



GRDP Per Capita and Waste Generation in Indonesia: Incorporating Regional Heterogeneity and Policy Interaction Analysis

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Article Info:

Article history:

Received: June 23, 2026

Revised: August 07, 2026

Accepted: August 12, 2026

Available Online: September 25,
2026

Keywords:

GRDP Per Capita; Jakstrada;
Sustainable Development; Two-
Way Fixed Effects; Waste
Management Policy; Waste
Generation



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Abstract

Background: Economic growth, reflected by an increase in GRDP per capita, may stimulate consumption activities and contribute to higher waste generation. However, this relationship can differ across regions depending on waste management capacity and policy implementation.

Objective: This study examines the relationship between GRDP per capita and waste generation at the district/city level in Indonesia by considering the moderating role of the Regional Waste Management Policy Strategy (*Jakstrada*).

Methods: This study employed panel data covering Indonesian districts/cities during 2019–2024 and estimated the model using the Two-Way Fixed Effects approach. Robustness checks were conducted through mean centering of interaction variables to assess the consistency of the findings.

Results: The estimation results indicate that GRDP per capita does not significantly affect waste generation in the baseline model. However, after incorporating *Jakstrada* as a moderating variable, the relationship becomes significant, showing that higher GRDP per capita is associated with increased waste generation. The negative and significant interaction coefficient demonstrates that *Jakstrada* weakens the tendency of waste generation growth associated with economic expansion. Further analysis indicates a potential nonlinear relationship between economic growth and waste generation. Robustness tests confirm the consistency of the coefficient direction and statistical significance.

Conclusion: The findings highlight the importance of regional waste management policies in ensuring that economic growth is accompanied by sustainable environmental management. Strengthening policy implementation can help reduce the environmental pressures arising from economic development.

To cite this article: Putri, A. D., & Soetjipto, W. (2026). GRDP per capita and waste generation in Indonesia: Incorporating regional heterogeneity and policy interaction analysis. *INKUBIS: Jurnal Ekonomi dan Bisnis*, 8(3), 2502-2515. <https://doi.org/10.59261/inkubis.v8i3.397>

INTRODUCTION

Waste generation has developed into one of the global environmental problems and is receiving increasing attention along with increasing economic activity, urbanization processes, and changes in people's consumption patterns (Lu et al., 2024; Nugroho et al., 2026; Voukkali et al., 2024). These dynamics encourage an increase in the amount of waste produced in various regions of the world (Yudartha et al., 2026). Based on the *What a Waste 2.0* report published by the World Bank in 2018, the total global waste generation was recorded at around 2.01 billion tons per year, with more than a third of it not being adequately managed and environmentally sound in 2016.

Countries with higher income levels, which despite accounting for only about 16% of the

world's population, tend to produce larger waste per capita that is almost 34% of total global waste. For low-income countries that account for 9% of the world's population, it generates only about 5% of total global waste. Overall waste generation has a positive relationship with economic growth (Kaza et al., 2018). When income increases gradually, the amount of waste produced by the community tends to increase. However, the speed of the increase in waste varies, depending on the level of income of the community. In low-income regions or countries, even a slight increase in ordinary income causes a considerable spike in waste generation. This happened because people began to shift from basic needs (simple meals, durable goods) to modern consumer goods that use more single-use packaging. As a result, the volume of waste increases rapidly (Zambrano-Monserrate et al., 2021). In contrast, at higher income levels, an increase in income is not always followed by a significant spike in waste generation, as consumption tends to reach a saturation point as well as being supported by more efficient consumption practices and better waste management systems (Maalouf & Mavropoulos, 2023).

At the national level, the waste problem in Indonesia is increasingly complex in line with the wide economic growth gap between regions (Iacovidou et al., 2025; Maskun et al., 2025; Wikurendra et al., 2024). The difference in GRDP per capita between districts/cities also forms different consumption patterns, where areas with higher economic activity tend to produce larger volumes of waste, especially from the household and trade sectors (Jovanca & Shara, 2025).

The increase in Gross Regional Domestic Product (GRDP) per capita in various districts/cities not only shows an improvement in people's welfare, but also has an impact on environmental conditions. Based on data from the National Waste Management Information System (SIPSN), the number of national waste generation has been recorded at more than 25 million tons per year since 2019 (Hartoyo, H., 2025).

