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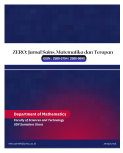

Structural Equation Modeling Multigroup on Waste Economy Management

[1] Anggun Fadhila Rizqia
Department of Statistics, Brawijaya University, Malang, Indonesia

[2] Solimun
Department of Statistics, Brawijaya University, Malang, 65145, Indonesia

[3] Nurjannah
Department of Statistics, Brawijaya University, Malang, 65145, Indonesia

[4] Fachira Haneinanda Junianto
Department of Statistics, Brawijaya University, Malang, 65145, Indonesia

[3] Kamelia Hidayat
Department of Statistics, Brawijaya University, Malang, 65145, Indonesia

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ABSTRACT

In recent years, urban waste has increased, leading to the demand for sustainable waste management based on circular economy. Facilities infrastructure and waste banks, play a role in improving 3R practices and the economic value of the community. This study used Structural Equation Modeling (SEM) with a Multigroup approach to analyze the effect of facility and infrastructure quality and waste banks on 3R-based waste management and waste economic management, moderated by environmental quality. In both groups, the impact of waste bank usage and 3R-based management was significant but stronger in moderate environments, with a significant difference (p-value = 0.032). Moderation also appeared in the influence of waste bank usage on waste economic management, where the difference was significant (p-value = 0.041). The results reveal that environmental quality moderates waste banks usage, 3R-based waste management and economic benefits, especially in environments with better quality.

Corresponding Author:

Anggun Fadhila Rizqia,
Department of Statistics,
Brawijaya University, Malang, Indonesia
Email: anggunfadhila24@gmail.com

1. INTRODUCTION

The increase in population and rapid urbanization produced a massive amount of waste. It is a heavy burden on environmental sustainability, public welfare, and economic stability. Not properly disposed of, waste not only damages the environment but also eliminates the economic potential in waste material [1]. In turn, a circular economy approach emerged, in which waste can be perceived as a resource through the application of the 3R principle (reduce, reuse, recycle) [2], [3].

For instance in Indonesia, community based waste management efforts like waste banks have been seen as a key driver to transform waste into an economic asset and increase awareness of environmental conservation among the population [4], [5]. Citizen participation is increasingly motivated by programs that give recycled waste in exchange for cash or savings. Furthermore, the development of the creative sector using recycled materials means new economic opportunities in the local context [6]. But challenges remain, be they low public engagement or insufficient facilities or government support for a more integrated waste management system [7].

A circular economy, based on the 3R principles and recycling centers for good has been demonstrated in some previous research to enhance the environmental awareness, citizen participation, and economic benefits in a sustainable manner. The approach showed methodological evidence from several researches that structural equation modeling (SEM) is an excellent analysis for complex cause-effect relationships in social and environmental settings. This approach will facilitate to establish direct, indirect and total effects and will offer a better understanding for the dynamics of waste management in the cities.

To gain a fuller understanding of these challenges, an analytical approach is required that can capture the interrelations between social, institutional, and behavioral factors in a coherent manner. SEM (Structural Equation Modeling) was widely used in earlier studies, given the ability to combine measurement models and structural models simultaneously [8], [9], [10] and to examine latent and observed variables in interdependent relationships [11], [12], [13], [14]. In comparison to simple regression, SEM does allow testing of causative relationships with more complex nature including direct and indirect relationships between latent constructs [15], [16], [17].

Nevertheless, much of the previous research assumes that these structural patterns are homogeneous. This does not reflect the differences between social or regional contexts that may occur, which can explain the diversity of social and ecological systems as such. Thus, multigroup SEM (MG-SEM) is necessary to evaluate whether the model structure is identical between different groups [18]. An important contribution this study would make is the application of MG-SEM to identify differences in structural relationships among groups, supplementing or extending previous studies, which were more concentrated on modeling identical groupings. This approach allows for the disclosure of dynamic variations not covered in previous studies and provides a more contextual understanding of the patterns of relationships between variables.

Several studies show that MG-SEM is effective for identifying behavioral variations based on moderating factors such as literacy, political policies, and environmental awareness. As illustrated in several studies, MG-SEM is effective in characterizing behavioral changes that may differ based on such moderating factors as literacy, political policies, and environmental awareness. For instance, variation in causal analyses was considered based on the relative level of health literacy in the samples of [18], whereas [14] stressed that social features were important to solar energy adoption. Moreover, [19] draws attention to the possibility of dealing with more complex structural differences with multilevel and nonlinear solutions. In contrast to these studies, the current research adopts R-based MG-SEM to compare the impact of facility quality, recycling center efficiency, 3R practices and waste management economic performance with the given environmental conditions (moderate and high).

The present literature further supports the fact that the quality of facility and infrastructure are essential for successful 3R activities [16], [20]. Recycling centers promote recycling as well as generate economic gain [21], [22], and 3R-based circular economy model enhance environmental resilience [23]. But the positive impact of these relationships is significantly affected by environmental context, and this context may vary through regions [16], [24]. Variability of environmental quality, institution capacity and social awareness could lead to different waste management styles. MG-SEM is a relevant tool for this type of study as it assesses stability of the structural linkage between variables at different environmental levels.

Nevertheless, no study has directly examined how variations in environmental quality affect the structural relationships between waste banks effectiveness, 3R practices, and the economic performance of waste management. Nor has any research compared these relationships using parametric MG-SEM between regions with moderate and high environmental conditions. This gap includes a lack of empirical evidence on whether the economic benefits of waste banks and 3R practices change significantly in different environmental contexts and how environmental quality shapes the strength of causal relationships in circular waste management.

