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# PRIORITIZING BARRIERS TO SUSTAINABLE 3R WASTE PROCESSING FACILITY OPERATIONS USING INTERPRETIVE STRUCTURAL MODELING AND MICMAC

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**ABSTRACT**

The implementation of the 3R Waste Processing Facility (TPS 3R) as a model for community-based waste management in Buleleng Regency has yet to achieve optimal effectiveness. This study aims to: (i) identify the principal factors impeding the sustainability of TPS3R implementation; (ii) rank these barriers according to their influence; and (iii) analyze the interrelationships among the barriers to ascertain the most dominant factors affecting TPS 3R success. The research employs the Interpretative Structural Modelling (ISM) and Matrice d'Impacts Croisés Multiplication Appliqués à un Classement (MICMAC) methods to construct a hierarchical structure and classify the influence of various obstacles. The analysis focuses on 21 barrier factors derived from six evaluation aspects outlined by the Indonesian Ministry of Public Works and Housing (PUPR). The ISM and MICMAC results reveal that the primary constraints affecting TPS3R implementation include limited household waste sorting practices, inadequate quality and quantity of human resources, a high volume of residual waste sent to landfills, restricted types of waste treatment technologies employed, and insufficient waste volume to support TPS3R operations. These findings align with previous studies in the Indonesian context. Consequently, future TPS3R strategies and policy development should prioritize addressing these dominant barriers to enhance the sustainability and effectiveness of waste management systems.
***Keywords*:** waste management, TPS 3R, barriers, ISM, MICMAC

## Introduction

In recent decades, the management of municipal solid waste has received increased attention due to escalating waste volumes and heightened environmental concerns. A widely adopted strategy is the establishment of community-based waste processing systems, notably the Reduce-Reuse-Recycle Waste Processing Facility (TPS 3R) in Indonesia. Public participation is deemed essential for effective waste management, encompassing planning, implementation, and policy decision-making (Kalra, 2020; Renn *et al.*, 1995). In the Indonesian context, community engagement is also mandated by national legislation, including Law No. 18 of 2008 on Waste Management and Ministry of Public Works Regulation No. 03/2013 on Waste Infrastructure.

Despite these policy mandates, meaningful community involvement in waste governance remains limited. Accurate data on public attitudes and preferences are challenging to obtain, often due to disinterest in lengthy surveys or a lack of technical capacity to assess complex waste management systems (Anuardo *et al.*, 2022). Moreover, the interdependency of various system components further complicates policy decision-making, necessitating the use of structured analytical tools.

To address these complexities, this study employs the ISM method, a structured and collaborative multi-criteria decision-making approach. ISM enables experts to visually map out and prioritize the interrelationships among system elements, facilitating clearer strategic planning (Darmawan, 2017; Mekonnen *et al.*, 2022). The method has been widely applied to waste management research, particularly for identifying bottlenecks, setting intervention priorities, and enhancing policy design (Attri *et al.*, 2013; Razavisousan & Joshi, 2022).

Prior studies have demonstrated ISM's utility in diverse contexts. Kholil *et al.* (2008) identified community participation and institutional clarity as key enablers of urban waste system success. Rifaldi *et al.* (2021) developed strategic waste governance frameworks based on stakeholder dynamics and regulatory gaps. Similarly, Rimantho *et al.* (2023) employed ISM to explore barriers to implementing a circular economy in rural areas, while Wang *et al.* (2023) combined ISM with DEMATEL to model municipal waste management barriers in Beijing.

In the Indonesian context, research by Manalu *et al.* (2022) and Sunardi & Akliyah (2023) identified policy absence, weak institutional capacity, and low public awareness as persistent obstacles in TPS 3R implementation. These findings underscore the importance of a system-thinking approach to designing localized waste solutions.

While existing studies have utilized ISM to investigate waste management barriers at municipal or national levels, a gap persists in applying this methodology specifically to the TPS3R model within semi-rural and peri-urban contexts, such as Buleleng Regency. Furthermore, this study distinctively integrates ISM with MICMAC analysis to categorize driver-dependence relationships among 21 indicators derived from national TPS 3R evaluation guidelines. This dual-method approach provides a more nuanced and hierarchical comprehension of primary and secondary barriers, a topic seldom comprehensively addressed in previous literature. Consequently, the study contributes a systematic model for obstacle prioritization, offering practical value to policymakers and planners responsible for enhancing community-based waste management in developing regions. This research endeavors to address these methodological and contextual gaps by systematically identifying and analyzing the most critical factors influencing the sustainability of TPS 3R operations in Buleleng, Bali. In doing so, it offers a robust framework for improving the effectiveness of decentralized waste management systems in Indonesia and similar global contexts.

## Materials and Methods

### Materials

This study utilized a qualitative survey methodology to investigate the primary obstacles impeding the sustainability of TPS 3R operations in Buleleng Regency, Bali Province. The research was conducted from June to October 2024. The barriers analyzed were identified through a review of pertinent literature, government documents, and expert experiences in the domain of solid waste management. These identified barriers were examined using ISM and MICMAC methods.

Both primary and secondary data were employed in this study. Secondary data were gathered through a comprehensive literature review and reports from pertinent government agencies in Buleleng Regency. Primary data were collected via questionnaires and structured interviews with stakeholders, including local government officials, TPS 3R managers, and academics. Expert consultations were conducted to validate the relevance of the identified barriers and to ascertain potential interactions among them within the context of TPS 3R implementation. Three experts representing academia, government institutions, and field operators participated in the ISM process. In ISM, a limited number of experts (6 experts) is deemed acceptable, as the focus is on the quality of knowledge rather than quantity (Duleba, 2019).