The difference in waste generation between districts/cities in Indonesia is not only caused by differences in population, but also by variations in income levels, economic structure, urbanization levels, and waste management capacity. Some areas with high GRDP per capita, especially big cities and centers of economic activity, show higher rates of waste generation than areas with lower economic activity. Although higher levels of regional income generally encourage an increase in waste generation, the presence of adequate management policies and facilities has been shown to significantly reduce the rate of waste generation (Mazzanti & Zoboli, 2009; Ratnadewati & Juvitasari, 2024). This condition indicates that the relationship between GRDP per capita and waste generation is not simple, but is influenced by policy and institutional factors at the regional level.

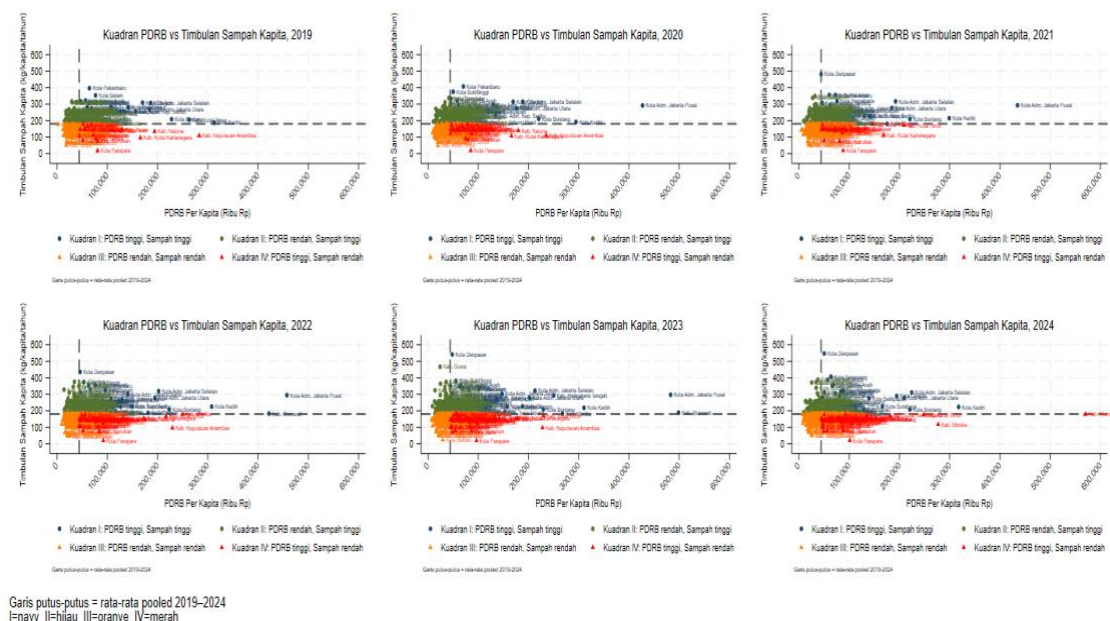


Figure 1. Scatter Plot Distribution of GRDP per Capita and Waste Generation Across Indonesian Districts/Cities, 2019–2024

The results of the quadrant analysis on the scatterplot of the relationship between GRDP

per capita and regency/city waste generation in Indonesia for the period 2019–2024 show a diverse distribution pattern and reflect the heterogeneity of economic conditions and waste management capacity between regions. Based on the median value of GRDP per capita and median waste generation as the dividing line, all districts/cities are grouped into four quadrants, each of which has different characteristics.

The visualization of the four quadrants confirms that the level of economic prosperity (GRDP per capita) is not the only determining factor in controlling waste generation in Indonesia. The existence of variations in regional economic structures, demographic disparities due to urbanization, and regional fiscal capacity inequality cause the dynamics of waste to be very complex (Aqilah, 2025). The empirical reality of these four quadrants provides a foundation for urgency why policy instruments such as Regional Waste Management Policies and Strategies (Jakstrada) are urgently needed as a moderation variable. These policies are needed to carry out structural interventions so that regions in Indonesia can break the linear relationship between the level of economic prosperity and environmental damage towards sustainable development targets.

In addition, based on the EPI (Environmental Performance Index) report in 2024, it is noted that waste management in Indonesia is still the worst in ASEAN, especially for solid waste management. Waste management efforts do not only focus on downstream management aspects, but also require intervention on the upstream side through changes in consumption patterns and increasing the efficiency of resource use to suppress waste formation from the beginning.