The urgency of this research stems from the increasing burden of municipal waste and the significant economic potential of unused waste materials. Under these conditions, an adaptive, evidence-based approach to waste management that takes into account the local environmental context is necessary. Understanding how environmental quality influences the effectiveness of 3R practices and the role of waste banks is an important step toward strengthening waste management policy at the regional level.

2. RESEARCH METHOD

2.1 Linearity Assumption

Linearity can be examined by checking the scatter plot and conducting a test using Ramsey's Regression Specification Error Test (RESET) [25], [26], [27]. The following are the steps in conducting Ramsey's RESET test [28], [13].

a) Determine the first regression equation (linear regression) as in the following equation.

$$Y_i = \beta_0 + \beta_1 X_{1i} + \varepsilon_i \tag{1}$$

$$\hat{Y}_i = \hat{\beta}_0 + \hat{\beta}_1 X_{1i} \tag{2}$$

Next, calculate the R_1^2 using the following equation.

$$R_1^2 = 1 - \frac{\sum_{i=1}^{n}\left(Y_i - \hat{Y}_i\right)^2}{\sum_{i=1}^{n}(Y_i - \bar{Y})^2} \tag{3}$$

b) Determine the second regression equation as a comparison model as in the equation.

$$Y_i = \beta_0^* + \beta_1^* X_{1i} + \beta_2 \hat{Y}_i^2 + \beta_3 \hat{Y}_i^3 + \varepsilon_i \tag{4}$$

$$\hat{Y}_i = \hat{\beta}_0^* + \hat{\beta}_1^* X_{1i} + \hat{\beta}_2 \hat{Y}_i^2 + \hat{\beta}_3 \hat{Y}_i^3 \tag{5}$$

Next, calculate the R_2^2 using the following equation.

$$R_2^2 = 1 - \frac{\sum_{i=1}^{n}\left(Y_i - \hat{Y}_i^*\right)^2}{\sum_{i=1}^{n}(Y_i - \bar{Y})^2} \tag{6}$$

c) Testing whether the relationship is linear or not.
Hypothesis for Ramsey's RESET:
$H_0: \beta_2 = \beta_3 = 0$ (Linear relationship between variables)
H_1: There is at least one $\beta_j \neq 0, j = 2,3$
Test statistic follows an F distribution as in equation below.

$$F = \frac{(R_2^2 - R_1^2)/2}{(1 - R_2^2)/(n-2)} \sim F_{2,n-2} \tag{7}$$

The decision to reject the Hypothesis null if the test statistic $F > F_{\alpha(2,n-2)}$, or when$p - value < 0,05$, which means the relationship between variables is nonlinear.

Where,

Y_i	: endogenous variable of the *i*-th observation ($i = 1,2,3,\dots,n$)
X_i	: exogenous variable of the *i*-th observation
n	: the number of observations
β_j	: the coefficient of influence of exogenous variables on endogenous
ε_i	: random error of the *i* endogenous variable
R^2	: coefficient of determination

2.2 Structural Equation Modeling (SEM)

Structural Equation Modeling (SEM) is a statistical modeling technique that is part of multivariate analysis involving relationships between variables and indicator models simultaneously [29]. SEM is a unique combination of two multivariate analysis techniques, namely factor analysis and multiple regression analysis [12]. The model used in this study was estimated using the ordinary least squares (OLS) method in RStudio. This method was chosen because the data met the basic requirements of linearity and did not exhibit any significant multicollinearity problems between the indicators. To ensure more stable estimation results, especially when violations of the homoscedasticity assumption cannot be completely ruled out, the analysis was supplemented by 1000 bootstrap iterations. The use of bootstrapping provides more robust standard errors and improves the accuracy of the significance tests of the parameters.

The path diagram resulting from the design of the structural model (inner model) and measurement model (outer model) can be seen in Figure 1.

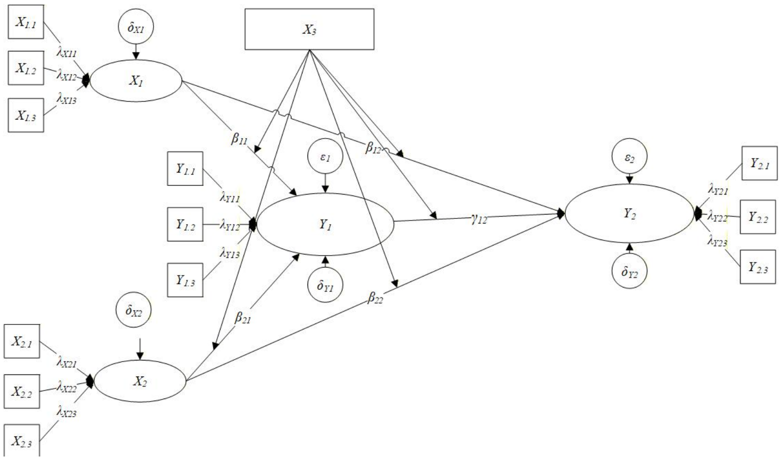

Figure 1. Path Diagram

where,

Y_q : endogenous latent variable q ($q = 1,2$)
X_p : exogenous latent variable p ($p = 1,2,3$)
λ_{yqi} : loadings for endogenous latent variables
λ_{xpi} : loadings for exogenous latent variables
i : number of manifest variables
β_{pq} : coefficient of influence of exogenous latent variable p on endogenous latent variable q
ε_h : model error for h
δ : measurement error in manifest variables for exogenous latent variables
ζ : measurement error on manifest variables for endogenous latent variables

The measurement model or *outer model* is a model that describes the relationship between latent variables and their indicators. There are two types of indicators used to measure latent variables, namely formative and reflective indicators. The formative indicator model does not require indicators to have the same factor (*common factor)*, so indicators do not need to be correlated with each other [29].

