robust and reliable assessment of the sustainability status of the Pohjentrek communal WWTP. All sustainability dimensions exhibit low stress values ranging from 0.14 to 0.15, indicating minimal distortion in the ordination process, while high square correlation (RSQ) values (0.94–0.95) confirm that the model explains most of the variation in the original data. These results suggest that the MDS configuration adequately represents the actual sustainability conditions of the system.

The reliability of the MDS outcomes is further supported by the Monte Carlo analysis conducted at a 95% confidence level. The differences between the MDS and Monte Carlo are consistently below 5% for all dimensions, with deviations ranging from only 0.69% to 2.84%, as shown in Table 3. This small deviation suggests that random error, scoring uncertainty, or variation in respondent judgments did not significantly distort the sustainability classification. This stability, supported by low stress values, confirms that the multidimensional configuration reliably represents the attribute structure. Consequently, the sustainability status and identified leverage attributes can be used as a basis for formulating targeted improvement strategies to strengthen overall system sustainability (Suprijanto et al., 2025). The Monte Carlo analysis results show a cluster at one point, indicating that the analysis results are stable and reliable as represented in Figure 3.

The sustainability assessment results indicate that the Pohjentrek communal WWTP falls within the "sufficient" sustainability category, suggesting that the system is functioning but still requires several improvements to achieve optimal sustainability performance. This finding is comparable with the results reported by Nurmiyanto et al. (2023), who assessed the sustainability of community-based wastewater treatment systems using a Sustainability System Index (SSI) framework and also identified several systems that were categorized as moderately or sufficiently sustainable. Their study emphasized that sustainability performance in communal wastewater treatment facilities is often constrained by operational consistency, financial capacity, and institutional management, even when the infrastructure itself is already available. The study conducted by Susanthi et al. (2023) in Bogor city, which applied a Multi-Dimensional Scaling (MDS) approach to evaluate the sustainability status of communal wastewater treatment systems. The study reported that several sustainability dimensions were categorized as moderately sustainable, indicating that while the systems were functioning, improvements in management practices, community participation, and operational consistency were still necessary to enhance long-term sustainability.

3.2 Leverage Analysis of Sustainability Attributes

3.2.1 Technical Aspect

The factors with highest leverage are WWTP performance (T6) and system reliability (T1). This indicates that technical sustainability is highly dependent on the operational performance of the WWTP unit and the effectiveness of the wastewater treatment system to produce effluent that meets quality standards. The result listed in the Table 4. This preliminary research was based on a single sampling, which was designed to evaluate point-in-time compliance with PermenLH/BPLH Number 11 / 2025 and to provide a brief capture of the operational performance of the CWWTP at the time of observation due to the unavailability of routine monitoring conducted by te CWWTP managers. Accordingly, the findings reflect instantaneous treatment conditions that are not intended to represent temporal variations in effluent quality nor to substitute for routine monitoring required for long term performance assessment.

In general, wastewater quality test results show that the Pohjentrek Village Communal Wastewater Treatment Plant has reduced the pollutant load for several parameters, especially BOD, COD, and fecal coliform. However, the effluent results for these three parameters still exceed the specified quality standards, indicating that treatment performance has not yet achieved regulatory compliance. A slight increase in the level of suspended solids (TSS) observed in the effluent, is due to the accumulation of activated sludge or the resuspension of material in the reactor, even though the value remained at the quality standard threshold of 30 mg/L. The ABR is known to have limitations in TSS removal efficiency, low efficiency values may occur when TSS concentration blocked the microorganism's activity or may also be caused by the microorganisms' decay Lumunon et al. (2021) so that suspended solids can still be carried to the next system (Nilandita et al., 2019).

The preliminary assessment was conducted in the absence of regular effluent monitoring, thus only provides snapshot treatment performance at the time sampling. The lack of continuous monitoring limits the ability to evaluate long term efficiency. These findings are consistent with recent literature emphasizing that the sustainability of communal wastewater treatment systems depends not only on infrastructure availability but also consistent treatment process performance, in achieving stable long-term reductions for organic pollutant and suspended solids loads (Zhang, 2025; Derco et al., 2024).