Several empirical studies show that the level of economic prosperity represented by GRDP or GRDP per capita is closely related to an increase in waste generation, although the strength and direction of these relationships vary between country and regional contexts. Studies in developed countries generally show that an increase in per capita income is followed by an increase in income Municipal Solid Waste (MSW), but the relationship is not mechanical and is strongly influenced by the social characteristics, urbanization level, and the policy framework of the waste management applied. In some cases, countries or regions with high income levels are actually able to reduce the growth rate of waste generation through the implementation of stricter environmental regulations, integrated waste management systems, and changes in people's consumption behavior (Akther et al., 2025; Blagoeva et al., 2023; Fauzi et al., 2025; Jovanca & Shara, 2025). This indicates that per capita income is not the only determining factor for waste generation, but interacts with institutional factors and applicable public policies.

On the other hand, Indonesia still faces various challenges in waste management and plastic recycling. The OECD (2025) notes that Indonesia's plastic recycling rate in 2022 is still around 5%, while the rate of mismanaged waste reaches 72%. Mismanaged waste is a condition when waste is not managed safely, for example being disposed of carelessly, burned openly, or not entering the formal management system so that it has the potential to pollute the environment. This condition shows that the waste collection, sorting, and processing system in Indonesia is still not optimal compared to developed countries. In addition to limited infrastructure, low rates of waste separation from sources, weak policy enforcement, and high dependence on the informal sector are also challenges in improving sustainable waste management in Indonesia. Therefore, strengthening waste management policies and increasing the implementation of the circular economy is important to support environmental sustainability in Indonesia.

However, most previous research has focused on cross-country or national-level analysis by relying on macro variables such as GRDP per capita, so it has not fully captured the dynamics of heterogeneity between regions within a country. In the context of Indonesia, which has a high variation in regional development levels, analysis at the district/city level is important to understand the relationship between the level of regional economic prosperity and waste generation more specifically. Therefore, by shifting the focus of research to the district/city level and using GRDP per capita as an indicator of regional economic prosperity, as well as including Jakstrada as a moderation variable, this research is expected to fill the existing research gap. This approach allows for empirical testing of the extent to which regional waste management policies play a role in strengthening or weakening the influence of per capita income on waste generation, thereby making an empirical and policy contribution that is relevant to sustainable waste management in Indonesia. This study further contributes by integrating subnational panel

evidence with a policy moderation framework, allowing the analysis to move beyond the assumption that economic growth produces uniform environmental consequences across regions.

The placement of regulations as a moderation variable in this study is since the relationship between per capita income and waste generation is not always linear, but is influenced by institutional capacity and policy effectiveness at the regional level. In this context, the existence of Regional Waste Management Policies and Strategies (Jakstrada) is an important instrument that functions not only as a technical guideline for waste management, but also as an intervention mechanism that is able to direct the impact of increasing per capita income so that it does not directly increase waste generation uncontrollably. Without strong and implementing regulations, an increase in economic activity has the potential to drive a significant increase in waste consumption and production. On the other hand, regions that have a commitment to good waste management policies through Jakstrada tend to be able to control and even suppress the growth rate of waste generation despite experiencing economic improvement. In addition, including Jakstrada as a moderation variable is a form of novelty in this study, because it allows a more comprehensive analysis in seeing how public policies play a role as a strengthening or weakening factor in the relationship between per capita income and waste generation.

This study aims to obtain empirical evidence on the phenomenon of waste management at the district/city level in Indonesia by analyzing the relationship between GRDP per capita and waste generation per capita, and examining the role of Jakstrada policy as a moderation variable in this relationship. Through this analysis, the research is expected to be able to make a theoretical contribution in enriching environmental economics studies, especially related to how per capita income and waste generation are influenced by public policies. Practically and policyly, the results of this research are projected to be an empirical reference for local governments to evaluate the effectiveness of Jakstrada, as well as provide strategic input for relevant ministries and institutions in formulating stronger synergies between economic development and sustainable waste management. The novelty of this research lies in positioning Jakstrada as an institutional mechanism that conditions the economic–environmental relationship rather than merely treating waste policy as a descriptive background factor.