A comprehensive list of barrier factors (Table 1) was formulated through a literature review and the TPS 3R Technical Guidelines (PUPR, 2017). Subsequently, a pairwise comparison questionnaire was developed, and stakeholders were solicited to evaluate potential interrelationships among these factors.

**Table 1 :** Description of Barrier Factors in TPS3R Implementation

| No. | Barrier Factor | Description |
|---|---|---|
| A1 | Regional regulations on TPS3R | Absence of local regulations on waste management |
| A2 | TPS3R development planning | No TPS 3R development program integrated into spatial planning (RTRW) |
| A3 | Volume of waste managed | Limited waste handled (<60% of planned service capacity) |
| A4 | Condition of infrastructure | Supporting infrastructure is inadequate or non-functional |
| A5 | Types of waste processing methods | Limited processing alternatives (only sorting available) |
| A6 | Equipment condition | Inadequate and malfunctioning equipment |
| A7 | Compost production | Low quality and quantity compost produced (<70% of organic waste) |
| A8 | Residue volume transported to landfill | High percentage of residue still sent to landfill (>40%) |
| A9 | Management institution | Waste management is not yet community-based (still run by government/individuals) |

| | | |
|---|---|---|
| A10 | Organizational structure | Organizational structure exists but is not functional |
| A11 | Human resources | Lack of qualified operators and workforce |
| A12 | Legal status of institution | Absence of notarial deed, village decree, or institutional bylaws |
| A13 | Administrative recordkeeping | Operational documentation is not maintained |
| A14 | Institutional support from local government | No facilitation from local government |
| A15 | Financial condition | Monthly financial deficit |
| A16 | Financial management | Inadequate financial recording |
| A17 | Financial assistance from government | No operational funding support from government |
| A18 | Household waste sorting | No source separation at the household level |
| A19 | Community service fee contributions | Less than 60% of residents pay waste service fees on time |
| A20 | Economic impact | No added economic value generated from TPS3R activities |
| A21 | Customer development | Customer growth is less than 50% |

## Methods

The ISM methodology was applied to develop a hierarchical structural model of the identified barrier factors. The steps involved in this modelling process are outlined below:

### Identification of Key Factors

The key factors influencing TPS 3R performance were derived from the PUPR (2017), as presented in Table 1.

### Structural Self-Interaction Matrix (SSIM)

A contextual relationship was established between each pair of factors using expert input. The relationships were coded using four symbols:

- V: Factor i influences factor j
- A: Factor j influences factor i
- X: Factors i and j influence each other
- O: No relationship between factors

### Reachability Matrix

The SSIM was converted into a binary reachability matrix by applying transformation rules:

- V becomes (1, 0),
- A becomes (0, 1),
- X becomes (1, 1),
- O becomes (0, 0).

Transitivity checks were then applied to derive the final reachability matrix, ensuring that if factor i leads to j and j leads to k, then i also lead to k.

### Level Partitioning

For each factor, the reachability set (including all factors it influences) and antecedent set (factors that influence it) were determined. The intersection of these sets was used to assign hierarchical levels iteratively, forming a multilevel structural model.

### ISM Diagraph

A hierarchical model (diagraph) was developed based on the final reachability matrix and assigned levels. Transitive links were eliminated to finalize the ISM model. Any inconsistencies in logical flow were reviewed and corrected with expert input.

### Data Analysis Procedure (MICMAC Analysis)

The MICMAC analysis was used to classify the factors based on two dimensions: driving power and dependence. Each factor was analyzed to determine the number of other factors it influences (driving power) and is influenced by (dependence). Factors were then grouped into four clusters:

- Cluster I – Autonomous: Weak driving and weak dependence
- Cluster II – Dependent: Weak driving, strong dependence
- Cluster III – Linkage: Strong driving, strong dependence (highly unstable)
- Cluster IV – Independent: Strong driving, weak dependence (critical factors)

The analysis was performed using the ISM Professional Software Version 2.0, which facilitated automatic calculation, matrix transformation, and graphical visualization of factor positioning and hierarchy.

### Model Validation

Model validity was ensured through the following mechanisms:

- Expert Triangulation: The ISM structure was reviewed and confirmed by three domain experts from different stakeholder groups (academia, government, and operators).
- Face Validity: Experts verified whether the hierarchical placement of factors accurately

reflected real-world conditions in TPS 3R operations.

- Sensitivity Testing: Selected entries in the reachability matrix were modified to observe changes in the hierarchy. The model showed minimal structural shifts, indicating high robustness.

These validation steps are consistent with standard practices in ISM research (Mekonnen *et al.*, 2022; Raj *et al.*, 2008) and provide confidence in the interpretability and reliability of the final model.

**Ethical Considerations**

This research adheres to standard ethical guidelines for social science research:

- Prior to participation, all respondents were provided with a clear explanation of the study's objectives and procedures.
- Informed consent was obtained from all participants.
- No personal identifiers were collected, and participant confidentiality was strictly maintained.

## Results and Discussion

### Results

This section offers a comprehensive analysis of the interconnected barriers impacting the operational sustainability of TPS 3R facilities in Buleleng Regency. Utilizing a systems-based modeling approach, 21 interdependent factors encompassing regulatory, institutional, technical, and behavioral dimensions were examined to elucidate their structural roles and mutual influences within the TPS 3R implementation framework. The primary aim of this section is to convert expert input into a structured comprehension of which barriers exert the most significant systemic impact and how they propagate through the waste management ecosystem. The application of ISM and MICMAC tools aids in the classification, ranking, and interpretation of these constraints, thereby informing both strategic planning and policy development.