The path analysis model in *the outer model* is written in the following equation.
Exogenous latent variables with formative properties

$$x_{1i} = \lambda_{x_{11}} X_{11i} + \lambda_{x_{12}} X_{12i} + \lambda_{x_{13}} X_{13i} + \delta_{x1i}$$
$$x_{2i} = \lambda_{x_{21}} X_{21i} + \lambda_{x_{22}} X_{22i} + \lambda_{x_{23}} X_{23i} + \delta_{x2i} \quad (8)$$

Endogenous latent variables with formative properties

$$y_{1i} = \lambda_{y_{11}} Y_{11i} + \lambda_{y_{12}} Y_{12i} + \lambda_{y_{13}} Y_{13i} + \delta_{y1i}$$
$$y_{2i} = \lambda_{y_{21}} Y_{21i} + \lambda_{y_{22}} Y_{22i} + \lambda_{y_{23}} Y_{23i} + \delta_{y2i} \quad (9)$$

The linear inner model path model corresponding to Figure 1 is written in the following equation.

$$Y_{1i} = \beta_{01} + \beta_{11} X_{1i} + \beta_{21} X_{2i} + \varepsilon_{1i}$$
$$Y_{2i} = \beta_{02} + \beta_{12} X_{1i} + \beta_{22} X_{2i} + \gamma_{12} Y_{1i} + \varepsilon_{2i} \quad (10)$$

Parameter estimation in SEM analysis uses the Ordinary Least Squares (OLS). The structural model path coefficients are estimated using the Ordinary Least Squares (OLS) corresponds to the following equation.

$$\hat{Y}_{ji} = \sum_{i \leftrightarrow j} \hat{\beta}_{ji} X_{ji} \quad (11)$$

$$\hat{\boldsymbol{\beta}}_j = (\boldsymbol{X}'\boldsymbol{X})^{-1}\boldsymbol{X}'\boldsymbol{Y} \quad (12)$$

where,

$\hat{\beta}_{ji}$: vector of path coefficient estimates
$\boldsymbol{X}$: matrix of exogenous latent variables
$\boldsymbol{Y}$: vector of endogenous latent variables

SEM estimation employs a resampling procedure (bootstrap) to obtain more robust standard errors for both the measurement and structural parameters [30], [31], [32]. The following sections describe the hypothesis testing procedures for both the outer and inner models.

a) Hypothesis testing for the outer model

$H_0: \lambda_i = 0$ vs $H_1: \lambda_i \neq 0$

t-test statistics:

$$t = \frac{\hat{\lambda}}{SE(\hat{\lambda})} \sim t_{n-1} \tag{13}$$

b) Hypothesis testing for the inner model

$H_0: \beta_m = 0$ vs $H_1: \beta_m \neq 0$

t-test statistics:

$$t = \frac{\hat{\beta}}{SE(\hat{\beta})} \sim t_{n-1} \tag{14}$$

2.3 Moderating Variable Analysis with a Multigroup Approach

A moderating variable is a variable that strengthens or weakens the relationship between exogenous and endogenous variables [29]. One important characteristic is that moderating variables are not influenced by exogenous or endogenous variables. In principle, moderating variable analysis using the multigroup method performs structural model analysis on two or more groups. The theoretical framework of moderating variables is presented in Figure 2.

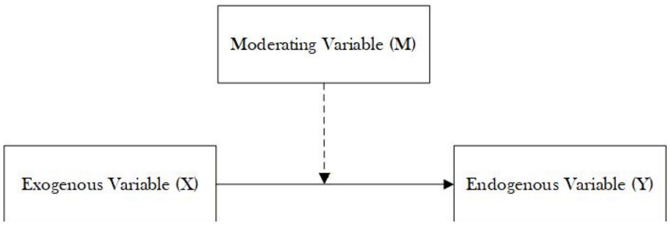

Figure 2. Theoretical Framework of Moderating Variables

Moderating variables can be divided into *nonmetric moderation* and *metric moderation*. *Nonmetric moderation* refers to categorical moderating variables, where grouping is based on certain characteristics of the variable. In structural modeling, the technique commonly used to handle *nonmetric* moderation is multigroup analysis. *Metric moderation* refers to continuous moderating variables, with the interaction method being the approach used.

The following is the equation for analyzing moderation variables.

$$\begin{aligned} Y_{1i} &= \beta_{11}X_{1i} + \beta_{12}X_{1i}M + \varepsilon_{1i} \\ Y_{2i} &= \beta_{21}X_{1i} + \gamma_{21}Y_{1i} + \beta_{22}X_{1i}M + \gamma_{22}Y_{1i}M + \varepsilon_{2i} \end{aligned} \tag{15}$$

where,

Y_q : endogenous latent variable q ($q = 1,2$)

X_p : exogenous latent variable p ($p = 1,2,3$)

M : moderation variable

β_{pq} : coefficient of influence of exogenous latent variable p on endogenous latent variable q

γ_{pq} : coefficient of influence of endogenous latent variable p on endogenous latent variable q

2.4 Data and Variables

The research was conducted using secondary data and simulations. The primary data was sourced by the research population consisted of communities from 24 villages and sub-districts in Batu City, with respondents aged 17 years and above. The research sample consisted of residents living in Batu District, determined using quota sampling of 100 respondents. The research variables used were Quality of Facilities and Infrastructure (X_1), Waste Banks (X_2) as exogeneous variables; 3R-Based Waste Management (Y_1) as intervening variable; Waste Economic Management (Y_2) as endogeneous variable, and Environmental Quality as moderation variable. All variables were tested for validity and reliability. The results showed that every questionnaire item met the criteria, indicating that all items were valid and reliable, therefore suitable for further analysis. The Multigroup SEM analysis in this study was conducted using RStudio.