Although the effluent quality does not meet regulatory standars, the system shows a reduction in pollutant loads between influent and effluent. This indicate that the treatment units are functioning and contributing to environmental pollution reduction. Therefore, the sufficient classification reflects a condition in which the system partially effective but need some improvement to ensure compliance to regulatory standards. This also emphazised the need for process optimization and improved regular monitoring to achieve both technical sustainability and regulatory compliance. Similar pattern was reported by Nurmiyanto et al. (2023) where the effluent quality showed considerable variation towards the regulatory standard, yet the system classified as sufficient based on MDS results. In this study, the operation of the CWWTP has resulted in a significant decrease in organic load indicators, demonstrating tangible environmental benefits despite incomplete compliance. Within the MDS-based sustainability framework, the "sufficient" category represents combination performance across multiple attributes in technical aspects and interpreted as overall system functionality. This occurs because sustainability classification does not rely solely on effluent compliance but reflects aggregated performance across multiple dimensions. Therefore, even when certain parameters do not fully meet regulatory standards, the system may still provide environmental benefits through pollutant load reduction and maintain functional

Table 3. MDS Analysis Result

Aspect	Stress Value	Square Correlation (RSQ)	MDS (%)	Monte Carlo (%)	Difference (%)
Technical	0.15	0.94	67.38	66.69	0.69
Social	0.14	0.95	82.71	80.37	2.34
Economic	0.14	0.95	74.02	72.01	2.01
Environmental	0.15	0.94	82.40	79.56	2.84
Institutional	0.15	0.95	72.10	70.98	1.12

Source: Analysis Result, 2025

Table 4. Wastewater Characteristics of Pohjentrek WWTP

Parameters	Influent*	Effluent*	Quality Standard**	Compliance	% Removal***
pH	7.72	7.33	6–9	Comply	5.05
BOD (mg/L)	72	43	12	Not Comply	40.28
COD (mg/L)	263	147	80	Not Comply	44.11
TSS (mg/L)	28	30	30	Comply	-7.14
Fecal Coliform (MPN/100 ml)	3200	610	200	Not Comply	80.94

Source: *Laboratorium test result; **PermenLH/BPLH No 11/2025; ***Analysis Result, 2025

operation, which contributes to its overall sustainability status. This perspective supports the interpretation in the present study that the Pohjentrek communal WWTP can be categorized as sufficiently sustainable, as the treatment system continues to reduce pollutant loads and deliver environmental benefits despite not yet achieving full compliance with effluent quality standards.

The attributes of physical condition of facilities and infrastructure (T2) have medium leverage values, indicating that physical aspects play a role in supporting technical sustainability, although they are not as crucial as process performance. Poorly maintained infrastructure can accelerate system degradation and reduce treatment efficiency. Recent literature emphasizes that preventive maintenance of wastewater treatment infrastructure is a more effective and economical approach than repairing after damage occurs (Flores-Alsina et al., 2021). Continuously recorded water quality data can be used as a basis for evaluating performance, adjusting unit operations, and making decisions. Muzioreva and Gumbo (2024) stated that the limited success of communal wastewater treatment plant systems is not only due to technology, but also due to the lack of optimal regular testing and operational quality monitoring. Therefore, strengthening the physical condition and regular monitoring of facilities needs to be part of the technical strategy.

Interestingly, the attribute of regular CWWTP unit maintenance (T7) shows the lowest leverage value. This condition indicates that maintenance activities have not yet become a major differentiating factor in technical sustainability, possibly due to suboptimal or non-standardized maintenance practices. However, various recent studies confirm that routine monitoring and scheduled maintenance is the main foundation for maintaining the stability of IPAL performance and extending the technical life of the system (Corominas et al., 2020; Ventura et al., 2024). Therefore, the low influence of this attribute indicates the need to strengthen the maintenance system so that its role in technical sustainability becomes more significant. Leveraging analysis for technical aspect as seen in Figure 4.

