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Analysis of the Influence of Household Organic Waste Management through the Utilization of Eco Enzyme and Public Awareness of Environmental Impacts

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Abstract. *The purpose of this study is to examine how waste management practices and environmental impact are affected in Wonomulyo District, Polewali Mandar Regency, by the use of eco-enzymes and organic waste management. The large amount of organic waste produced in conventional markets and the general lack of knowledge about environmental effects serve as the foundation for the study. Partial Least Squares Structural Equation Modeling (PLS-SEM) with SmartPLS 3 was used in a quantitative manner. Structured questionnaires addressing eco-enzyme, organic waste, environmental impact, and waste management factors were used to gather data from household respondents. The findings demonstrate that eco-enzyme, like organic waste management, has a favorable and noteworthy impact on waste management and environmental impact. The relationship between eco-enzyme and waste management, as well as between organic waste and waste management, is mediated by environmental impact, which also has a major impact on waste management. In order to achieve efficient and sustainable waste management, these findings emphasize the significance of combining community-based appropriate technology with increased environmental consciousness. The study's conclusions can be used as a foundation for developing regional regulations pertaining to the control of organic waste and the mitigation of climate change.*

Keywords: *Eco-Enzyme, Organic Waste, Environmental Impact, Waste Management*

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INTRODUCTION

Organic waste is one of the biggest challenges to environmental management in Indonesia. Data from the Ministry of Environment and Forestry (Riyanto et al., 2021; Farahdiba et al., 2023; Janetasari & Bokányi, 2022) shows that more than 60% of national waste generation comes from organic waste, particularly food, vegetable, and fruit scraps. This problem becomes even more complex when management is ineffective, leading to air, soil, and water pollution, as well as increasing public health risks (Fallo et al., 2024; Bouwer, 2002; Kelly & Fussell, 2015; Smith et al., 2013; Craig et al., 2008)

Wonomulyo District in Polewali Mandar Regency, West Sulawesi, is one of the areas facing serious organic waste problems. As the largest trading center in the region, Wonomulyo has a central market that produces large volumes of organic waste daily. However, a lack of management facilities, limited transportation vehicles, and low public awareness lead to waste accumulation and unpleasant odors (Muslimaini et al., 2024a). In November 2020, local media

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reports showed piles of garbage along the streets of Wonomulyo Central Market due to the lack of adequate disposal facilities. The situation worsened in January 2023, when vendors complained of a foul odor emanating from rotting fruit and vegetable scraps. This disrupted trading activities and reduced vendors' turnover (Heryawati et al., 2024).

The problem reached its peak in September 2024, when waste collection was temporarily suspended due to the lack of an active landfill. As a result, waste piled up in market areas and residential areas, triggering environmental pollution and threatening public health. This case highlights the urgency of effective organic waste management at the local level (Syarif et al., 2022). Improperly managed organic waste produces methane (CH_4), which has a global warming potential 25–30 times greater than carbon dioxide (CO_2) (IPCC, 2021). Furthermore, the resulting leachate can pollute groundwater, reduce soil quality, and endanger aquatic ecosystems (Abu-Rukah & Al-Kofahi, 2001; Fatta et al., 1999). These impacts emphasize that organic waste management is not merely a local issue but is also linked to climate change mitigation efforts. (Muslimaini et al., 2024b).

One approach being introduced is the use of eco-enzymes, a liquid produced by fermenting organic waste such as fruit and vegetable scraps with sugar and water. This product has benefits as an organic fertilizer, an environmental cleaner, and a waste decomposition agent (Susilowati et al., 2021; Gelu et al., 2025). The use of Eco Enzyme not only helps reduce the volume of organic waste but also provides added economic value (Hapsari & Sutama, 2022; Rasit et al., 2019; Ghinea et al., 2025; Gumilar et al., 2023). Various studies show that Eco Enzyme can reduce the volume of organic waste by up to 50% at the household level and improve soil and water quality (Aji et al., 2025; Maharani et al., 2024; Mukhlis et al., 2025; Yuliani et al., 2022). Countries such as Japan and Germany have integrated this fermentation method as part of their national strategies for waste reduction and climate change mitigation (Sihite, 2024; Kasiński et al., 2024; Wang et al., 2023; Ahmed et al., 2020; Langsa et al., 2024).

However, in Indonesia, research related to Eco Enzyme is still limited, generally at the laboratory or small community scale. Research that combines the technical aspects of Eco Enzyme utilization with public awareness in the context of organic waste management is still rare (Mardiana et al., 2022; Sharma et al., 2024; Sutiharni et al., 2025). The identified research gap is the lack of quantitative studies that simultaneously measure the effectiveness of Eco Enzyme in reducing household organic waste and its impact on public behavior and awareness. Most previous studies focused on product characteristic tests, without linking them to changes in waste management behavior in the community (Yusmansyah et al., 2025; Sekito et al., 2013; Concari et al., 2020).