The research uses latent variables from the Likert measurement scale. The variables employed in this study are represented through several indicators as in Table 1.

Table 1. Research Variable

Variable	Indicator
	Facilities and Infrastructure Maintenance ($X_{1.1}$)

Variable	Indicator
Quality of Facilities and Infrastructure (X_1)	Quality of Facilities and Infrastructure ($X_{1.2}$) Ease of Use of Facilities and Infrastructure ($X_{1.3}$)
Waste Banks (X_2)	Waste Banks in Residents' Homes ($X_{2.1}$) Effectiveness of Waste Banks ($X_{2.2}$) Operational Efficiency of Waste Banks ($X_{2.3}$)
3R-Based Waste Management (Y_1)	Effectiveness of Reduce ($Y_{1.1}$) Effectiveness of Reuse ($Y_{1.2}$) Effectiveness of Recycle ($Y_{1.3}$)
Waste Management Economics (Y_2)	Efficiency of Waste Management Economics ($Y_{2.1}$) Waste as an Economic Resource ($Y_{2.2}$) Sustainability of Waste Management Economics ($Y_{2.3}$)
Environmental Quality (X_3)	Environmental Awareness Environmental Maintenance Community Attitudes Toward the Environment

Validity checks were performed on each item in the questionnaire by looking at the corrected item total correlation value. The instrument was declared valid if the corrected item total correlation value was ≥ 0.3. The results of the validity check on 30 respondents are presented in Table 2 as follows.

Table 2. Validity Check

Variable	Item	Corrected Item Total Correlation	Result
Quality of Facilities and Infrastructure (X_1)	$X_{1.1.1}$	0.693	Valid
	$X_{1.1.2}$	0.755	Valid
	$X_{1.2.1}$	0.918	Valid
	$X_{1.2.2}$	0.923	Valid
	$X_{1.3.1}$	0.956	Valid
	$X_{1.3.2}$	0.938	Valid
Waste Banks (X_2)	$X_{2.1.1}$	0.614	Valid
	$X_{2.1.2}$	0.784	Valid
	$X_{2.2.1}$	0.946	Valid
	$X_{2.2.2}$	0.911	Valid
	$X_{2.3.1}$	0.925	Valid
	$X_{2.3.2}$	0.759	Valid
3R-Based Waste Management (Y_1)	$Y_{1.1.1}$	0.645	Valid
	$Y_{1.1.2}$	0.839	Valid
	$Y_{1.2.1}$	0.390	Valid
	$Y_{1.2.2}$	0.691	Valid
	$Y_{1.3.1}$	0.459	Valid
	$Y_{1.3.2}$	0.539	Valid
Waste Management Economics (Y_2)	$Y_{2.1.1}$	0.812	Valid
	$Y_{2.1.2}$	0.830	Valid
	$Y_{2.2.1}$	0.347	Valid
	$Y_{2.2.2}$	0.698	Valid
	$Y_{2.3.1}$	0.816	Valid
	$Y_{2.3.2}$	0.425	Valid
Environmental Quality (X_3)	$X_{3.1.1}$	0.418	Valid
	$X_{3.1.2}$	0.337	Valid
	$X_{3.2.1}$	0.416	Valid
	$X_{3.2.2}$	0.414	Valid
	$X_{3.3.1}$	0.744	Valid
	$X_{3.3.2}$	0.321	Valid

Based on Table 2, it is obtained that all items have a Corrected Item Total Correlation value greater than 0.3, so all statement items in the pilot test stage are valid in measuring variables. Next, a reliability check was conducted on each variable in the study on 30 respondents. The reliability check results are presented in Table 3.

Table 3. Reliability Check

Variable	Cronbach Alpha	Result
Quality of Facilities and Infrastructure (X_1)	0,999	Reliable
Waste Banks (X_2)	0,998	Reliable
3R-Based Waste Management (Y_1)	0,996	Reliable
Waste Management Economics (Y_2)	0,944	Reliable
Environmental Quality (X_3)	0,992	Reliable

Based on Table 3, it can be seen that all variables have a Cronbach's Alpha reliability value greater than 0.6, meaning that the variables of Environmental Quality, Facilities and Infrastructure, Use of Waste Banks, Use of the 3R Principle, and Waste Economy are reliable in measuring variables at the trial stage.

3. RESULT AND ANALYSIS

3.1. Determination of Groups

Grouping was determined based on the Environmental Quality variable, with the aim of grouping communities into different levels of perception of the environmental conditions they experience. In this study, a value of 3.5 was used as the basis for grouping. This threshold was set in accordance with the guidelines from [33] which explain that on a five-point Likert scale, a value of 3.5 is at the upper limit of the moderate category. In addition, this is also supported by the average score for environmental quality variables, which is 3.57.
Based on these criteria, the community was divided into two categories, namely:

1) Medium Group, which is the community with an average Environmental Quality score ≤ 3.5.
2) High Group, which consists of communities with an average Environmental Quality score > 3.5.