3.2.2 Social Sustainability

The results of leverage analysis in the social dimension show that several community attributes play an important role in determining the sustainability of communal wastewater treatment plant management. Understanding the function of communal wastewater treatment plants (S3) has the highest leverage value, which means that the community's perception and understanding of the objectives and benefits of communal wastewater treatment plants are the main triggers for further participation and social sustainability of the system. Based on the results of identifying the background of the community in Pohjentrek Village, data shows that the community is dominated by high school education levels with a percentage of 39%. The level of education influences the community's perception of participating in the management of communal wastewater treatment plants (Pratiwi et al., 2023). Community involvement and education are equally important in promoting sustainable practices and reducing pollution at its source (Astuti et al., 2024). This finding is confirmed with recent studies that community awareness and knowledge about the benefits of sanitation systems can significantly increase their involvement in the maintenance process and active contribution to the system (Sunaryo and Soewondo, 2024). Furthermore, trust in the management group (S5) and public awareness (S4) show

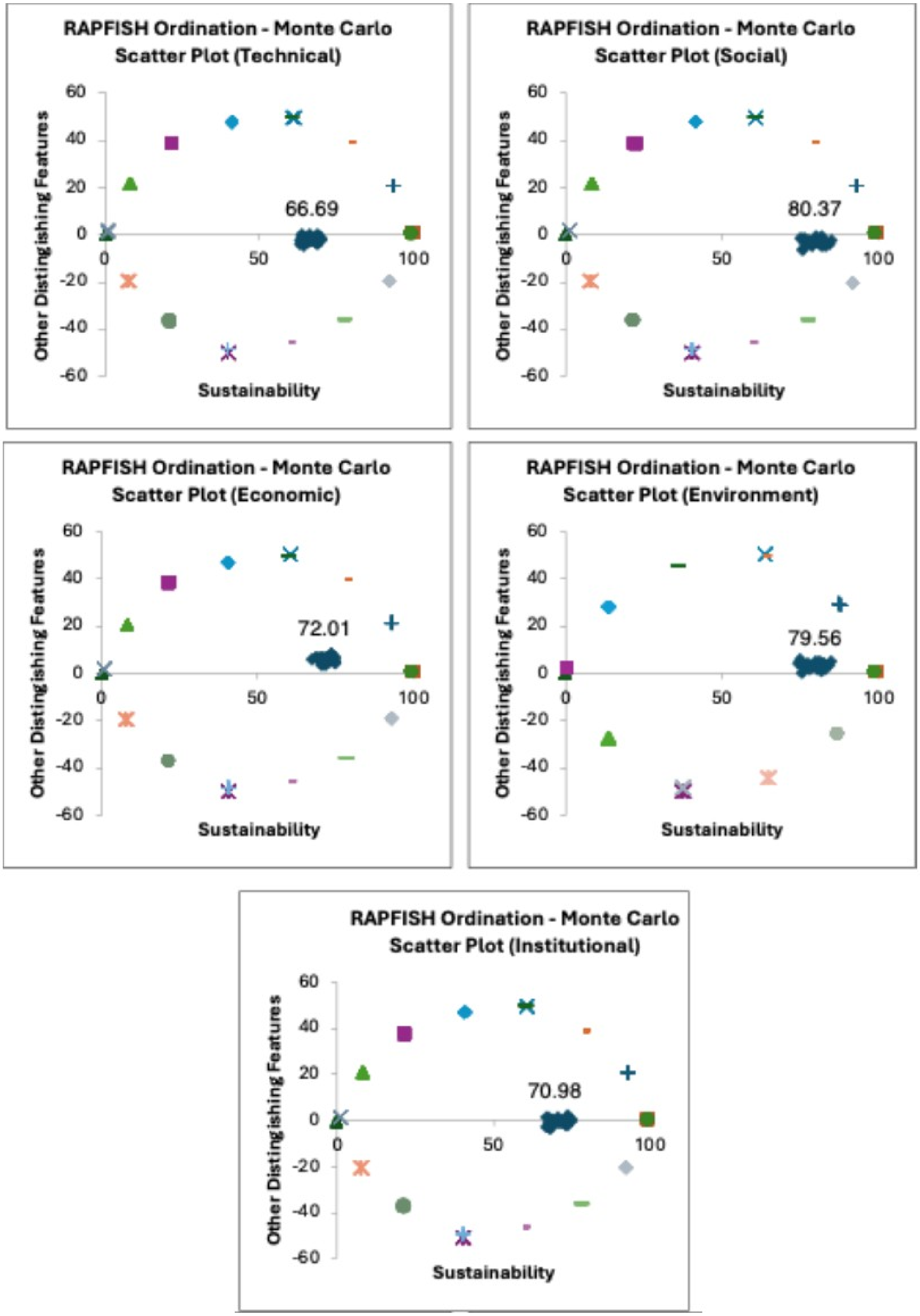

Figure 3. Monte Carlo Results on Pohjentrek CWWTPs

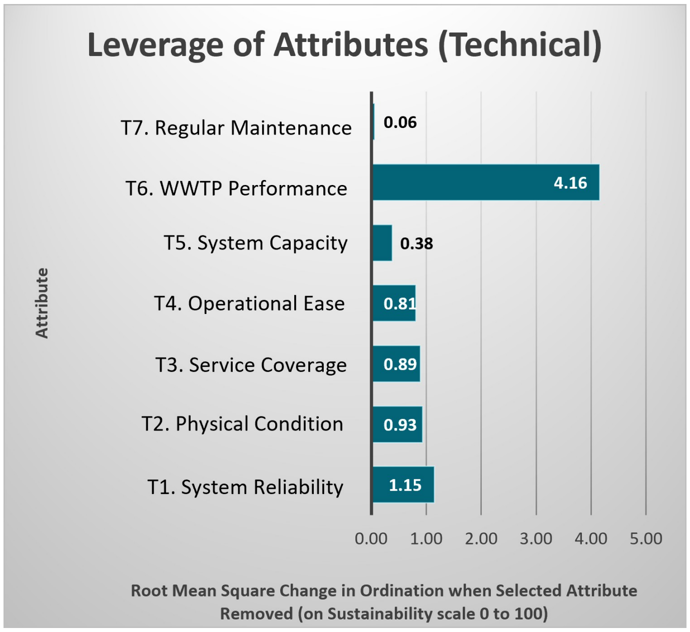

Figure 4. Leveraging Scatter Plot of Technical Aspects

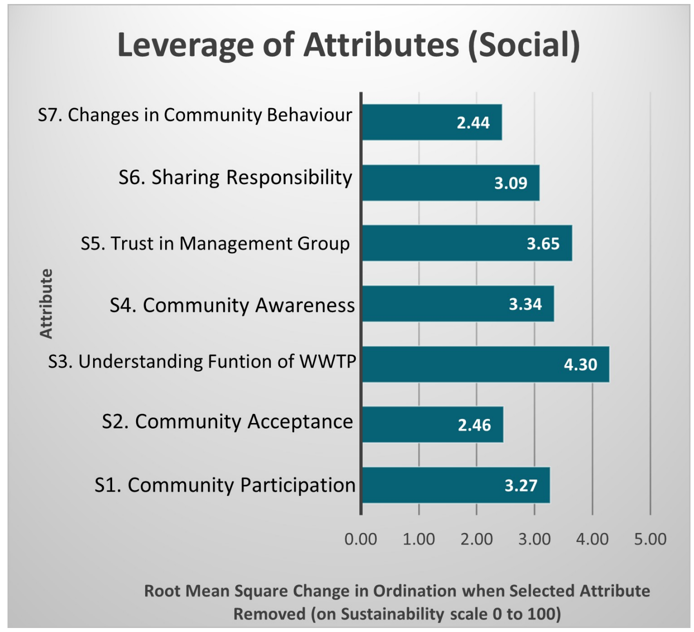

Figure 5. Leveraging Scatter Plot of Social Aspects