Frame of Mind

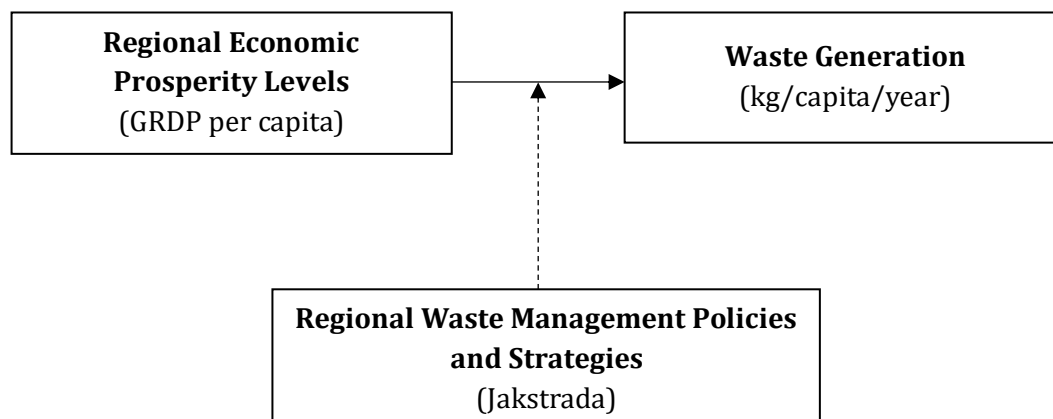


Figure 2. Research Framework

Research Hypothesis

Based on the framework of thought and the analysis model used, the research hypothesis is formulated as follows.

H1: GRDP per capita has a positive relationship with the generation of waste per capita in districts/cities in Indonesia.

H2: Regional policies and strategies for waste management (Jakstrada) moderate the relationship between GRDP per capita and waste generation per capita in districts/cities in Indonesia.

METHOD

This study employed an explanatory quantitative method to analyze the relationship

between economic and environmental variables at the district/city level in Indonesia. This approach was chosen because it enabled the empirical testing of relationships between variables using numerical data and statistical analysis techniques. Using this approach, the influence of GRDP per capita on waste generation could be measured objectively, while also evaluating whether the existence of Regional Policies and Strategies for Waste Management (Jakstrada) affected the strength of the relationship between the two variables. The focus of this study was to examine the influence of GRDP per capita on waste generation and to determine whether the existence of the Jakstrada Policy functioned as a moderating factor affecting the relationship between the two variables.

The panel structure was specifically designed to control for unobserved, time-invariant characteristics across districts/cities and common temporal shocks through district and year fixed effects.

This study employed a panel data approach that combined two dimensions: the cross-sectional dimension of regional units and the time dimension. The data analyzed included several districts/cities that were observed repeatedly over several observation periods. This approach offered advantages over the use of cross-sectional and time-series data separately because it was able to capture variations both across regions and over time.

The object of this study was waste generation at the district/city level in Indonesia. Waste generation was defined as the amount of waste generated by the activities of residents in an area over a specified period. The research subjects included all districts/cities in Indonesia with complete and consistent data for the variables under study during the observation period. Regencies/cities were selected as the units of analysis because local governments had direct authority over waste management, including the preparation and implementation of the Jakstrada.

The variables examined in this study were waste generation, GRDP per capita, Jakstrada, population (population density), school-age population, number of waste banks, and expenditure per capita.

This study employed panel data regression using a Two-Way Fixed Effects approach as the main analytical technique. To analyze the relationship between regional economic activity and waste generation, the study included GRDP per capita and its squared term as explanatory variables in the regression model. The inclusion of the squared term was intended to accommodate the possibility of a non-linear relationship between per capita income and waste generation, in line with the theoretical proposition known in the environmental economics literature as the Environmental Kuznets Curve (EKC).

The estimation procedure was complemented by robustness testing using mean-centering of the interaction variables to examine the consistency of the moderation effects and reduce potential multicollinearity concerns.