The analysis began with the development of the Structural Self-Interaction Matrix (SSIM) (Table 2), in which each pair of factors was compared based on expert knowledge using four possible relationships: V (leads to), A (is led by), X (mutual influence), and O (no influence). For instance, the factor "Regional Regulation on TPS 3R (A1)" was assessed to have greater influence than "TPS 3R Development Plan (A2)," and thus marked with a V. This approach facilitated the transformation of qualitative judgments into structured data, which was then used to construct the Initial Reachability Matrix (IRM) (Table 3).

**Table 2 :** Structural Self-Interaction Matrix for TPS 3R governance factors.

| Factors | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 | 13 | 14 | 15 | 16 | 17 | 18 | 19 | 20 | 21 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1 | | O | X | X | A | A | A | A | O | A | A | X | O | O | O | O | X | A | O | A | O |
| 2 | | | A | X | A | A | A | A | 0 | A | A | X | O | X | O | O | O | A | O | A | X |
| 3 | | | | X | X | V | X | X | V | V | X | V | V | V | V | V | V | X | V | X | V |
| 4 | | | | | A | X | A | A | X | X | A | X | O | O | O | O | O | A | O | A | X |
| 5 | | | | | | X | V | X | V | V | X | V | V | V | V | V | V | X | V | X | V |
| 6 | | | | | | | A | X | O | O | X | O | O | V | O | X | O | A | O | A | O |
| 7 | | | | | | | | X | V | V | X | V | V | V | V | V | V | A | V | X | V |
| 8 | | | | | | | | | V | V | X | V | V | V | V | V | V | X | V | X | V |
| 9 | | | | | | | | | | X | A | X | X | X | O | O | O | A | O | A | A |
| 10 | | | | | | | | | | | A | X | X | X | O | O | O | A | A | A | O |
| 11 | | | | | | | | | | | | V | V | V | V | V | V | X | V | X | V |
| 12 | | | | | | | | | | | | | O | O | O | O | O | A | O | A | O |
| 13 | | | | | | | | | | | | | | X | X | X | X | X | X | X | X |
| 14 | | | | | | | | | | | | | | | O | O | X | A | A | X | O |
| 15 | | | | | | | | | | | | | | | | X | X | X | X | X | X |
| 16 | | | | | | | | | | | | | | | | | X | X | X | X | X |
| 17 | | | | | | | | | | | | | | | | | | X | O | A | O |
| 18 | | | | | | | | | | | | | | | | | | | V | V | V |
| 19 | | | | | | | | | | | | | | | | | | | | A | X |
| 20 | | | | | | | | | | | | | | | | | | | | | A |
| 21 | | | | | | | | | | | | | | | | | | | | | |

**Table 3 :** Initial Reachability Matrix

| **Faktors** | **1** | **2** | **3** | **4** | **5** | **6** | **7** | **8** | **9** | **10** | **11** | **12** | **13** | **14** | **15** | **16** | **17** | **18** | **19** | **20** | **21** |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1 | **1** | **0** | **1** | **1** | **0** | **0** | **0** | **0** | **0** | **0** | **0** | **1** | **0** | **0** | **0** | **0** | **1** | **0** | **0** | **0** | **0** |
| 2 | **0** | **1** | **0** | **1** | **0** | **0** | **0** | **0** | **0** | **0** | **0** | **1** | **0** | **1** | **0** | **0** | **0** | **0** | **0** | **0** | **1** |
| 3 | **1** | **1** | **1** | **1** | **1** | **1** | **1** | **1** | **1** | **1** | **1** | **1** | **1** | **1** | **1** | **1** | **1** | **1** | **1** | **1** | **1** |
| 4 | **1** | **1** | **1** | **1** | **0** | **1** | **0** | **0** | **1** | **1** | **0** | **1** | **0** | **0** | **0** | **0** | **0** | **0** | **0** | **0** | **1** |
| 5 | **1** | **1** | **1** | **1** | **1** | **1** | **1** | **1** | **1** | **1** | **1** | **1** | **1** | **1** | **1** | **1** | **1** | **1** | **1** | **1** | **1** |
| 6 | **1** | **1** | **0** | **1** | **1** | **1** | **0** | **1** | **0** | **0** | **1** | **0** | **0** | **1** | **0** | **1** | **0** | **0** | **0** | **0** | **0** |
| 7 | **1** | **1** | **1** | **1** | **0** | **1** | **1** | **1** | **1** | **1** | **1** | **1** | **1** | **1** | **1** | **1** | **1** | **0** | **1** | **1** | **1** |
| 8 | **1** | **1** | **1** | **1** | **1** | **1** | **1** | **1** | **1** | **1** | **1** | **1** | **1** | **1** | **1** | **1** | **1** | **1** | **1** | **1** | **1** |
| 9 | **0** | **0** | **0** | **1** | **0** | **0** | **0** | **0** | **1** | **1** | **0** | **1** | **1** | **1** | **0** | **0** | **0** | **0** | **0** | **0** | **0** |
| 10 | **1** | **1** | **0** | **1** | **0** | **0** | **0** | **0** | **1** | **1** | **0** | **1** | **1** | **1** | **0** | **0** | **0** | **0** | **0** | **0** | **0** |
| 11 | **1** | **1** | **1** | **1** | **1** | **1** | **1** | **1** | **1** | **1** | **1** | **1** | **1** | **1** | **1** | **1** | **1** | **1** | **1** | **1** | **1** |
| 12 | **1** | **1** | **0** | **1** | **0** | **0** | **0** | **0** | **1** | **1** | **0** | **1** | **0** | **0** | **0** | **0** | **0** | **0** | **0** | **0** | **0** |
| 13 | **0** | **0** | **0** | **0** | **0** | **0** | **0** | **0** | **1** | **1** | **0** | **0** | **1** | **1** | **1** | **1** | **1** | **1** | **1** | **1** | **1** |
| 14 | **0** | **1** | **0** | **0** | **0** | **0** | **0** | **0** | **1** | **1** | **0** | **0** | **1** | **1** | **0** | **0** | **1** | **0** | **0** | **1** | **0** |
| 15 | **0** | **0** | **0** | **0** | **0** | **0** | **0** | **0** | **0** | **0** | **0** | **0** | **1** | **0** | **1** | **1** | **1** | **1** | **1** | **1** | **1** |
| 16 | **0** | **0** | **0** | **0** | **0** | **1** | **0** | **0** | **0** | **0** | **0** | **0** | **1** | **0** | **1** | **1** | **1** | **1** | **1** | **1** | **1** |
| 17 | **1** | **0** | **0** | **0** | **0** | **0** | **0** | **0** | **0** | **0** | **0** | **0** | **1** | **1** | **1** | **1** | **1** | **1** | **0** | **0** | **0** |
| 18 | **1** | **1** | **1** | **1** | **1** | **1** | **1** | **1** | **1** | **1** | **1** | **1** | **1** | **1** | **1** | **1** | **1** | **1** | **1** | **1** | **1** |
| 19 | **0** | **0** | **0** | **0** | **0** | **0** | **0** | **0** | **0** | **1** | **0** | **0** | **1** | **1** | **1** | **1** | **0** | **0** | **1** | **0** | **1** |
| 20 | **1** | **1** | **1** | **1** | **1** | **1** | **1** | **1** | **1** | **1** | **1** | **1** | **1** | **1** | **1** | **1** | **1** | **0** | **1** | **1** | **0** |
| 21 | **0** | **1** | **0** | **1** | **0** | **0** | **0** | **0** | **1** | **0** | **0** | **0** | **1** | **0** | **1** | **1** | **0** | **0** | **1** | **1** | **1** |