The results of the grouping show that there are 25 communities included in the medium group and 75 communities included in the high group. This composition illustrates that most communities assess their environmental conditions as high, which means that the perception of environmental quality in general is relatively good. The grouping process was carried out by calculating the average score of each community from all indicators that make up the Environmental Quality variable, then comparing it with the threshold value of 3.5.

3.2. Linearity Test

The results of the test using Ramsey's RESET test can be seen in the following table.

Table 4. Linearity Test Results

Relationship	Ramsey RESET Test			
	Medium Group		High Group	
	p-value	Result	p-value	Result
$X_1 \rightarrow Y_1$	0.412	Linear	0.673	Linear
$X_1 \rightarrow Y_2$	0.238	Linear	0.351	Linear
$X_2 \rightarrow Y_1$	0.589	Linear	0.417	Linear
$X_2 \rightarrow Y_2$	0.768	Linear	0.642	Linear
$Y_1 \rightarrow Y_2$	0.533	Linear	0.284	Linear

Based on Table 4, it can be seen the results of linearity testing between each variable. Based on the results of the Ramsey RESET test above, all relationships between variables in the Medium and High groups have p-values greater than 0.05. Thus, it can be concluded that all relationships between variables are linear.

3.3. Measurement Model

The results of the measurement model can be seen in the following table.

Table 5. Measurement Model

Variable	Indicator	Medium Group		High Group	
		Outer Weight	p-value	Outer Weight	p-value
X_1	$X_{1.1}$	0.411	0.008	0.284	0.031
	$X_{1.2}$	0.372	0.014	0.462	0.002
	$X_{1.3}$	0.438	0.005	0.329	0.026
X_2	$X_{2.1}$	0.396	0.010	0.478	0.001

	$X_{2.2}$	0.455	0.003	0.364	0.019
	$X_{2.3}$	0.287	0.037	0.321	0.028
	$Y_{1.1}$	0.334	0.028	0.415	0.006
Y_1	$Y_{1.2}$	0.442	0.004	0.382	0.011
	$Y_{1.3}$	0.368	0.017	0.291	0.044
	$Y_{2.1}$	0.437	0.005	0.318	0.033
Y_2	$Y_{2.2}$	0.389	0.009	0.456	0.003
	$Y_{2.3}$	0.304	0.041	0.327	0.030

Based on Table 5, the results of the measurement model analysis show that all indicators in the four variables are significant (p-value < 0.05) and contribute positively to the formation of latent variables. However, there are differences in the most dominant indicators between the Medium Group and the High Group, which illustrate variations in focus between groups.

In the Medium Group, the indicator Ease of Use of Facilities and Infrastructure ($X_{1.3}$) has the highest contribution to the Quality of Facilities and Infrastructure variable (X_1), indicating that ease of use of facilities is more decisive in determining quality perceptions than other aspects. Meanwhile, in the Waste Banks variable (X_2), the most dominant indicator is Effectiveness of Waste Banks ($X_{2.2}$), indicating that operational effectiveness is key to the success of the waste bank system in this group. For the 3R-Based Waste Management construct (Y_1), the Effectiveness of Reuse ($Y_{1.2}$) has the greatest influence, emphasizing the importance of reuse activities in supporting 3R practices. Meanwhile, in Waste Management Economics (Y_2), the highest contribution comes from Efficiency of Waste Management Economics ($Y_{2.1}$), indicating that management efficiency is a top priority in the economic aspect of waste management in the middle group.

In contrast, in the High Group, the most influential factor in the Quality of Facilities and Infrastructure (X_1) construct is Quality of Facilities and Infrastructure ($X_{1.2}$), emphasizing that the physical quality of facilities is a major factor in groups with higher levels of management. In the Waste Banks (X_2) construct, the Waste Banks in Residents' Homes ($X_{2.1}$) indicator is the dominant factor, indicating that community involvement through the existence of household waste banks is an important aspect. For 3R-Based Waste Management (Y_1), the Effectiveness of Reduce indicator ($Y_{1.1}$) is more prominent, showing that this group is more focused on waste reduction efforts at the source. Meanwhile, in Waste Management Economics (Y_2), the Waste as an Economic Resource ($Y_{2.2}$) indicator is the most influential, meaning that at higher management levels, the economic orientation is more directed towards utilizing waste as a value-added resource.

3.4. Structural Model

The results of the structural model can be seen in the following table.

Table 6. Structural Model

Relationship	$\hat{\beta}_i$	Medium Group			High Group			Difference Test (p-value)
		Coef.	SE	p-value	Coef.	SE	p-value	
$X_1 \rightarrow Y_1$	$\hat{\beta}_1 X_1$	0.312	0.094	0.002*	0.284	0.091	0.005*	0.831
$X_1 \rightarrow Y_2$	$\hat{\beta}_2 X_1$	0.146	0.083	0.078	0.231	0.085	0.011*	0.477
$X_2 \rightarrow Y_1$	$\hat{\beta}_3 X_2$	0.427	0.088	0.000*	0.263	0.093	0.004*	0.032*
$X_2 \rightarrow Y_2$	$\hat{\beta}_5 X_2$	0.211	0.091	0.018*	0.396	0.087	0.000*	0.041*
$Y_1 \rightarrow Y_2$	$\hat{\beta}_7 Y_1$	0.368	0.081	0.000*	0.342	0.084	0.001*	0.824