Furthermore, no research has specifically examined the implementation of Eco Enzyme in a region with socio-economic characteristics and trade patterns like Wonomulyo. However, the local context significantly influences the success of implementing community-based waste management technology (Wikaningrum & Pratamadina, 2022; Colon & Fawcett, 2006; Challcharoenwattana & Pharino, 2018).

The novelty of this research lies in the empirical analysis that combines two important variables: the utilization of Eco Enzyme and the level of community awareness, and examines the influence of both on organic waste management and its environmental impact (Sumartono et al., 2022; Nizar et al., 2025). This research will also provide a quantitative overview of Eco Enzyme's potential to reduce household organic waste generation and map the level of community participation in environmentally friendly practices (Illahi et al., 2023). By adopting a quantitative approach and statistical analysis, the research results are expected to inform policymaking at the regional level and contribute to the academic literature on appropriate technology-based organic waste management. In addition to providing environmental benefits, this research has the potential to support the achievement of the Sustainable Development Goals (SDGs), specifically goal 11 (Sustainable Cities and Human Settlements), goal 12 (Responsible Consumption and Production), and goal 13 (Addressing Climate Change).

Based on this background, the objectives of this research are: (1) To identify the level of household organic waste management in Wonomulyo District; (2) To analyze the extent to which Eco Enzyme is utilized by the community; (3) To measure the level of public awareness of the environmental impacts of organic waste management; and (4) To examine the influence of Eco Enzyme utilization and public awareness on organic waste management and its environmental impacts.

LITERATURE REVIEW

Organic waste management is an environmental challenge that requires a multidisciplinary approach. Theoretically, community-based waste management can be explained through the Theory of Planned Behavior (TPB), which states that behavior is influenced by intentions, which in turn are determined by attitudes, subjective norms, and perceived behavioral control. In the context of household waste management, the TPB is relevant for measuring the influence of environmental awareness on waste sorting and processing behavior. In addition to the TPB, the Norm Activation Model (NAM) adds a moral dimension that motivates pro-environmental actions.

This model explains that awareness of the negative consequences of environmentally harmful behavior can activate personal norms to act. In organic waste management, awareness of environmental impacts such as pollution and greenhouse gas emissions can trigger better waste management practices. The Eco Enzyme concept itself is rooted in the principles of a circular economy, which emphasizes the reuse of resources through environmentally friendly processes. Eco Enzymes are fermented organic waste products that offer ecological and economic benefits. This product can be used as a liquid organic fertilizer, a cleaner, and even a waste decomposition agent, thus supporting the reduction of waste generation at the source.

Research by Anriawan (2025) and Astuti et al. (2026) showed that implementing Eco Enzyme at the household level can reduce organic waste volume by 40–50%. A study by Sith et al. (2019) in Japan confirmed similar benefits, including improved soil and water quality. However, quantitative evidence regarding the impact of Eco Enzyme on people's behavior in specific social contexts is still limited. Globally, several developed countries, such as Japan and Germany, have integrated organic waste fermentation technology as part of their national waste management strategies.

The OECD (2022) notes that the successful implementation of this technology is influenced by public policy support, economic incentives, and active community participation. However, in Indonesia, research related to EcoEnzymes still predominantly focuses on technical aspects, such as raw material formulation and chemical property analysis, without directly linking them to changes in community behavior. This indicates a research gap in integrating technical and social approaches to assess the effectiveness of ecoenzymes.

Previous research also indicates that the level of community environmental awareness influences the success of community-based waste management programs (KLHK, 2023). However, no research model has simultaneously measured the relationship between ecoenzyme utilization, community awareness, and organic waste management outcomes. Furthermore, most studies have not considered contextual variables such as socio-economic conditions, the availability of waste management infrastructure, and local consumption patterns.

These factors are particularly relevant in areas like Wonomulyo District, which has the unique characteristics of being a trading center with a high volume of organic waste generation. The conceptual framework in this study combines the variables of Eco Enzyme utilization and environmental awareness as predictors of organic waste management outcomes. This relationship is analyzed using a quantitative approach to measure both direct and indirect influences. This study also positions the perceived benefits of Eco Enzyme as a mediating variable, which can strengthen the relationship between environmental awareness and waste management practices.

Thus, the proposed model can explain the psychological and social mechanisms that drive waste management behavior based on appropriate technology. Evaluation of previous research results shows that technical interventions without a behavior change approach are often less effective in the long term. Therefore, the integration of these two approaches is expected to produce a more sustainable management model. The novelty of this research lies in the integration of technical and social analysis in studying Eco Enzyme, and its focus on the context of traditional markets like Wonomulyo, which present unique challenges and opportunities. This approach has not been widely explored in Indonesian or international literature.