RESULTS AND DISCUSSION

Results

Estimated Results

Table 1

Estimation Results of the Two-Way Fixed Effects (TWFE) Model and Jakstrada Moderation
Dependent Variable: $\ln(\text{Capita Waste Generation})$

Variables	(1) Model 1	(2) Model 2	(3) Model 3: Moderation
$\ln(\text{GRDP per Capita})$	1.351 (2.398)	1.871 (2.571)	4.838* (2.530)
$\ln(\text{GRDP per Capita})^2$	-0.046 (0.117)	-0.072 (0.125)	-0.206 (0.124)
Jakstrada Policy		-0.031 (0.051)	
$\ln(\text{Population Density})$		-0.009 (0.018)	0.002 (0.016)
$\ln(\text{Number of Waste Banks})$		0.008	0.010

	(0.008)	(0.007)	
ln(Per Capita Expenditure)	-0.772	-0.890	
	(0.824)	(0.794)	
Mean Years of Schooling	-0.051	-0.055	
	(0.069)	(0.070)	
Jakstrada Policy		35.001***	
		(11.218)	
Jakstrada Policy × ln(GRDP per Capita)		-6.479***	
		(2.070)	
Jakstrada Policy × [ln(GRDP per Capita)] ²		0.298***	
		(0.095)	
Constant	-4.006	1.164	-14.062
	(12.371)	(13.550)	(13.022)
Year FE	Yes	Yes	Yes
District FE	Yes	Yes	Yes
Observations	570	570	570
R-Squared	0.025	0.043	0.075

Note: The dependent variable in all models is the natural logarithm of capita waste generation (ln (Capita Waste Generation)). Standard errors are reported in parentheses. All models apply district/city fixed effects, while Models (1) and (2) additionally include year fixed effects.

Statistical significance is indicated by * $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$.

In Model 1, the relationship seen is still the most basic, namely the relationship between GRDP per capita and waste generation per capita. From the estimated results, the linear coefficient of GRDP has a positive value of 1.351, while the squared coefficient has a negative value of -0.046. In a directional way, these results still lead to an inverted-U pattern that is in line with the Environmental Kuznets Curve (EKC) hypothesis, where in the early stages, the increase in income tends to be followed by an increase in waste generation, but at higher income levels the rate of increase begins to slow down. However, the two coefficients are not statistically significant, so the basic relationship between GRDP per capita and waste generation cannot be firmly identified in the simplest model. This does not mean that the economic-waste relationship does not exist, but rather indicates that the relationship may not be homogeneous across regions.

In Model 2, this study began to add Jakstrada as a variable that stands alone with GRDP and control variables. Mathematically, this model can be written as:

$$\begin{aligned} \ln(\text{Per capita waste generation}_{it}) \\ = \beta_0 + \beta_1 \ln(\text{GRDP per kapita}_{it}) + \beta_2 [\ln(\text{GRDP per kapita}_{it})^2] + \sum \beta_4 Z_{it} + \alpha_i \\ + \delta_t + \varepsilon_{it} \end{aligned}$$

with is a dummy Jakstrada. J

Model 3 is the real crux of moderation testing. Mathematically, this model can be written as:

$$\begin{aligned} \ln(\text{Per capita waste generation}) \\ = \beta_0 + \beta_1 \ln(\text{GRDP per kapita}_{it}) + \beta_2 [\ln(\text{GRDP per kapita}_{it})^2] \\ + \beta_3 \text{Jakstrada}_{it} + \beta_4 [\ln(\text{GRDP per kapita}_{it}) \times \text{Jakstrada}_{it}] \\ + \beta_5 ([\ln(\text{GRDP per kapita}_{it})^2] \times \text{Jakstrada}_{it}) + \beta_6 \ln(X_{it}) + \alpha_i + \delta_t + \varepsilon_{it} \end{aligned}$$

Based on the estimated results, the equation becomes:

$$\begin{aligned} \ln(\text{Per capita waste generation}) \\ = -14,062 + 4,838X - 0,206X^2 + 35,001J - 6,479(JX) + 0,298(JX^2) + \sum \beta_4 Z_{it} \\ + \alpha_i + \delta_t + \varepsilon_{it} \end{aligned}$$

The results of the estimation show that the ln coefficient (GRDP per capita) in the basic condition is 4.838 and the squared coefficient is -0.206. In addition, the main or most important result is the interaction coefficient of Jakstrada × ln (GRDP per capita) of -6.479 and the interaction coefficient of Jakstrada × ln(GRDP per capita)² of 0.298 and both are significant. This means that Jakstrada has completely changed the relationship between GRDP per capita and waste generation, or it can be said that the economic influence on waste is not the same between regions that have Jakstrada and regions that do not have Jakstrada. These findings indicate that policy

capacity determines whether economic expansion translates into greater environmental pressure, supporting the argument that institutional interventions are essential in sustainable development pathways.