a fairly high leverage value, reflecting the importance of strong social relationships between residents and CWWTP managers. Trust is the foundation for the community to support collective decisions, such as joint problem solving and the sustainability of economic and non-economic contributions to the system (Prayitno et al., 2024). Strong trust enables management groups to act credibly and encourages the community to believe that their contributions will be used fairly.

Community acceptance (S2) shows a small leverage value, which does not necessarily indicate weakness but rather suggests that the communal wastewater treatment plant has been widely accepted by the community and is no longer a major factor influencing sustainability variation. When sanitation programs are socially accepted, variability in community perception tends to decline (Heshemi, 2020). However, this does not mean the attribute can be neglected. Sustained social acceptance still requires continuous communication, transparent management, and active community involvement in the operational oversight of the CWWTP (Adnyana et al., 2020; Monzon-Rayes et al., 2025). Leveraging analysis for social aspect as seen in Figure 5.

3.2.3 Economic Sustainability

The leverage analysis results show that other funding attributes (F6) have the highest leverage value in economic aspects, which means that this attribute is the most dominant factor influencing the economic sustainability index of communal wastewater treatment plants. However, currently, communal IPAL funding is still highly dependent on regular residents' contributions, while other funding sources such as government subsidies, sanitation program assistance, or partnership institution support are not yet optimally available or have not been successfully accessed by managers, making the system's financial condition vulnerable.