By addressing this research gap, this study is expected to provide theoretical contributions to the development of community-based organic waste management models, while also providing practical recommendations for regional policy. The developed conceptual framework will serve as the basis for designing research instruments, analyzing data, and drawing conclusions relevant to the research objectives. This model combines independent variables (Eco Enzyme utilization, environmental awareness), dependent variables (organic waste management outcomes), and mediating variables (perceived benefits). Thus, this literature review not only summarizes the theories and results of previous research, but also builds a solid conceptual foundation to support the empirical analysis that will be carried out.

METHODS

Research Design

The research design was a quantitative research design where the Partial Least Squares Structural Equation Modeling (PLS-SEM) methodology with the help of SmartPLS 3 software was used. The use of quantitative design was found reasonable due to the research purpose that entails hypothesis testing and quantifying the level of impact between various latent constructs, i.e. eco-enzyme utilization, organic waste management, environmental impact and public awareness. The PLS-SEM was selected specifically in comparison with covariance-based SEM because it can be used in complex models with mediating variables, is applicable in exploratory research, and is more robust in the case where data distribution could be not in the normality. Besides, since the research on eco-enzime use is new in the Indonesian setting, PLS-SEM was a suitable method of analysis to conduct assessment on measurement validity and structural interrelationship.

Population and Sample

The study population was based on households in Wonomulyo District in Polewali Mandar Regency, West Sulawesi. The district was deliberately chosen due to its socio-economic characteristics as a regional trading center, which produces an unevenly large amount of organic waste, especially on conventional markets and in terms of household food consumption. This context is especially applicable to the research of eco-enzyme practices effectiveness and the influence of the public awareness on the development of waste management behavioral patterns. I used purposive sampling sample method where the inclusion criteria included (1) that a household was engaged in any kind of organic waste management practice, or (2) a household had had pre-exposure to eco-enzyme practice methods either through community-based programs or informal household-based experiments. This was a way of ensuring that the respondents were in the right position of giving meaningful answers based on experience and knowledge.

Data Collection Procedures

The survey was carried out by means of a structured questionnaire between [insert month/year]. The survey tool was to be used through personal administration where trained enumerators visited the sampled homes. Face-to-face administration was selected to minimize the chances of non-response bias, clarify ambiguous items where required, and to enhance the reliability of answers. The respondents were well informed on the objectives and their rights as participants before they filled the questionnaire. They were assured that they were not obliged to participate, that their identities will not be disclosed and that all information they will provide will be confidential. Data were collected with an informed consent. Enumerators were trained on methods of conducting the survey and ethical standards to increase the accuracy of the results and reduce the error margin of measurement. The administration process occupied around [insert time] minutes per household and this was deemed to be reasonable enough to administer to the respondents without them feeling survey fatigue. It was also the procedure that guaranteed increased completion rates and decrease in missing data, which is important in quantitative SEM-based studies.

Research Instrument

The research tool was a structured questionnaire created by modifying and combining questions used by previous researchers on the use of eco-enzymes, management of household waste, and environmental awareness (Astuti et al., 2025). The tool was constructed in a manner that operationalized four broad constructs, Eco-Enzyme Utilization (X1), Organic Waste Practices (X2), Environmental Impact (Z), and Waste Management Behavior (Y). Each construct was recorded in terms of five indicators. In case of eco-enzyme, the frequency of production, use modes and benefits in the household were examples of indicators of eco-enzyme use. The practices on organic waste were evaluated using waste segregation, reduction and disposal practices. Environmental impact was quantified by household perceptions of the reduction of pollution, control of odors, the quality of soil and water and the perception of greenhouse gas emissions. Indicators of waste management behavior were sorting, composting, recycling, and attending to joint waste management programs. Measurement was done on a five-point Likert scale with 1 (strongly disagree) to 5 (strongly agree) with the ability to give subtle measurements of attitudes and behaviors. In order to achieve clarity and contextual aptitude, the instrument was tested on a small sample size of [insert number] households in Wonomulyo. The pilot feedback led to making some changes in ambiguous wording and enhancing cultural appropriateness. The final questionnaire form had acceptable face validity, whereby the items were sufficient to measure the constructs of interest.

Data Analysis

The data gathered were examined by Partial Least Squares Structural Equation Modeling (PLS-SEM) with SmartPLS 3. The analysis was done in accordance with the two steps. First of all, the measurement model (outer model) was tested to determine whether there was indicator reliability, construct reliability, convergent validity, and discriminant validity. In particular, factor loading, Cronbachs alpha, composite reliability (CR) and average variance extracted (AVE) were measured. The Fornell-Larcker criterion and cross-loading were used to test the discriminant validity. The measures taken in these steps were the measurement of the latent constructs with minimal error and separation among them. Second, structural model (inner model) was undertaken to test hypothesized relationships between variables. Path coefficients were compared as a method of identifying the strength and direction of influence among constructs. The explanatory power of the model was measured using the coefficient of determination (R 2) with cut-offs of 0.75, 0.50 and 0.25 indicating substantial, moderate and weak explanatory power of the model, respectively. In order to measure the importance of direct and indirect effects, bootstrapping of 5,000 resamples was performed which provided t-statistics and p-values to test hypotheses. This intensive process presented sound support to the conceptual framework.