For areas without Jakstrada, the interaction component is missing and the equation becomes: ($J = 0$)

$$\ln(\text{Per capita waste generation}) = -14,062 + 4,838X - 0,206X^2 + \sum \beta_4 Z_{it}$$

This means that in areas that do not have a Jakstrada, the increase in GRDP per capita is still related to the increase in waste generation, but the relationship is not linear because the squared coefficient is negative. Its marginal derivatives are:

$$\frac{\partial \ln(TS)}{\partial X} = 4,838 - 0,412X$$

The equation shows that in areas that do not have a Jakstrada, the influence of GRDP per capita on waste generation is not constant. The magnitude of the influence depends on the level of GRDP per capita owned by the region. The initial coefficient of 4.838 indicates that at low-income levels, the increase in economic activity is still related to the increase in waste generation. However, the coefficient shows that the influence is weakening as income levels increase. $-0,412X$

As for the region with Jakstrada, the equation becomes: ($J = 1$)

$$\ln(\text{Per capita waste generation}) = (-14,062 + 35,001) + (4,838 - 6,479)X + (-0,206 + 0,298)X^2 + \sum \beta_4 Z_{it}$$

So:

$$\ln(\text{Per capita waste generation}) = 20,939 - 1,641X + 0,092X^2 + \sum \beta_4 Z_{it}$$

Its marginal derivatives change into:

$$\frac{\partial \ln(TS)}{\partial X} = -1,641 + 0,184X$$

Robustness Check

Table 2

Robustness Check Results Using Mean-Centering Dependent Variable: $\ln(\text{Capita Waste Generation})$

Variables	(1) Model 1	(2) Model 2	(3) Model 3: Moderation
Centered GRDP per Capita	0.409 (0.284)	0.388 (0.280)	0.579** (0.275)
Centered (GRDP per Capita) ²	-0.046 (0.117)	-0.072 (0.125)	-0.206 (0.124)
Jakstrada Policy	—	-0.031 (0.051)	—
$\ln(\text{Population Density})$	—	-0.009 (0.018)	0.002 (0.016)
$\ln(\text{Number of Waste Banks})$	—	0.008 (0.008)	0.010 (0.007)
$\ln(\text{Per Capita Expenditure})$	—	-0.772 (0.824)	-0.890 (0.794)
Mean Years of Schooling	—	-0.051 (0.069)	-0.055 (0.070)
Jakstrada Policy	—	—	-0.097* (0.054)
Jakstrada Policy $\times$ Centered GRDP per Capita	—	—	-0.311*** (0.115)
Jakstrada Policy $\times$ Centered (GRDP per Capita) ²	—	—	0.298*** (0.095)
Constant	5.094*** (0.082)	12.842* (7.633)	13.936* (7.353)

Year FE	Yes	Yes	Yes
District FE	Yes	Yes	Yes
Observations	570	570	570
R-squared	0.025	0.043	0.075

Standard errors in parentheses. All models use Fixed Effects (district/city). Models (1)-(2) include year fixed effects. * $p < 0.10$, ** $p < 0.05$, $p < 0.01$

In Model 1, the GRDP coefficient per capita of the mean-centering result remained positive at 0.409, while the coefficient squared of GRDP per capita remained negative at -0.046. Although the value of the linear coefficient changes compared to the main model, the direction of the relationship formed remains the same.

In Model 2, the estimation results also show a pattern that is identical to the main model. The GRDP coefficient per capita remained positive at 0.388, the squared coefficient remained negative at -0.072, while the Jakstrada coefficient remained negative at -0.030.

In Model 3, the moderation model is the focus of the research. After mean-centering, the interaction coefficient between Jakstrada and GRDP per capita remained negative and significant at -0.311, while the interaction coefficient between Jakstrada and the square of GRDP per capita remained positive and significant at 0.298.

Analysis of Regency and City Heterogeneity

Table 3

Results of Regency and City Heterogeneity Analysis Heterogeneity of Regency and City: ln(Per Capita Waste Generation)