Based on survey data and the economic profiles of respondents, the current contribution amount is only around IDR 5,000 / USD 0.03 per month per household, reflecting the economic reality of the local community, most of whom have incomes below the Regional Minimum Wage. This condition is parallel to the findings of sanitation economics studies which show that the ability to pay sanitation fees is very limited in low-income communities (Widomski and Musz-Pomorska, 2025), so that a financing base that relies solely on community contributions is often insufficient to cover operational costs and improvement cost (Wu et al., 2022). Thus, the low capacity of community contributions, driven by low-income levels reinforces the reason why other funding attributes are the most influential in the economic dimension.

The regularity of fee payments (F5) and the appropriateness of fees (F3) also play an important role in CWWTP sustainability, indicating that community compliance and perceptions of fee amounts are critical to the stability of operational financing. The sanitation economics literature emphasizes that a financing system designed in accordance with local economic conditions will increase the community's ability and willingness to pay, as well as maintain a consistency of contributions (Widomski and Musz-Pomorska, 2025). For example, research in the Indonesian context found that most communities are willing to pay monthly contributions if these contributions are still considered affordable and in line with their economic capacity, even though their ability to pay decreases when contributions are incidental or unexpected (Brontowiyono et al., 2022).

Low leverage values on affordability indicate that the community generally does not view contributions as an economic burden that limits their involvement in CWWTP management. This is consistent with findings in recent studies stating that users' perceived affordability will decrease as a sustainability issue if contribution costs exceed households' economic capacity (Brouwer et al., 2023). Effective financing models require a combination of reasonable user fees and external funding, especially in low-income communities (Elliot et al., 2023). Leveraging analysis for economic aspect as seen in Figure 6.

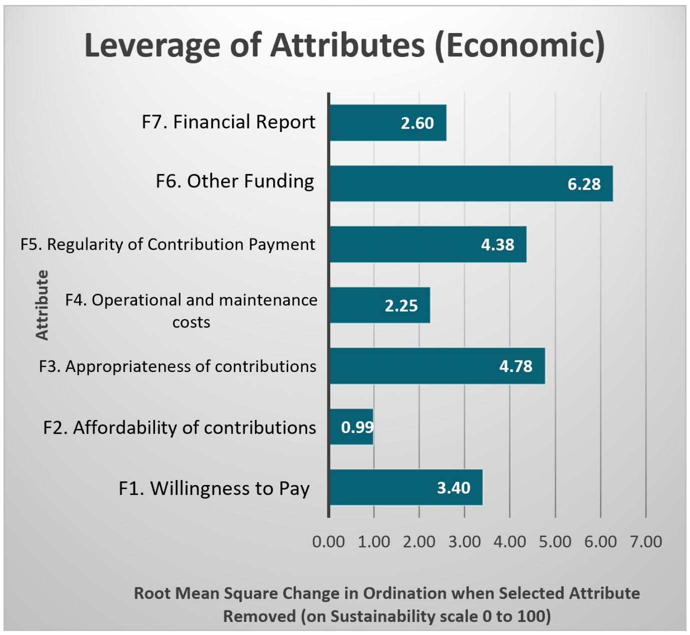

Figure 6. Leveraging Scatter Plot of Economic Aspects

3.2.4 Environmental Aspect

The results leverage analysis on the environmental dimension show that the quality of treated wastewater effluent (E3) is the most sensitive attribute and has the greatest impact on the environmental sustainability of communal wastewater treatment plants. The high leverage value for this attribute indicates that the ability of wastewater treatment plants to reduce pollutant loads and produce effluent that meets environmental quality standards is a key factor in minimizing negative impacts on receiving water bodies. This finding is in line with literature which confirms that effluent quality is a key indicator of the effectiveness of wastewater treatment systems, as it directly determines the level of water pollution and the ecological risks posed (Mubarok et al., 2023). In this research, WWTP effluent has not met the quality standard of Indonesian regulation (PermenLH/BPLH No 11 / 2025). Therefore, improving the consistency of effluent quality needs to be a top priority through process optimization, influent load control, and regular wastewater quality monitoring.