Note: Significant at p-value < 0.05

Based on the multigroup test results Table 6, in the group with moderate Environmental Quality (Medium Group), all relationships between variables show a positive direction of influence, and most are significant at the 5% level. In this group, Quality of Facilities and Infrastructure (X_1) has a significant positive effect on 3R-Based Waste Management (Y_1) and Waste Management Economics (Y_2). This means that the better the facilities and infrastructure, the higher the effectiveness of 3R-based waste management and the greater its contribution to the economic aspects of waste management. In addition, Waste Banks (Y_2) also have a significant positive effect on both dependent variables, with a stronger effect on 3R-Based Waste Management (Y_1). These findings indicate that the existence and effectiveness of waste banks are key factors in promoting the success of the 3R system, especially in environments with moderate quality. The relationship between $Y_1 \rightarrow Y_2$ is also significant, indicating that increasing the effectiveness of 3R management also strengthens the economic benefits generated from waste management.

In the group with high Environmental Quality (High Group), the analysis results also show a positive relationship between variables, but with a different pattern of influence. In this group, the influence of Waste Banks (X_2) on Waste Management Economics (Y_2) is more dominant than its influence on 3R-Based Waste

Management (Y_1). This means that in a better-quality environment, the role of waste banks is not only to support the implementation of 3R, but also to directly strengthen the economic aspects of waste management. Meanwhile, the influence of Quality of Facilities and Infrastructure (X_1) on both dependent variables remains significant, indicating that the availability of adequate facilities remains an important foundation in a sustainable waste management system.

The difference test (t-test) shows that a significant difference occurs in the two main relationships, namely $X_2 \rightarrow Y_1$ and $X_2 \rightarrow Y_2$, which means that Environmental Quality (Medium vs. High) acts as a moderating variable in these relationships. Thus, it can be concluded that the role of Waste Banks (X_2) differs significantly between the two groups. In the group with medium environmental quality, waste banks play a greater role in improving the effectiveness of the 3R system, while in the group with high environmental quality, their contribution is stronger in strengthening the economic dimension of waste management. Overall, these results confirm that Environmental Quality functions as a partial moderator, as it only affects some of the relationships between constructs, particularly those involving the Waste Banks variable (X_2). In other words, the better the environmental quality, the more optimal the role of waste banks in creating effective waste management while providing greater economic impact.

3.5. Model Fit Evaluation

The model fit in SEM was evaluated using several indices. In this study, Root Mean Square Error of Approximation (RMSEA), Standardized Root Mean Square Residual (SRMR), Comparative Fit Index (CFI), and Tucker–Lewis Index (TLI) were used. All model fit evaluations were performed for each group (moderate and high environment). The result of model fit evaluation can be seen in Table 7.

Table 7. Model Fit Evaluation

Fit Index	Medium Group	High Group
RMSEA	0.064	0.058
SRMR	0.052	0.047
CFI	0.948	0.956
TLI	0.933	0.943

Based on Table 7, it can be seen that the models for both groups are feasible. The RMSEA values for both groups indicate that the models fit, as they are less than 0.08 for both (the moderate group has a value of 0.064 and the high group has a value of 0.058). The same applies to SRMR, where both groups have values less than 0.08, indicating minimal model residuals. CFI and TLI in both groups show values above the 0.90 threshold. This indicates adequate model fit in both groups. Overall, all indices show that the model represents the data well, with slightly higher fit performance in the high group.

4. CONCLUSION

Based on the results of the structural model analysis and the multigroup testing of the Environmental Quality variable, several conclusions can be drawn. The difference test indicates that Environmental Quality functions as a partial moderator, as it only moderates the relationships between Waste Banks and 3R-Based Waste Management, as well as between Waste Banks and Waste Management Economics. In the medium Environmental Quality group, the influence of Waste Banks on 3R-Based Waste Management ($\hat{\beta} = 0.427$) is stronger than its influence on Waste Management Economics ($\hat{\beta} = 0.211$). However, in the high Environmental Quality group, the pattern shifts, with Waste Banks exerting a greater influence on Waste Management Economics ($\hat{\beta} = 0.396$) than on 3R-Based Waste Management ($\hat{\beta} = 0.263$). Based on the calculation of several model fit indices, it was found that the models in both groups were feasible and represented the data well. The model fit index in the high environmental quality group showed slightly better performance than the moderate group. This suggests that the level of environmental quality shapes the extent to which waste banks enhance 3R practices and generate economic benefits in waste management.

Future research may consider using Bayesian SEM to obtain more flexible and robust parameter estimates, especially in the context of multigroup SEM. In addition, nonlinear and nonparametric analyses can also be used to capture non-linear relationship patterns. Research also needs to involve larger samples to improve estimation stability, model fit accuracy, and generalization of findings to a broader population.

5. REFERENCES

[1] N. A. Jauhariyah, N. I. Susanti, Mahmudah, F. N. S. Indana, and M. K. Qohar, "Pengembangan Pemberdayaan Ekonomi Pesantren Melalui Pengelolaan Sampah Secara Berkelanjutan," *Loyal. J. Pengabdi. Kpd. Masy.*, vol. 6, no. 1, pp. 116–127, 2023, [Online]. Available: https://ejournal.iaida.ac.id/index.php/loyal/article/view/2250

[2] I. Aiguobarueghian, U. M. Adanma, E. O. Ogunbiyi, and O. N. Solomon, "Waste management and circular economy: A review of sustainable practices and economic benefits," *World J. Adv. Res. Rev.*, vol. 22, no. 2, pp. 1708–1719, 2024, doi: https://doi.org/10.30574/wjarr.2024.22.2.1517.