Following the conversion of the SSIM into the IRM, the Final Reachability Matrix (FRM) was generated by applying transitivity rules if factor A affects B and B affects C, then A is assumed to affect C. This logical transformation is crucial for understanding indirect influences within the system.

The final matrix (Table 4) laid the foundation for calculating two key metrics for each factor: driving power (total number of factors it influences) and dependence (total number of factors by which it is influenced).

**Tabel 4 :** Final Reachability Matrix

| **Factors** | **1** | **2** | **3** | **4** | **5** | **6** | **7** | **8** | **9** | **10** | **11** | **12** | **13** | **14** | **15** | **16** | **17** | **18** | **19** | **20** | **21** |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1 | **1** | **0** | **1** | **1** | **1** | **1** | **1** | **1** | **1** | **1** | **1** | **1** | **1** | **1** | **1** | **1** | **1** | **1** | **1** | **1** | **1** |
| 2 | **0** | **1** | **0** | **1** | **0** | **1** | **0** | **0** | **1** | **1** | **0** | **1** | **0** | **1** | **0** | **0** | **1** | **0** | **0** | **1** | **1** |
| 3 | **1** | **1** | **1** | **1** | **1** | **1** | **1** | **1** | **1** | **1** | **1** | **1** | **1** | **1** | **1** | **1** | **1** | **1** | **1** | **1** | **1** |
| 4 | **1** | **1** | **1** | **1** | **0** | **1** | **0** | **1** | **1** | **1** | **1** | **1** | **1** | **1** | **0** | **1** | **0** | **0** | **0** | **0** | **1** |
| 5 | **1** | **1** | **1** | **1** | **1** | **1** | **1** | **1** | **1** | **1** | **1** | **1** | **1** | **1** | **1** | **1** | **1** | **1** | **1** | **1** | **1** |
| 6 | **1** | **1** | **0** | **1** | **1** | **1** | **0** | **1** | **1** | **1** | **1** | **1** | **1** | **1** | **1** | **1** | **1** | **1** | **1** | **1** | **1** |
| 7 | **1** | **1** | **1** | **1** | **0** | **1** | **1** | **1** | **1** | **1** | **1** | **1** | **1** | **1** | **1** | **1** | **1** | **1** | **1** | **1** | **1** |
| 8 | **1** | **1** | **1** | **1** | **1** | **1** | **1** | **1** | **1** | **1** | **1** | **1** | **1** | **1** | **1** | **1** | **1** | **1** | **1** | **1** | **1** |
| 9 | **0** | **0** | **0** | **1** | **0** | **0** | **0** | **0** | **1** | **1** | **0** | **1** | **1** | **1** | **1** | **1** | **1** | **1** | **1** | **1** | **1** |
| 10 | **1** | **1** | **0** | **1** | **0** | **0** | **0** | **0** | **1** | **1** | **0** | **1** | **1** | **1** | **1** | **1** | **1** | **1** | **1** | **1** | **1** |
| 11 | **1** | **1** | **1** | **1** | **1** | **1** | **1** | **1** | **1** | **1** | **1** | **1** | **1** | **1** | **1** | **1** | **1** | **1** | **1** | **1** | **1** |
| 12 | **1** | **1** | **0** | **1** | **0** | **0** | **0** | **0** | **1** | **1** | **0** | **1** | **0** | **0** | **0** | **0** | **0** | **0** | **0** | **0** | **0** |
| 13 | **0** | **0** | **0** | **0** | **0** | **0** | **0** | **0** | **1** | **1** | **0** | **0** | **1** | **1** | **1** | **1** | **1** | **1** | **1** | **1** | **1** |
| 14 | **0** | **1** | **0** | **0** | **0** | **0** | **0** | **0** | **1** | **1** | **0** | **0** | **1** | **1** | **0** | **0** | **1** | **1** | **0** | **1** | **0** |
| 15 | **0** | **0** | **0** | **0** | **0** | **0** | **0** | **0** | **0** | **0** | **0** | **0** | **1** | **0** | **1** | **1** | **1** | **1** | **1** | **1** | **1** |
| 16 | **0** | **0** | **0** | **0** | **0** | **1** | **0** | **0** | **0** | **0** | **0** | **0** | **1** | **0** | **1** | **1** | **1** | **1** | **1** | **1** | **1** |
| 17 | **1** | **0** | **0** | **0** | **0** | **0** | **0** | **0** | **0** | **0** | **0** | **0** | **1** | **1** | **1** | **1** | **1** | **1** | **1** | **1** | **1** |
| 18 | **1** | **1** | **1** | **1** | **1** | **1** | **1** | **1** | **1** | **1** | **1** | **1** | **1** | **1** | **1** | **1** | **1** | **1** | **1** | **1** | **1** |
| 19 | **0** | **0** | **0** | **0** | **0** | **0** | **0** | **0** | **0** | **1** | **0** | **0** | **1** | **1** | **1** | **1** | **0** | **0** | **1** | **0** | **1** |
| 20 | **1** | **1** | **1** | **1** | **1** | **1** | **1** | **1** | **1** | **1** | **1** | **1** | **1** | **1** | **1** | **1** | **1** | **0** | **1** | **1** | **0** |
| 21 | **0** | **1** | **0** | **1** | **0** | **0** | **0** | **0** | **1** | **0** | **0** | **0** | **1** | **0** | **1** | **1** | **0** | **0** | **1** | **1** | **1** |