Ethical Considerations

The research followed the ethics of a study. The participants were made well aware of the purpose of the study and the voluntary aspect of the study and their right to discontinue the study at any point without repercussion. No personal identifiers were captured in the data and anonymity was ensured. The data was saved in a safe location and were used on academic purposes only. The research received ethical consent of [insert institution or ethics committee] and followed the requirements of institutions as well as national regulations regarding handling research with human subjects.

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RESULTS AND DISCUSSION

Reflective Construct Measurement Model Test (Outer Model)

The measurement model aims to represent the relationship between constructs and their corresponding indicator variables (commonly referred to as the outer model in PLS-SEM). The measurement model explains how the construct is measured and is reliable, valid, and reliable by examining convergent validity, discriminant validity, and construct reliability. The outer model in SmartPLS is as follows:

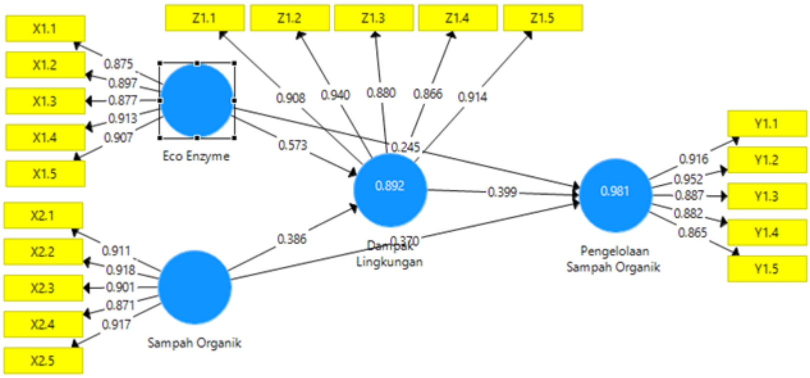

Figure 1. Outer Model of Research in SmartPLS 3

The degree to which a construct's measurements should be substantially correlated is the validity test for reflective constructs. The loading factor value for each construct indicator shows how well a reflective construct passes the validity test. As a general rule, the average extracted value (AVE) must be larger than 0.5 and the standard loading factor value must be 0.7 or above. According to Diamantopoulos & Winklhofer (2001), a high loading factor suggests that the construct's indicators share a lot of similarities and, as a result, have the same meaning. The loading factor and AVE results for each indicator are as follows.:

Table 2. Initial Test of Reflective Construct Validity

Variables	Dimensions	AVE	Information
Eco Enzyme	X1.1	0,875	0,7993
	X1.2	0,897	
	X1.3	0,877	
	X1.4	0,913	
	X1.5	0,907	
Organic Waste	X2.1	0,911	0,8168
	X2.2	0,918	
	X2.3	0,901	
	X2.4	0,871	
	X2.5	0,917	
Environmental Impact	Y1.1	0,916	0,8115
	Y1.2	0,952	
	Y1.3	0,887	
	Y1.4	0,882	
	Y1.5	0,865	
Organic Waste Management	Z1.1	0,908	0,8133
	Z1.2	0,940	
	Z1.3	0,880	
	Z1.4	0,866	
	Z1.5	0,914	

Source: SmartPLS Output 3, 2025

Generally speaking, when removing indicators from the scale results in higher composite reliability and average variance extracted (AVE) values, those with outer loadings between 0.40 and 0.70 should be eliminated. In the meanwhile, the construct should not include indicators with extremely low outer loadings (below 0.40). It can be inferred that all indicators have satisfied the rule of thumb because the outside loadings are much above the AVE value and far from 0.4. As a result, there is no need to reestimate or remove signs.

Disability Validity

The degree to which a construct is actually different from other constructs according to empirical standards is known as discriminant validity. A construct is said to have discriminant validity if it is distinct and captures phenomena that other constructs in the model do not. Each variable's cross-loading value needs to be more than 0.70 in order to evaluate discriminant validity with a reflective construct. The results of discriminant validity are displayed in the following table.