[3] E. K. Purwendah, Rusito, and A. Periani, "Kewajiban Masyarakat dalam Pemeliharaan Kelestarian Lingkungan Hidup Melalui Pengelolaan Sampah Berbasis Masyarakat," *J. locus delicti*, vol. 3, pp. 121–134, 2022, doi: https://doi.org/10.23887/jld.v3i2.1609.

[4] D. Mandasari, B. Wirjodirdjo, and M. Anityasari, "Peningkatan Fasilitas Bank Sampah sebagai Perkotaan di TPS Surabaya," *J. Tek. ITS*, vol. 9, no. 2, 2025, doi: https://doi.org/10.12962/j23373539.v9i2.56123.

[5] D. Ariefahnoor, N. Hasanah, and A. Surya, "Pengelolaan Sampah Desa Gudang Tengah Melalui Manajemen Bank Sampah," *J. Kacapuri*, vol. 1, no. 1, pp. 14–30, 2020, doi: https://doi.org/10.31602/jk.v3i1.3594.

[6] L. Astriani, T. Y. Mulyanto, M. Bahfen, and D. Dityaningsih, "Meningkatkan Ekonomi Masyarakat Melalui Produk Kreatif dari Pengolahan Sampah Plastik," *Semin. Nas. Pengabdi. Masy. LPPM UMJ*, pp. 1–9, 2020, [Online]. Available: http://jurnal.umj.ac.id/index.php/semnaskat

[7] A. Rahman, E. R. Asrijati, and S. Rowi, "Membangun Ecoliterancy dan Penegakan Hukum Persampahan di Kabupaten Lombok Tengah," *J. Ilmu Pemerintah. Suara Khatulistiwa*, vol. VIII, no. 01, p. 97, 2023, [Online]. Available: https://ejournal.ipdn.ac.id/khatulistiwa/article/view/3365/1588

[8] F. Magno, F. Cassia, and C. M. Ringle, "A brief review of partial least squares structural equation modeling (PLS-SEM) use in quality management studies," *TQM J.*, vol. 36, no. 5, pp. 1242–1251, 2024, doi: https://doi.org/10.1108/TQM-06-2022-0197.

[9] F. H. Junianto, A. A. R. Fernandes, Solimun, and R. B. Hamdan, "Structural Equation Modeling Semiparametric in Modeling the Accuracy of Payment Time for Customers of Credit Bank in Indonesia," *JTAM (Jurnal Teor. dan Apl. Mat.*, vol. 8, no. 4, pp. 1082–1095, 2024, doi: https://doi.org/10.31764/jtam.v8i4.23668 This.

[10] T. R. Syafriana, Solimun, N. W. S. Wardhani, A. Iriany, and A. A. R. Fernandes, "Development of Nonparametric Structural Equation Modeling on Simulation Data Using Exponential Functions," *Math. Stat.*, vol. 11, no. 1, pp. 1–12, 2023, doi: https://doi.org/10.13189/ms.2023.110101.

[11] J. J. Faraway, *Extending the Linear Model with R: Generalized Linear, Mixed Effects and Nonparametric Regression Models (2nd ed)*. CRC Press, 2016.

[12] J. F. Hair, G. T. M. Hult, C. M. Ringle, M. Sarstedt, N. P. Danks, and S. Ray, *Partial Least Squares Structural Equation Modeling (PLS-SEM) Using R*. 2021.

[13] Solimun, A. A. R. Fernandes, I. Rahmawati, L. Muflikhah, F. Ubaidillah, and A. Al Rohimi, "Research on Structural Flexibility and Acceptance Model (SFAM) Reconstruction based on Disruption Innovation in the Social Humanities and Education Sector," *WSEAS Trans. Math.*, vol. 20, pp. 657–675, 2021, doi: https://doi.org/10.37394/23206.2021.20.70.

[14] M. H. Asif, T. Zhongfu, B. Ahmad, M. Irfan, A. Razzaq, and W. Ameer, "Influencing factors of consumers' buying intention of solar energy: a structural equation modeling approach," *Environ. Sci. Pollut. Res.*, vol. 30, no. 11, pp. 30017–30032, 2023, doi: https://doi.org/10.1007/s11356-022-24286-w.

[15] S. Xavier and T. L. Alexander, "Interaction and Quadratic effect on Cardio Vascular Disease : A Nonlinear Structural Equation Modeling," *Int. J. Adv. Res.*, vol. 3, no. 10, pp. 832–841, 2015, [Online]. Available: https://www.journalijar.com/article/6464/interaction-and-quadratic-effect-on-cardio-vascular-disease:-a-nonlinear-structural-equation-modeling/

[16] W. Kisworo, S. Suhardono, I. AN, and I. W. K. Suryawan, "Evaluating the Impact of Community Attitudes on the Sustainability of 3R Temporary Waste Disposal Sites Using Structural Equation Modeling-Partial Least Square (SEM-PLS) in Sukoharjo," *Nat. Environ. Pollut. Technol.*, vol. 24, no. 2, 2025, doi: https://doi.org/10.46488/NEPT.2025.v24i02.D1702.