Table 5 presents the results of these calculations. Factors such as Waste Segregation by the Community (A18), Human Resources (A11), Residual Volume to Landfill (A8), Type of Management (A5), and Waste Volume Managed (A3) were found to have the highest driving power scores (all scoring 21), positioning them as critical drivers in the TPS 3R implementation system. Conversely, factors like Administrative Management (A13), Economic Impact (A20), Customer Development (A21), and Financial Management (A16) had the highest dependence scores, indicating that they are more affected by other system components than they influence them.

**Tabel 5 :** Driving power and its influence ranking as well as its dependency and dependency hierarchy

| Factors | *Driver Power* | *Rank* | *Dependence* | Hirarchy |
|---|---|---|---|---|
| A1 | 20 | 2 | 13 | 6 |
| A2 | 10 | 8 | 14 | 5 |
| A3 | 21 | 1 | 9 | 9 |
| A4 | 14 | 5 | 15 | 4 |
| A5 | 21 | 1 | 8 | 10 |
| A6 | 19 | 3 | 12 | 7 |
| A7 | 20 | 2 | 8 | 10 |
| A8 | 21 | 1 | 10 | 8 |
| A9 | 13 | 6 | 17 | 3 |
| A10 | 15 | 4 | 17 | 3 |
| A11 | 21 | 1 | 10 | 8 |
| A12 | 6 | 12 | 14 | 5 |
| A13 | 11 | 7 | 19 | 1 |
| A14 | 8 | 10 | 17 | 3 |
| A15 | 8 | 10 | 17 | 3 |
| A16 | 9 | 9 | 18 | 2 |
| A17 | 10 | 8 | 17 | 3 |
| A18 | 21 | 1 | 15 | 4 |
| A19 | 7 | 11 | 17 | 3 |
| A20 | 19 | 3 | 18 | 2 |
| A21 | 9 | 9 | 18 | 2 |

To further categorize the interrelationships, MICMAC analysis was applied. This method plots factors (Figure 1) into four quadrants based on their driving power and dependence:

Quadrant I (Independent) : High driving power, low dependence
Quadrant II (Linkage) : High driving power, high dependence
Quadrant III (Dependent) : Low driving power, high dependence
Quadrant IV (Autonomous) : Low driving power, low dependence