Water pollution and their impacts (E4) as well as diseases caused by domestic wastewater pollution (E2) also show high leverage values. This confirms the close relationship between the performance of communal wastewater treatment plants and environmental and community health conditions. Previous study shows that wastewater pollution can increase the risk of environment-based diseases, such as diarrhea, cholera, skin diseases, or cancer especially in densely populated areas with limited sanitation (Lin et al., 2022). Thus, the management of communal wastewater treatment plants should not only focus on technical aspects but also be positioned as an instrument for the integrated protection of public health and the environment.

The relatively low leverage value for the attribute of preventing contamination of raw water sources (E5) can be interpreted as an indication that the community has already felt some of the benefits of protecting the raw water sources they use. In densely populated residential areas such as RT 01 and RT 02, reducing the flow of wastewater directly into the soil or surface water can reduce the potential for contamination of wells by domestic wastewater pollutants, so that the prevention of raw water source pollution occurs indirectly through the function of IPAL. This discussion is also supported by studies showing that the relationship between wastewater treatment plants and groundwater quality is greatly influenced by the quality of CWWTP treatment. In a study in Yogyakarta, the existence of communal IPALs that meet certain standards shows that effluent discharged in accordance with safety parameters can minimize direct threats to groundwater quality in the surrounding area (Brontowiyono et al., 2022). Leveraging analysis for environmental aspect as seen in Figure 7.

3.2.5 Institutional Aspect

The institutional aspect index score was 72.10, which is classified as moderately sustainable. The leverage analysis found that the sustainability of communal wastewater treatment plant management is highly dependent on institutional aspects and the active participation of managers and the community (I6). Field condition reveals that the level of activity among managers may vary. Some managers are very proactive in carrying out their duties, while others are not yet performing to their full potential. Previous studies have shown that the active involvement of the community and managers in all stages of decentralized wastewater treatment system management is one of the determining factors for the success and continuity of operations, while also increasing a sense of ownership of the system that has been built (Monzon-Rayes et al., 2025).

In addition, clarity of the tasks and responsibilities of the management group is an important aspect because institutional structures without a clear division of roles tend to risk a decline in management effectiveness. Institutional arrangements have a significant influence on the governance of communal wastewater treatment plants and

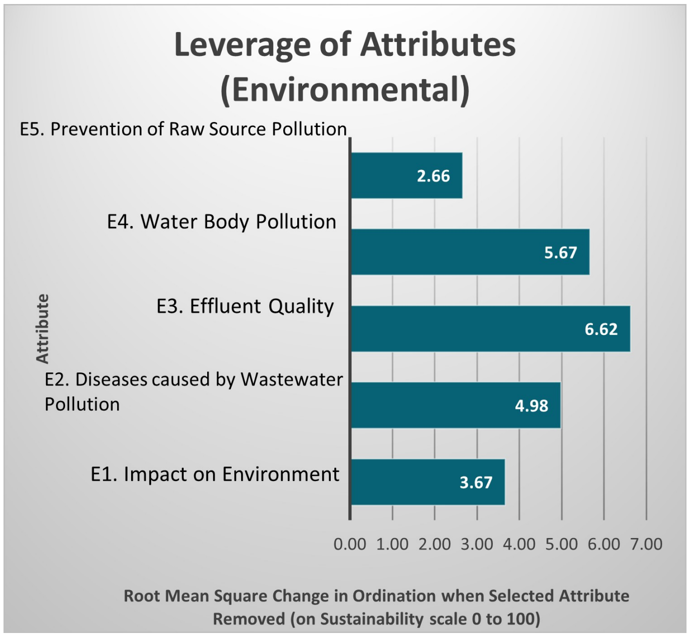

Figure 7. Leveraging Scatter Plot of Environmental Aspects

are an important indicator in determining the sustainability of community-based sanitation systems, so they need to be explicitly formulated in SOPs and work guidelines (Sumanto et al., 2025).

This also explains why strengthening the duties and responsibilities of the management group (I2) is the next attribute after K6 in the sensitivity order. The results of the study show that there are no technical operators yet and when technical problems arise with the communal wastewater treatment plant, the head of management steps in to handle them, which shows that the division of tasks within the management organization has not been well internalized. Training is limited to the initial operational phase, and the lack of post-construction training weakens the technical capacity of managers to deal with operational issues that arise, so that the role of individuals such as the management chairperson becomes very dominant in resolving technical problems that occur. Study in Kazakhstan shows that a resilient organization is one that has a clear division of roles and integrated coordination mechanism, active public involvement, and a sustainable training program to improve the capacity of managers and operators, that will strengthen the foundation of institutional sustainability in the long run (Kudaibergenova et al., 2026).