Table 3. Cross Loading Values

	X1_Eco Enzyme	**X2_ Organic Waste**	**Y_ Waste Management**	**Z_ Environmental Impact**
X1.1	0,875	0,752	0,846	0,880
X1.2	0,897	0,833	0,863	0,828
X1.3	0,877	0,872	0,868	0,810
X1.4	0,913	0,871	0,875	0,833
X1.5	0,907	0,862	0,859	0,826
X2.1	0,864	0,911	0,878	0,836
X2.2	0,848	0,918	0,894	0,844
X2.3	0,853	0,901	0,855	0,806
X2.4	0,818	0,871	0,850	0,833
X2.5	0,852	0,917	0,896	0,851
Y1.1	0,848	0,933	0,916	0,867
Y1.2	0,919	0,926	0,952	0,911
Y1.3	0,889	0,808	0,887	0,854
Y1.4	0,810	0,874	0,882	0,895
Y1.5	0,879	0,811	0,865	0,837
Z1.1	0,761	0,759	0,812	0,908
Z1.2	0,913	0,905	0,942	0,940
Z1.3	0,875	0,752	0,846	0,880
Z1.4	0,834	0,921	0,913	0,866
Z1.5	0,819	0,807	0,844	0,914

The table above shows that the correlation value of one construct's indicators is higher than that of the other constructs. Furthermore, the cross-loading value for each construct indicator meets the recommended value of 0.70. These results indicate that the data has good discriminant validity. Another method to test the discriminant validity of reflective constructs is to compare the square root of the AVE for each construct with the correlation between constructs in the model. Good discriminant validity is indicated by the square root of the AVE for each construct being greater than the squared correlation with other constructs. The results of the discriminant validity test are shown in the following table:

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Table 4. Fornell-Larcker criterion

	X1_Eco Enzyme	X2_ Organic Waste	Y_ Waste Management	Z_ Environmental Impact
X1	0,894			
X2	0,937	0,904		
Y	0,965	0,968	0,901	
Z	0,935	0,923	0,969	0,902

Table 5. AVE Values and AVE Roots

	X1_Eco Enzyme	X2_ Organic Waste	Y_ Waste Management	Z_ Environmental Impact
X1	0,894			
X2	0,937	0,904		
Y	0,965	0,968	0,901	
Z	0,935	0,923	0,969	0,902

Based on the data in Tables 1.4 and 1.5, it can be concluded that the AVE root for all constructs is higher than the correlation between constructs, so it is stated that all variables in this study have good discriminant validity.

Reliability Test

To demonstrate the instrument's accuracy, precision, and consistency in measuring the construct, reliability testing is carried out. Cronbach's alpha and composite reliability are two methods for assessing dependability. It is advised to employ composite reliability when testing a construct instead of Cronbach's alpha, as the latter will lead to an underestimate. Generally speaking, a construct's composite reliability value needs to be higher than 0.7 in order to be considered reliable. Because it shows how accurately, consistently, and precisely an instrument measures a reality, a construct needs to be dependable. The outcomes of the composite reliability values in the table below are as follows:

Table 6. Composite Reliability Values

	X1_Eco Enzyme	X2_ organic waste	Y_ Waste management	Z_ Environmental impact
X1	0,894			
X2	0,937	0,904		
Y	0,965	0,968	0,901	
Z	0,935	0,923	0,969	0,902

Source: SmartPLS 3 output

According to the findings in the above table, all constructions had composite reliability values more than 0.7, with the work engagement variable indicating the lowest value at 0.894. Consequently, it can be said that every construct in this study satisfies the reliability test and is trustworthy.

Results of the Structural Model Test (Inner Model)

Assessing the structural model (inner model) is the next stage in analyzing the PLS-SEM results once the measurement model (outer model) has produced results that are satisfactory. The theoretical model (the theoretical relationship between exogenous and endogenous constructs) is supported by the structural model.

The coefficient of determination, or R-squared value

The degree to which external constructs explain endogenous constructs is shown by the R-squared value. The R-squared number is used to assess a structural model's prediction ability. A

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robust model is indicated by a value of 0.75, a moderate model by a value of 0.50, and a weak model by a value of 0.25. The table below displays the R-squared value results.:

Table 7. R-Square Value

	R Square	Adjusted R Square
Waste management	0,981	0,980
Environmental impact	0,892	0,890

The Waste Management variable has an R-square value of 0.981, according to the data processing results in the above table. This indicates that the Eco-Enzyme Organic Waste construct can account for 98% of the Waste Management variable. With an R-squared value of 0.892, the Environmental Impact variable may then be described by the Eco-Enzyme Organic Waste construct with an 89% explanation rate. Based on these findings, it can be said that the structural model test (inner model) results for the performance and work engagement variables fall into the "strong" model category.

Results of Hypothesis Testing

The next test is to use the bootstrapping process to determine the influence of factors on path coefficients or to determine the relevance of the proposed relationship between components. The size of the T-statistic value is then determined using the bootstrapping output.