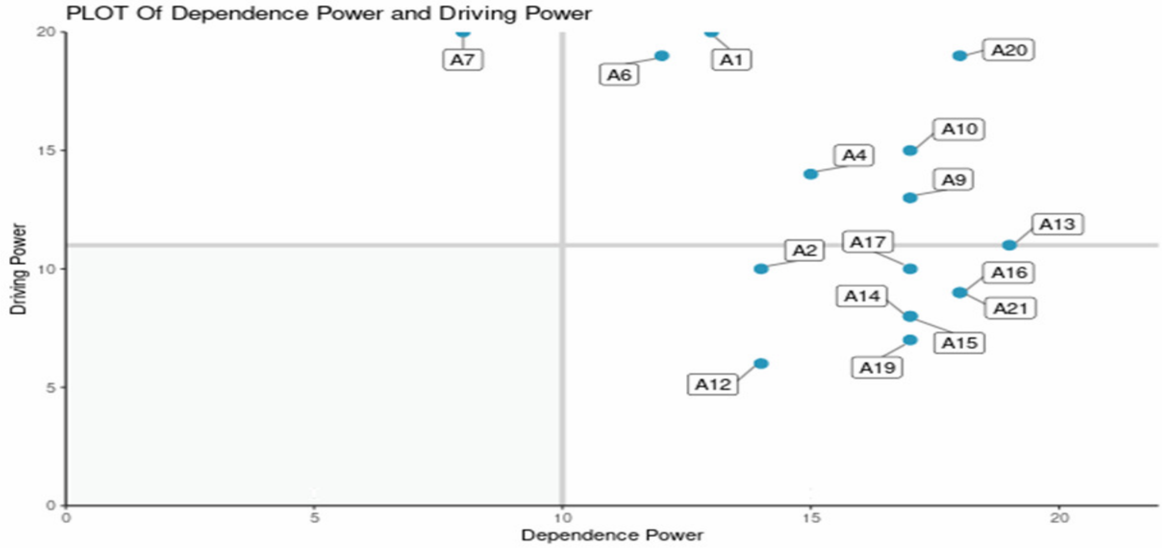


**Fig. 1 :** Plot of Dependence Power and Driving Power

From this classification, A18, A11, A8, A5, and A3 appeared in the independent quadrant (Quadrant I), signifying their role as upstream causes rather than downstream effects. These are the variables that should be prioritized in any intervention, as improving them can lead to ripple effects throughout the system. These findings are consistent with existing research by Kholil *et al.* (2008), who noted that low public participation and inadequate sorting significantly compromise urban waste system performance. Moreover, Sunardi & Akliyah (2023), emphasized that non-segregated waste streams lead to higher operational costs, poor compost quality, and increased landfill burdens.

In contrast, factors like A13, A20, A21, and A16 fell into the Dependent quadrant (Quadrant III), implying that changes in these factors are largely outcomes of other system dynamics. They are useful indicators of systemic health but are less effective as primary intervention points. For example, improving financial records (A16) or generating economic returns (A20) without addressing foundational issues like public engagement and infrastructure would be unsustainable.

Linkage factors (Quadrant II) such as Local Regulation (A1), Equipment Condition (A6), Compost Production (A7), and Organizational Structure (A10) presented both high influence and high susceptibility to change. This dual sensitivity makes them pivotal yet potentially unstable components. According to Poduval *et al.* (2015), such linkage elements require careful coordination and integrated planning, as interventions in these areas may lead to feedback loops either positive or destabilizing across multiple layers of the system.

The hierarchical model constructed from the ISM results (Figure 2) revealed a cascading structure of influence distributed across twelve levels. At the base (Level 12) are core technical and behavioral constraints: Waste Volume Managed (A3), Type of Waste Management (A5), Residual Volume Transported (A8), Human Resources (A11), and Waste Segregation (A18). These are the foundational bottlenecks whose resolution is likely to unlock progress across various other dimensions of the system.

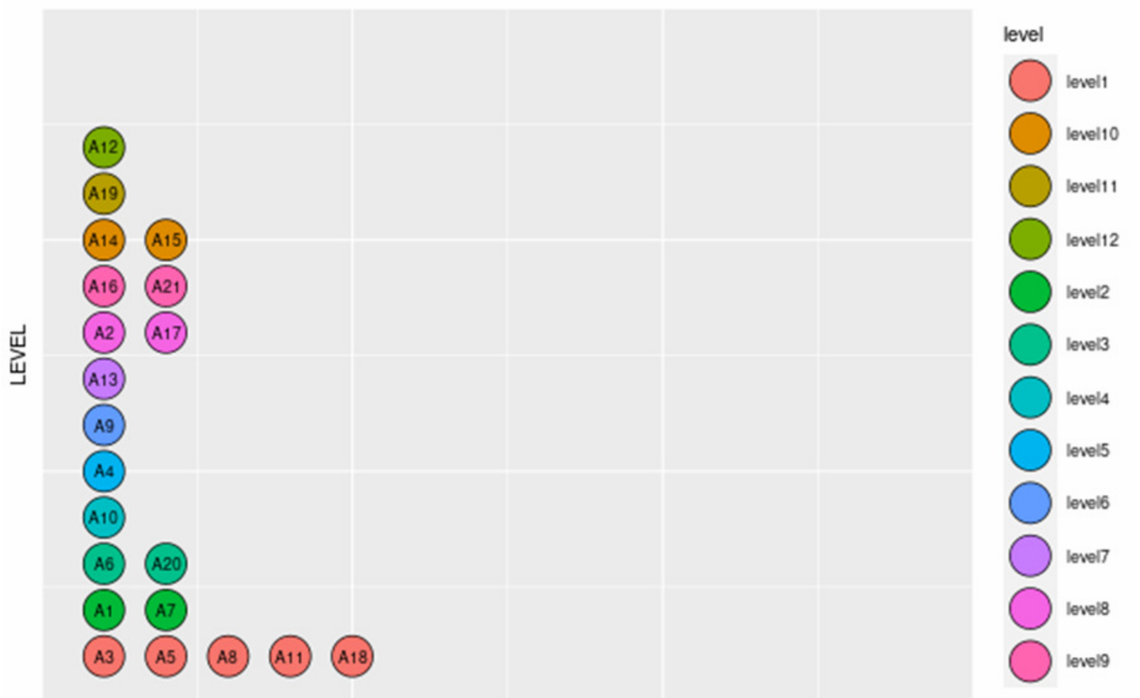


**Fig. 2 :** ISM Structural Model Diagram of Key Indicators of Barriers to TPS 3R Management

Moving up the hierarchy, the model shows a series of interdependencies where improvements in lower-tier constraints trigger enhancements in mid- and upper-level factors. For instance, resolving waste sorting and labor limitations would enhance compost production (A7) and infrastructure utilization (A6), which in turn influence economic viability (A20) and institutional structure (A10). The chain continues up to factors like Legal Status of Management Institutions (A12) and Community Fee Contributions (A19) at the highest levels, which are outputs rather than causes of system functionality.