Variables	(1) Cities: Moderation	(2) No Regencies: Moderation	(3) No Cities: Moderation	(4) Regencies: Moderation
ln(GRDP per Capita)	7.836*** (2.521)	-1.088 (8.679)	9.487* (4.833)	5.604 (11.960)
ln(GRDP per Capita) ²	-0.321*** (0.108)	0.057 (0.432)	-0.394* (0.209)	-0.255 (0.594)
Jakstrada Policy	0.085 (0.051)	-0.067 (0.067)	—	—
ln(Population Density)	-0.010 (0.013)	0.002 (0.024)	-0.008 (0.015)	-0.001 (0.020)
ln(Number of Waste Banks)	0.005 (0.009)	0.008 (0.010)	0.006 (0.010)	0.012 (0.010)
ln(Per Capita Expenditure)	-0.552 (1.488)	-1.087 (0.971)	-0.539 (1.470)	-1.265 (0.791)
Mean Years of Schooling	0.033 (0.089)	-0.114 (0.088)	0.035 (0.090)	-0.116 (0.084)
Jakstrada Policy	—	—	18.976 (33.793)	79.637 (67.824)
Jakstrada Policy × ln(GRDP per Capita)	—	—	-3.404 (6.088)	-15.166 (13.404)
Jakstrada Policy × [ln(GRDP per Capita)] ²	—	—	0.153 (0.273)	0.720 (0.662)

Constant	-36.821** (13.721)	21.100 (46.242)	-46.276** (22.162)	-13.038 (62.348)
Year FE	Yes	Yes	Yes	Yes
District FE	Yes	Yes	Yes	Yes
Observations	198	372	198	372
R-squared	0.182	0.046	0.186	0.113

Notes: Standard errors are reported in parentheses. All models include district and year fixed effects. Columns (1) and (3) use the city subsample; columns (2) and (4) use the regency subsample. * $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$.

Source: Author's Edited Results, 2026

The heterogeneity analysis demonstrates that the EKC pattern is more evident in cities than in regencies. Cities exhibit a statistically significant inverted-U relationship between GRDP per capita and waste generation, both before and after accounting for the moderating role of Jakstrada. In contrast, no statistically significant EKC pattern is found in regencies. Moreover, the insignificant interaction terms indicate that Jakstrada does not significantly moderate the relationship between economic development and waste generation in either district type. Overall, these findings reveal heterogeneity in the economic development–waste generation relationship across local administrative contexts, while evidence of Jakstrada as a significant moderator remains limited at the disaggregated level.

Discussion

Estimation Results of the Two-Way Fixed Effects (TWFE) Model and Jakstrada Moderation

From the estimated results, the $\ln$ coefficient (GRDP per capita) increased to 1.871 and the squared coefficient to -0.072, but both are still not significant. The Jakstrada coefficient of -0.031 is also not significant. This means that the existence of Jakstrada at this level has not shown a strong direct difference in waste generation when viewed as an average effect. Substantively, this shows that when other factors have been controlled, the existence of Jakstrada has not been immediately seen as a difference in the average generation of waste between regions. In other words, Jakstrada at this stage has not worked primarily as a factor that directly reduces waste, but only as a variable that needs to be further tested whether it changes the relationship between GRDP and waste.

This insignificance requires careful interpretation, where in environmental econometrics, this result does not necessarily mean that the Environmental Kuznets Curve (EKC) relationship does not exist in Indonesia, but rather indicates the existence of extreme regional heterogeneity and structural variation between regions that hold back the estimated average effect. Akther et al. (2025) assert that the determinants of urban waste generation often fail to show uniform linear significance at the macro level due to disparities in technological capacity and governance at the local level that are in stark contrast to each other. This condition is reinforced by Abae (2025) which states that regions within a country often do not show homogeneous waste management behavior due to differences in the path of regional economic prosperity.

In the context of this study, Jakstrada was included in Model 2 because it represents aspects of waste management policies that can affect how GRDP per capita is translated into environmental impact. Panayotou (1997) also showed that better policies and institutions can slope the EKC curve and accelerate the improvement of environmental quality, thus theoretically supporting the addition of the Jakstrada variable in the analysis. In simple language, Panayotou lays the groundwork that economic effects on the environment can differ depending on the quality of the policies involved.

Therefore, the weak significance of Models 1 and 2 methodologically provides a strong theoretical justification for the importance of including local policy and institutional variables as conditioning *factors*. The relationship between GRDP per capita and waste generation in developing countries cannot move mechanically and automatically follows the EKC hypothesis, but must be intervened by regulatory instruments in the future (Ari & Şentürk, 2020). This empirical fact confirms the urgency of including the interaction variable of the Regional Waste Management Policy and Strategy (Jakstrada) in Model 3.