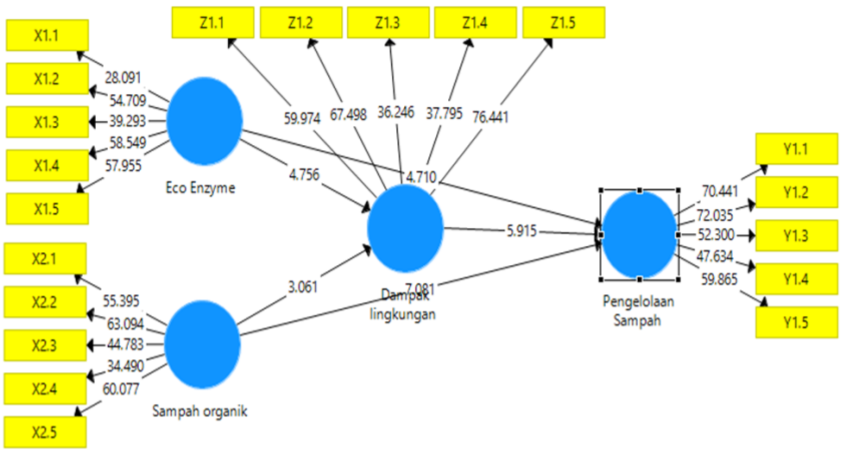

Figure 2. Research Construct Relationship Model Using the Bootstrapping Method

Direct Effect

The idea that an exogenous influencing variable directly influences an endogenous influenced variable can be tested with the use of direct impact analysis. The table below displays the outcomes of the data processing:

Table 8. Direct Effect Results

	Original Sample (O)	Sample Mean (M)	Standard Deviation (STDEV)	T Statistics (| O/STDEV |)	P Values
X1 -> Y	0,245	0,253	0,054	4,537	0,000
X1 -> Z	0,573	0,572	0,117	4,879	0,000
X2 -> Y	0,370	0,364	0,057	6,502	0,000
X2 -> Z	0,386	0,386	0,122	3,163	0,002
Z -> Y	0,399	0,397	0,071	5,652	0,000

Source: SmartPLS 3 outputX1= Eco Enzyme; X2=Organic Waste; Z=Environmental Impact; Y=Waste Management

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To ascertain the link between variables, the path coefficient test findings in the following table can be understood by looking at the original sample values. The degree of significance of the link between variables is assessed using the T-statistic. This study's hypothesis testing yielded a t-table of 2.0025 with a significance level of 5% (two-tailed) and a 95% confidence level. The outcome is significant if the T-statistic value exceeds the t-table value. Two of the five hypotheses based on the test data in the above table are accepted. The outcomes of the hypothesis testing for every construct are as follows: (1) EcoEnzyme's path coefficient on waste management is 0.245, with a P-value of 0.000 and a t-statistic of 4.537. Given that the P-value is less than 5% (0.000 <0.05), it can be said that EcoEnzyme significantly and favorably affects waste management.

Hypothesis 1 (H1) is so approved; (2) EcoEnzyme's path coefficient on environmental impact is 0.573, with a P-value of 0.000 and a t-statistic of 4.879. Given that the P-value is less than 5% (0.000 <0.05), it can be said that EcoEnzyme significantly and favorably affects environmental impact. Hypothesis 2 (H2) is so approved; (3) With a t-statistic of 6.502 and a P-value of 0.000, the organic waste path coefficient on waste management is 0.370. Given that the P-value is less than 5% (0.000 <0.05), it can be said that organic waste significantly and favorably affects waste management. Hypothesis 3 (H3) is so approved; (4) With a t-statistic of 3.163 and a P-value of 0.000, the path coefficient of organic waste on environmental impact is 0.386. Given that the P-value is less than 5% (0.000 <0.05), it can be said that organic waste significantly and favorably affects the environment. Hypothesis 4 (H4) is so approved; (5) The t-statistic value is 3.163, the P value is 0.000, and the route coefficient value for the environmental impact on waste management is 0.386. Waste management is positively and significantly impacted by the environmental impact, as indicated by the P value of less than 5% (0.000 <0.05). The conclusion that follows is that hypothesis 5 (H5) is accepted.

Indirect Influence

The notion that exogenous variables have an indirect impact on endogenous variables through intervening variables that is, variables that mediate the impact of exogenous variables on endogenous variables was tested using indirect effect analysis. The following table displays the path coefficients from the SmartPLS 3 test.

Table 9. Results of Direct Influence

	Original Sample (O)	Sample Mean (M)	Standard Deviation (STDEV)	T Statistics (| O/STDEV |)	P Values
X1 -> Z -> Y	0,229	0,225	0,052	4,430	0,000
X2 -> Z -> Y	0,154	0,156	0,064	2,409	0,016

Sumber: Output SmartPLS

Description X1=Eco Enzyme; X2=Organic Waste; Z=Environmental Impact; Y=Waste Management

With a t-statistic of 4.43 and a P-value of 0.000, Eco Enzyme's path coefficient on waste management through environmental impact is 0.229. Given that the P-value is less than 5% (0.000 <0.05), it can be said that Eco Enzyme significantly and favorably affects waste management through its impact on the environment. This indicates that the relationship between Eco Enzyme and waste management may be mediated by environmental impact. Hypothesis 6 (H6) is so approved. The environmental impact of organic waste on waste management has a t-statistic of 2.409, a P-value of 0.016, and a path coefficient of 0.154. Given that the P-value is less than 5% (0.000 <0.05), it can be said that organic waste significantly and favorably affects waste management through its effects on the ecosystem. This indicates that the interaction between organic waste and waste management may have an environmental impact, with environmental

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impact serving as a mediating variable. The conclusion that follows is that hypothesis 7 (H7) is accepted.