This hierarchical flow reflects insights from complex systems theory, where leverage points tend to be in deeply embedded structural elements (Meadows, 2008). It also reinforces findings from international literature on decentralized waste management, which consistently highlight the importance of community engagement, human capacity, and technical adequacy in sustainable operations (Parinduri *et al*., 2024; Rada & Cioca, 2017; Wang *et al*., 2023).

## Discussion

The MICMAC quadrant diagram (Figure 1) presents a visual representation of how TPS 3R constraint factors are distributed across four strategic zones. This mapping enables decision-makers to allocate resources and design interventions more effectively.

In this study, the most critical factors influencing the effectiveness of TPS 3R implementation are found in Quadrants I and II of the MICMAC analyses zones characterized by high system sensitivity and influence. Quadrant I (Independent) include high-leverage variables such as A3 (Waste Volume Managed), A5 (Type of Management), A8 (Residual Waste to Landfill), A11 (Human Resources), and A18 (Waste Segregation by Households), all of which act as primary drivers of change across the entire structure. Focusing intervention efforts on these elements can generate cascading improvements that ultimately stabilize dependent factors located in Quadrant III. For instance, A18 Waste Segregation by Households, positioned at the base of the ISM hierarchy and the top of the influence scale, is a foundational component. Without effective source separation, downstream processes like composting (A7), volume handling efficiency (A3), and reduction in landfill dependency (A8) become severely constrained. This finding aligns with research by Rachman *et al*. (2021), which demonstrates that community sorting behavior is a strong predictor of system-wide performance. Similarly, A11 Human Resources plays a pivotal role, as the presence of skilled and adequate staff not only enhances daily operational outcomes but also strengthens the system's resilience. The International Labour Organization *et al*. (2023) emphasizes that workforce development is a crucial pillar of sustainable waste management systems, noting that investments in training and capacity building are essential for the effective functioning of these systems.

Quadrant II (Linkage), meanwhile, houses complex factors like Regulatory Support (A1), Equipment Condition (A6), and Organizational Structure (A10). These components exhibit high sensitivity and interdependence. Adjusting one of them could result in significant shifts throughout the system, either stabilizing or destabilizing it. For instance, inconsistent regulatory support may undermine operator motivation and budg *et al* locations ultimately reducing service quality.

Thus, these linkage variables should be approached through integrated, cross-sectoral planning, involving local government, community leaders, and financial stakeholders. As Marín-González *et al*. (2022) emphasize, cross-sectoral cooperation is essential for sustainable local development, requiring coordinated efforts across various sectors to effectively address complex challenges.

Quadrant III (Dependent factors) like Administrative Management (A13) and Economic Impact (A20) serve as output indicators. They reflect how well upstream processes are functioning but do not influence system transformation on their own. These should be monitored closely as performance metrics, rather than targets for reform.

The hierarchical ISM model (Figure 2) reinforces a layered intervention strategy by illustrating the TPS 3R system as a network of cascading influences, allowing policymakers to identify precise entry points and determine the appropriate sequence for action. At the foundation, Levels 12 to 10 encompass the core infrastructural and operational drivers A3 (Waste Volume Managed), A5 (Type of Management), A8 (Residual Waste to Landfill), A11 (Human Resources), A18 (Waste Segregation by Households), and A6 (Equipment Condition) which should be prioritized through short-term investments such as community education campaigns, staff training programs, and the provision or repair of operational equipment. Moving up the hierarchy, Levels 9 to 6 contain more structural and institutional constraints, including A10 (Organizational Structure), A9 (Management Institution), and A13 (Administrative Practices), which require mid-term institutional strengthening initiatives like clarifying governance roles across village and district levels and improving coordination between TPS 3R operators. Finally, Levels 5 to 1, which include strategic and regulatory elements such as A2 (TPS 3R Development Plan), A17 (Government Assistance), and A12 (Institutional Legality), represent long-term systemic maturity goals that can only function effectively if foundational constraints have first been addressed. This staged framework supports coherent policy design by aligning intervention scope with systemic readiness.

This layered logic is consistent with waste management transitions in other emerging economies. For instance, a study in Da Nang, Vietnam by Duleba (2019) advocates similar phased interventions beginning with public behavior and operational barriers before addressing regulatory frameworks. Likewise, research in Ethiopia and Indonesia emphasizes the pivotal role of institutional arrangements and stakeholder coordination. Mekonnen *et al*. (2022) highlight how demographic changes, organizational effectiveness, and clearly defined responsibilities are foundational to sustainable waste management transitions. Similarly, Kholil *et al*. (2008) demonstrate that the success of urban waste management systems depends heavily on public participation, legal clarity, and organizational responsiveness to urban dynamics.