[17] K. Ghafourian, K. Kabirifar, A. Mahdiyar, M. Yazdani, S. Ismail, and V. W. Y. Tam, "A synthesis of express analytic hierarchy process (EAHP) and partial least squares-structural equations modeling (PLS-SEM) for sustainable construction and demolition waste management assessment: The case of Malaysia," *Recycling*, vol. 6, no. 4, pp. 1–24, 2021, doi: https://doi.org/10.3390/recycling6040073.

[18] T. Tajima, K. Harada, Y. Oguma, and S. S. Sawada, "Does health literacy moderate the psychological pathways of physical activity from guideline awareness to behavior ? A multi - group structural equation modeling," *BMC Public Health*, pp. 1–13, 2023, doi: https://doi.org/10.1186/s12889-023-15012-3.

[19] S. Humberg, S. Grund, and S. Nestler, "Estimating nonlinear effects of random slopes: A comparison of multilevel structural equation modeling with a two-step, a single-indicator, and a plausible values approach," *Behav. Res. Methods*, vol. 56, no. 7, pp. 7912–7938, 2024, doi: https://doi.org/10.3758/s13428-024-02462-

9.
[20] H. Purwanto, R. Nurhasana, and A. Rohimah, "Assessing the Feasibility of Small-Scale RDF Technology in Urban Solid Waste Management Using Cost-Benefit Analysis," *Adv. Sustain. Sci. Eng. Technol.*, vol. 7, no. 3, pp. 1–15, 2025, doi: https://doi.org/10.26877/asset.v7i3.1988.
[21] E. Antriyandarti *et al.*, "Climate change mitigation through strengthening of waste bank role and 3R (reduce, reuse, recycle) application in urban area," *IOP Conf. Ser. Earth Environ. Sci.*, vol. 1253, no. 1, 2023, doi: https://doi.org/10.1088/1755-1315/1253/1/012097.
[22] M. Irfan, B. Warsito, and S. Suryono, "Waste Banks Management Information System Using K-Means Cluster Approach Based On Geographic Information System," *E3S Web Conf.*, vol. 317, 2021, doi: https://doi.org/10.1051/e3sconf /202131705019.
[23] G. C. R. Hasibuan *et al.*, "Integrating circular economy into construction and demolition waste management: A bibliometric review of sustainable engineering practices in the built environment," *Case Stud. Chem. Environ. Eng.*, vol. 11, no. October 2024, p. 101159, 2025, doi: 10.101https://doi.org/10.1016/j.cscee.2025.1011596/j.cscee.2025.101159.
[24] M. N. Azimi, M. M. Rahman, and T. Maraseni, "FinTech and circular economy: The role of institutional quality and state fragility," *J. Clean. Prod.*, vol. 525, no. September, p. 146543, 2025, doi: https://doi.org/10.1016/j.jclepro.2025.146543.
[25] F. H. Junianto, A. A. R. Fernandes, Solimun, and R. B. Hamdan, "DEVELOPMENT OF SEMIPARAMETRIC PATH ANALYSIS MODELING TRUNCATED SPLINE : DETERMINANTS OF INCREASED REGIONAL ECONOMIC GROWTH," *BAREKENG J. Math. Its Appl.*, vol. 18, no. 2, pp. 949–960, 2024, doi: https://doi.org/10.30598/barekengvol18iss2pp0949-0960.
[26] D. V. Amanda, A. Iriany, A. A. R. Fernandes, and Solimun, "ANALYSIS OF PATH NONPARAMETRIC TRUNCATED SPLINE MAXIMUM CUBIC ORDER IN BANKING CREDIT OF RISK BEHAVIOR MODEL," *BAREKENG J. Math. Its Appl.*, vol. 18, no. 4, pp. 2639–2652, 2024, doi: https://doi.org/10.30598/barekengvol18iss4pp2639-2652.
[27] A. S. Suriaslan, I. N. Budiantara, and V. Ratnasari, "Truncated spline regression for binary response: a comparative study of nonparametric and semiparametric approaches," *Commun. Math. Biol. Neurosci.*, pp. 1–22, 2025, doi: https://doi.org/10.28919/cmbn/9209.
[28] A. A. R. Fernandes and Solimun, *Analisis Regresi Dalam Pendekatan Fleksibel.* UB Press, 2021.
[29] Solimun, A. A. R. Fernandes, and Nurjannah, *Metode Statistika Multivariat Pemodelan Persamaan Struktural (SEM) Pendekatan WarpPLS.* 2017.
[30] M. F. Papalia, Solimun, and Nurjannah, "COMPARISON OF RESAMPLING EFFICIENCY LEVELS OF JACKKNIFE AND DOUBLE JACKKNIFE IN PATH ANALYSIS," *BAREKENG J. Math. Its Appl.*, vol. 17, no. 2, pp. 807–818, 2023, doi: https://doi.org/10.30598/barekengvol17iss2pp0807-0818.
[31] R. Beran, "Prepivoting A Bootstrap View of Test Statistics : Asymptotic Refinements," *J. Am. Stat. Assoc.*, vol. 82, no. 403, pp. 687–697, 1988, [Online]. Available: http://www.jstor.org/stable/2289292
[32] H. L. Shang, "Double bootstrapping for visualising the distribution of descriptive statistics of functional data," *J. Stat. Comput. Simul.*, vol. 91, no. 10, pp. 1–22, 2017, doi: https://doi.org/10.48550/arXiv.2102.01144.
[33] Solimun, A. A. R. Fernandes, Nurjannah, and L. A. Akhrani, *Rancangan Pengukuran Variabel: Angket dan Kuesioner (Pemanfaatan R).* UB Press, 2022.