The current research proves that the application of eco-enzymes and organic waste procedures can considerably enhance the management of waste in households in Wonomulyo. Nevertheless, closer analysis of the findings shows some significant details. Eco-enzime has a direct impact on waste management, although that impact is large (= 0.245), it is quite small compared to the indirect effect through environmental impact (= 0.229). It implies that almost half of the eco-enzyme effect does not work by its technical effect in isolation but by the perception of environmental improvement by households. Likewise organic waste practices have direct effects (4) and indirect effects (2.154), with the indirect channels constituting nearly a third of the overall effect. These results emphasize the fact that sustainable waste management is more than a technical adoption, but rather a highly interrelated phenomenon with awareness, perception, and reinforcement of behavior. The extremely large R2 (0.981 wastage management and 0.892 environmental impact) indicate that the model accounts a disproportionately large percentage of variance, which is uncharacteristic of behavioral and social science studies. Although this shows a good fit in the context, it also creates methodological concerns regarding potential overfitting, overlapping of constructs or amplifying effects that are context-specific. Such a two-sided interpretation of strength of the model on the one hand and risk of inflation on the other must be handled with care, not to overclaim.

Theoretical Integration and Critical Reflection (Expanded)

The results of this research offer a unique contribution to environmental behavior theories, especially, the Theory of Planned Behavior (TPB) and the Norm Activation Model (NAM). TPB assumes that attitudes, subjective norms, and perceived behavioral control influence behavior whereas NAM emphasizes the mobilization of personal moral norms by the personal conscience awareness and responsibility attribution. The findings of this area indicate that the practice of eco-enzymes overlays both models, indicating that in scenarios of acute environmental stress, eco-enzymes models may be complementary, but not competing. Considering the approach based on TPB, eco-enzyme enhances the perceived behavioral control because it makes waste management easier (odor control, faster decomposition, less necessity to use formal collection). It also improves attitudes since it offers economic and aesthetic co-benefits (fertilizer production, cleaner household surroundings). Notably, the subjective norms are reinforced indirectly by eco-enzyme using the community groups and the markets because the households increasingly see that eco-enzyme is a widespread commodity and accepted socially.

Regarding NAM, eco-enzyme makes people more conscious of the consequences since its effects are apparent and instantaneous: people can smell the decrease in odor, see cleaner lawns and fewer pests. The awareness promotes the application of personal norms, which promotes long-term waste management habits. The NAM pathway of environmental perception in this analysis exemplifies precisely this mediating effect of environmental perception: households will follow and maintain eco-enzyme practices not necessarily because they are easy, but because they find it morally obligatory when they realize the environmental payoffs. Theoretically, it implies that the technical interventions may be used as norm-activations. Attitudes and norms are considered to be antecedents of behavior in traditional models. In this case, it seems that behavior (eco-enzyme practice) and perception (environmental improvement) enhance each other in a feedback mechanism: the slightest behavioral changes can trigger the visible changes, which, in turn, triggers norms and reinforces subsequent behavior.

This dynamic suggests a possible expansion of TPB and NAM to a sustainability context: technical innovations cannot be viewed as exogenous to the behavioral setting but as combined cues to behavior change that can modify perceptions and normative commitments. This questions the dichotomy that is dominant in the literature between technological measures (in terms of efficiency and waste treatment capacity) and behavioral measures (in terms of education and awareness). Wonomulyo evidence indicates that this kind of division is unnatural. As a matter of

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fact technology and awareness are co-constitutive: eco-enzyme is not merely a decomposing agent but also a psychological and normative catalyst. This observation enriches theoretical knowledge relevant to the capacity of low-cost, visible technologies to establish themselves as part of the social-psychological processes, generating enduring pro-environmental behaviours in resource-limited environments.

Comparison and Critique of Past Studies (Extended)

These results are in line with previous studies which show that eco-enzyme has the technical potential to diminish the level of organic waste. Much of the available literature is, however, highly technocentric. Research tends to focus on the laboratory tests of the quality, chemical composition, or agricultural applicability of the eco-enzyme (Illahi et al., 2023), but seldom considers the behavioral, social, and situational aspects of adoption. This renders a research gap in which eco-enzyme is considered a product and not a component of a socio-technical system. The present study bridges this gap directly by demonstrating that eco-enzyme has an impact on waste management via environmental awareness as an intermediating variable, and repackages eco-enzyme as a technical, as well as a behavioral, intervention.