Based on the structural insights derived from the ISM and MICMAC analysis, several strategic interventions are recommended to address the most critical constraints affecting TPS 3R implementation in Buleleng Regency. First, the institutionalization of community-based waste sorting (A18) is essential. This requires a regulatory mandate for source separation, accompanied by targeted public education and adequate infrastructure, such as dual-bin systems. The experience from Jakarta Selatan demonstrates that enhancing community participation, clarifying regulations, and strengthening organizational structures significantly improves waste management effectiveness (Kholil *et al*., 2008). Additionally, Mekonnen *et al*. (2022) underscore the importance of institutional arrangements and clearly defined responsibilities among stakeholders, which are crucial for ensuring sustainable waste management practices.

Second, investments in workforce capacity (A11) should be prioritized. Providing technical training, certification programs, and professional development pathways for TPS 3R personnel will ensure operational continuity. This strategy also enhances the utilization of equipment (A6), minimizes downtime, and improves the overall quality of compost produced (A7). Third, to reduce dependency on final disposal at landfills (A8), households and businesses should be encouraged to preprocess waste. This can be supported by incentive structures such as reduced tariffs for low-residue contributors, thereby promoting upstream waste minimization.

Fourth, TPS 3R operations need to transition beyond simple sorting mechanisms (A5, A3) toward more diversified and value-added models. Innovative practices such as household-scale biodigesters, black soldier fly composting, and plastic extrusion technologies have demonstrated potential in increasing resource recovery and financial viability (Kaza *et al*., 2018; Sharholy *et al*., 2008). Fifth, linkage factors such as regulatory frameworks (A1), equipment condition (A6), and organizational structure (A10) should be improved through integrated and coordinated interventions. This may include forming cross-sectoral task forces that involve local government, waste operators, and community stakeholders to ensure alignment across administrative, legal, and logistical domains.

Lastly, dependent factors like administrative recordkeeping (A13), economic outcomes (A20), and customer growth (A21) should serve as performance indicators. These variables, although not suitable for direct intervention, can be used to monitor system performance over time. Developing a dynamic monitoring dashboard that visualizes these metrics will enable continuous feedback and support data-driven decision-making in TPS 3R governance. The findings of this study confirm that TPS 3R systems are deeply interwoven structures where technical, institutional, and social components interact in nonlinear ways. The ISM hierarchy and MICMAC quadrant demonstrate that constraints cannot be treated as isolated issues. Instead, they must be understood as systemic challenges whose resolution depends on identifying and leveraging high-impact entry points.

This research reinforces the theoretical framing of systems thinking in waste governance. Meadows (2008), where leverage points such as household behavior (A18) and institutional capability (A11) determine the broader system's ability to evolve and self-regulate. Moreover, the combination of ISM and MICMAC provides both depth and direction in structural analysis a dual-method strategy that aligns with recent best practices in sustainability policy design (Raj *et al*., 2008; Wang *et al*., 2023).

From a practical standpoint, the study also contributes to the growing body of literature on community-based waste management (CBWM) in Southeast Asia. While much of the existing research has focused on metropolitan areas (e.g., Jakarta, Manila, Bangkok), this study adds nuance by focusing on a semi-rural regency where institutional fragmentation and resource limitations are more pronounced. As such, it offers insights that are replicable in similar low- and middle-income settings.

Despite the comprehensive structural analysis conducted in this study, several limitations must be acknowledged. First, the ISM methodology relies on input from a small group of domain experts, which, while methodologically appropriate, introduces a degree of subjectivity and may not fully reflect the perspectives of broader stakeholder groups such as informal waste workers or community members. Second, the regional focus on Buleleng Regency limits the geographical scope of the findings; although the results may be applicable to other districts with similar socio-institutional characteristics, caution is advised when generalizing them to urban or industrialized areas with different operational dynamics. Third, the use of ISM and MICMAC provides a static representation of the system capturing relationships at a single point in time without accounting for the dynamic evolution of factors or real-time feedback mechanisms. Future research would benefit from integrating system dynamics modeling tools, such as Vensim or STELLA, to simulate temporal changes and assess the long-term impacts of various policy interventions

Building on the findings and acknowledging the study's limitations, several directions are recommended for future research to deepen and broaden understanding of TPS 3R implementation. First, longitudinal studies should be conducted to evaluate how interventions influence system performance over time, using time-series data on key metrics such as waste volume reduction, compost quality, or household participation rates. Second, comparative regional studies involving areas with diverse institutional capacities will enhance the generalizability of the results and support the identification of best practices across varying contexts. Third, integrating ISM with dynamic simulation tools such as system dynamics modeling platforms will allow researchers to test policy scenarios and forecast long-term system behaviors under different intervention strategies. Finally, future studies should adopt more stakeholder-centered approaches by incorporating the voices and experiences of community members, informal sector workers, and local NGOs, thereby capturing operational nuances and socially embedded challenges that may be overlooked in expert-driven analyses.

## Conclusion

In conclusion, the integrated ISM–MICMAC analysis conducted in this study identified and structured 21 key barriers affecting TPS 3R implementation in Buleleng Regency. The analysis revealed that variables such as waste segregation by households, human resources, residual waste volume, and type of processing are critical leverage points with the highest driving power. Conversely, dependent factors such as administrative practices and economic returns reflect systemic health but are not effective starting points for reform.

The hierarchical and quadrant-based findings provide actionable insights for local governments, TPS 3R operators, and policy designers. The study shows that systemic transformation in waste management is possible when interventions are prioritized, sequenced, and implemented with an understanding of interdependence. In doing so, the study offers both theoretical contributions to the field of systems-based waste governance and practical guidance for actors in developing regions working toward more resilient, inclusive, and sustainable waste systems.

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