The optimization of government support (I7) shows the lowest leverage value in institutional sustainability, although in practice this external support is still limited and has not been routinely felt by beneficiaries at the operational stage. The data shows that assistance from government such as sludge suction service remains limited. Study in Jakarta shows that integrated support such as government and local community forms a good partnership that could improve sanitation service (Cecilia et al., 2023). Other studies have also found that sanitation programs that include institutional assistance from the start of construction to the operational phase tend to be more successful in maintaining organizational performance in the long term (Brontowiyono et al., 2022). Thus, although the value of leverage for government support appears to be low in the sustainability model, the facts on the ground illustrate that minimal support will weaken the organizational structure of managers, because managers must carry out communal WWTP management without adequate external facilitation. Leveraging analysis for institutional aspect as seen in Figure 8.

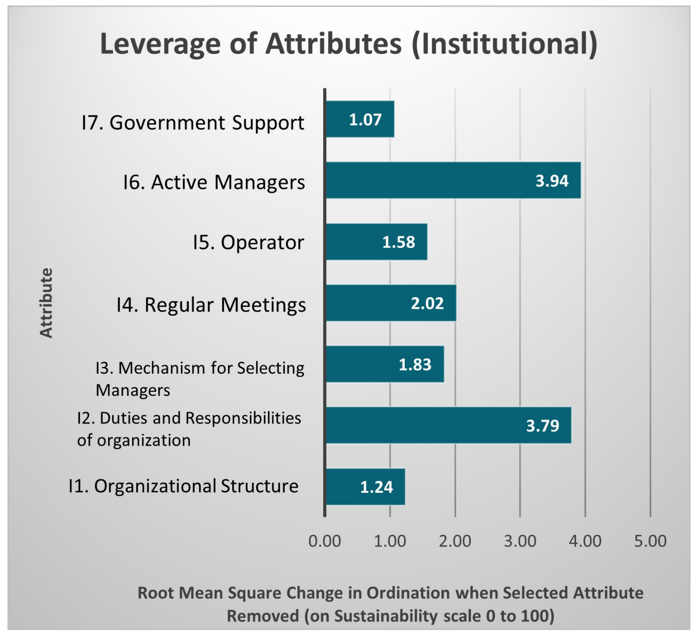

Figure 8. Leveraging Scatter Plot of Institutional Aspects

Based on the sustainability assessment, the future management of the Pohjentrek communal WWTP should prioritize to strengthen the technical, economic, and institutional aspects while maintaining the already strong social and environmental performance. Management direction should focus on transitioning the system from community-dependent management toward a hybrid governance model that combines community participation with structured government facilitation. This includes institutionalizing routine technical and managerial training, integrating the communal WWTP into local sanitation planning and budgeting frameworks. Financial policies should also promote diversified funding mechanisms to ensure long-term operation and maintenance. By aligning local government support with community-based management, the Pohjentrek communal WWTP can be elevated from a sufficiently sustainable system to a resilient and adaptive sanitation service that supports long-term public health and environmental protection.

4. CONCLUSIONS

This study shows that the sustainability of the Pohjentrek communal wastewater treatment plant is influenced by the interaction of technical, social, economic, environmental, and institutional dimensions. The assessment results indicate that the social and environmental aspects achieved the highest sustainability performance, with index values of 82.71 and 82.40, respectively, placing them in the very sustainable category. This reflects strong community acceptance and the perceived environmental benefits of the system, particularly in reducing potential groundwater pollution in densely populated areas. In contrast, the technical, economic, and institutional aspects were classified as sufficiently sustainable, with index values of 67.38, 74.02, and 72.10, respectively. Although these dimensions remain functional, their sustainability is relatively vulnerable due to limited financial resources, reliance on local managerial commitment, and the absence of systematic technical monitoring and institutional support. Overall, the findings suggest that while the communal WWTP provides significant social and environmental benefits, strengthening the technical, economic, and institutional dimensions through improved organizational capacity, diversified funding mechanisms, and continuous technical support is essential to ensure the long-term sustainability of sanitation services in Pohjentrek Village.

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