Moreover, past eco-enzyme work in Indonesia has generally been described as small-scale community projects (Heryawati et al., 2024; Muslimaini et al., 2024a), and in many cases has not been subjected to rigorous statistical analysis. Although such researches can be helpful in giving insights on feasibility, they lack explanatory capacity to ascertain whether adoption of eco-enzymes would translate into behavioral change that is measurable. Through the application of PLS-SEM, the given study provides a quantitative theory-based analysis that transcends the description of the issue. It is a methodological rigor that makes it possible to, in addition to ensuring the technical clarity of eco-enzyme, to show its psychological and normative effect, which is a rather overlooked aspect of the previous studies.

Meanwhile, this paper also casts major questions to the preceding findings. Such high values of R 2 (0.981 and 0.892) indicate that the causes of waste management and environmental perceptions almost entirely can be attributed to the eco-enzyme and organic waste practices. Conversely, other behavioral-environmental researches seldom record a R 2 more than 0.60 (Lopez & Cuasialpud-Canchala, 2025). Such a dissimilarity can suggest that earlier research unduly downplayed the potential of eco-enzyme due to their failure to capture the contextual prominence of waste management failures in crisis prone environments such as Wonomulyo where failure of waste management systems form powerful motivation on alternative interventions. But it can also lack methodological quality as there is overlaps between constructs, common method variance, or homogeneity in samples that can overstate explained variance. In contrast to earlier contributions which report the positive eco-enzyme results without a second thought, this article predicts such dangers which makes it add to the more skeptical and critical view of the eco-enzyme promise.

The second complaint about the earlier research is that it tends to generalize the benefits of eco-enzyme by not paying much attention to the local socio-economic and cultural environments. The outcomes here are contrary to what the research in urban Indonesia (Mardiana et al., 2022) presumes about the homogeneity of adoption potential. The urgency of waste issues, the observability of environmental payoffs, and the social networks of markets and households are the reasons that eco-enzyme adoption is highly affected in Wonomulyo. Such contextual drivers might not be available in more urban or better-serviced regions, and the issue of transferability of results between contexts may be in question. This paper reveals that eco-enzyme should be analyzed on its own socio-economic situation and the author argues that claims made about the one-size-fits-all nature of these assertions are inappropriate in this situation.

In conclusion, although prior studies have already proven the technical potential of eco-enzyme, it has seldom considered it as a behavioral stimulant and challenged its situational constraints. This paper confirms the usefulness of eco-enzyme, and challenges simplistic accounts, demonstrating that its performance lies in its dynamic capacity to be both technically

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useful and environmentally perceived as well as local socio-cultural circumstances. Under the acute waste crisis in Wonomulyo, a good eco-enzyme adoption ground is presented; however, the outcome may not be representative of other less-impacted areas. The intensity of waste issues such as the odor, threats to their health, inability to use the collection systems probably increases the responsiveness of households to interventions. In part, this contextual aspect clarifies the extraordinarily high explanatory power of the model. Nevertheless, it also poses major questions: would eco-enzyme behavior have a similar leverage in cities with more well-developed waste infrastructure? Or is its effectiveness very much dependent on situations in which formal systems have failed? By placing eco-enzyme in the context of the socio-economic environment of Wonomulyo, the paper highlights the importance of context sensitive waste management policies, as opposed to blanket solutions.

Although the study is both informative on theory and practice, there are limitations that should be considered seriously. First, the use of self-reported data of the surveys implies the risks of common method bias and social desirability bias. The respondents can exaggerate the environmental friendliness practices because of cultural values. Second, cross-sectional design constrains the causal statements- it may imply the direction, but one cannot completely prove it. Third, the high values of R 2 which are impressive in their own right provide the concern of overfitting and indicates a possibility of the constructs to measure overlapping dimensions. Conclusions should be handled carefully without further robustness tests (e.g. collinearity diagnostics), PLSpredict tests). The identification of these limitations enhances the validity of the results and indicates definite directions regarding the methodological improvement of the work in the future.

CONCLUSION

All of the hypotheses put out in this study were shown to be true based on the path analysis results. The application of Eco Enzyme not only improves the efficiency of organic waste management but also lessens adverse environmental effects, as evidenced by the first study's favorable and significant effects on waste management (H1) and environmental impact (H2). Second, organic waste had a significant and positive impact on environmental impact (H4) and waste management (H3), suggesting that better organic waste management has a direct effect on environmental conditions. Third, waste management was positively and significantly impacted by environmental impact (H5), suggesting that enhancing environmental quality can support community waste management practices. Environmental effect also functioned as a significant intermediary variable, according to the mediation analysis. trash management via environmental impact was positively and significantly impacted by the usage of Eco Enzyme (H6), while trash management through environmental impact was positively and significantly impacted by organic waste (H7). All things considered, these results demonstrate that using Eco Enzyme and organic waste treatment, both directly and by enhancing environmental impact, are significant, mutually supporting elements in attaining more sustainable and efficient waste management. By showing how Eco Enzyme and organic waste play a dual role as both a technical factor and a catalyst for improvements in environmental management practices, this research model adds to the body of knowledge.

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