Model 3 is not a mere technical addition, but rather a logical response to two mutually reinforcing findings, namely, first, the insignificance of the GRDP coefficient per capita in Models 1 and 2 which indicates a heterogeneity of parameters that has not been captured, and second, a quadrant distribution pattern that empirically shows that areas with equivalent GRDP per capita can generate significantly different waste generation. The insignificance of the relationship between GRDP per capita and waste generation in Model 1 indicates that GRDP per capita alone is not enough to explain the variation in waste generation. The relationship is likely influenced by other factors that determine how economic activity translates into an increase or decrease in waste generation. In the study of solid waste dynamics, Ari & Şentürk (2020) affirms that the relationship between economic output growth and environmental degradation cannot be allowed to proceed mechanically without intervention. Regulations and formal institutional commitments are necessary as a controlling instrument to suppress the negative externalities of people's economic activities. Therefore, as explained in the study of Akther et al. (2025), the failure of pure economic models in capturing the significance of data is often caused by the absence of local governance variables that function as conditioning factors in the field. This argument is reinforced by the findings.

In areas that already have a Jakstrada, the pattern of relationships has changed significantly. The initial coefficient becomes negative at -1.641, which indicates that at a given income level, an increase in economic activity is no longer automatically followed by an increase in waste generation. In other words, the existence of Jakstrada changes the sensitivity of waste generation to GRDP per capita.

This change shows the magnitude of the Jakstrada's moderation. The linear coefficient, which was originally 4.838 changed to -1.641, so that the existence of Jakstrada reduced the influence of GRDP per capita on waste generation by -6.479 points. Meanwhile, the squared coefficient changes from -0.206 to 0.092, which means that the shape of the nonlinear relationship also changes. In other words, Jakstrada is not just about minimizing economic influence, but about changing the way GRDP per capita is translated into waste generation.

The Jakstrada dummy coefficient of 35.001 needs to be read carefully. In the interaction model, this coefficient indicates the level difference at the reference point, but is not the core of the moderation. The essence of moderation lies precisely in the significant interaction coefficient, because that coefficient shows that the relationship between GRDP and waste generation is indeed different between regions that have and those that do not have a Jakstrada. Thus, the results of this study show that regional waste management policies work as a conditioning factor that weakens the relationship between GRDP per capita and waste generation.

After the interaction coefficient, the marginal effect analysis clarifies that the influence of GRDP per capita on waste generation is indeed different according to the status of the Jakstrada. In areas without Jakstrada, the marginal effect of GRDP per capita on waste generation is still positive and relatively larger, while in areas that have a Jakstrada, the marginal effect decreases and tends to be smaller. This difference shows that the existence of Jakstrada weakens the sensitivity of waste generation to GRDP per capita. In other words, when the regional waste management policy has been running, additional economic activities will no longer translate into additional waste generation in the same amount as in regions that do not have a Jakstrada.

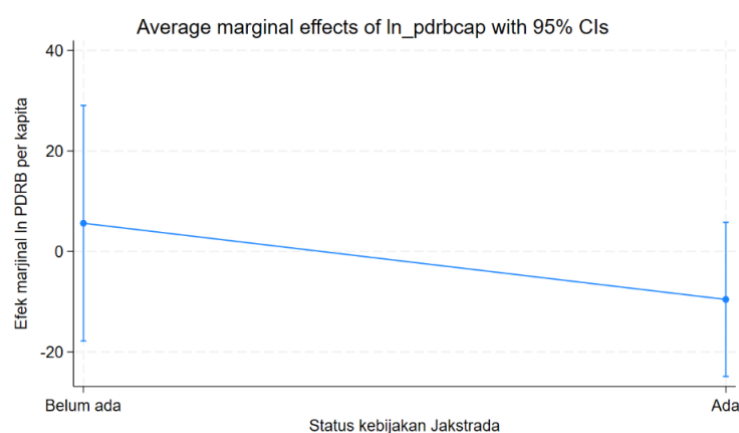


Figure 3. Average Marginal Effect of GRDP per Capita in the Condition of Existence and Absence of Jakstrada

Source: Author's Edited Results, 2026

Figure 3 shows that the average marginal effect (GRDP per capita) on waste generation differs according to the policy status of the Jakstrada. In areas that do not have a Jakstrada, the marginal effect of GRDP per capita is positive at 4.838. This shows that the increase in economic activity is still related to the increase in waste generation. On the other hand, in areas that already have Jakstrada, the marginal effect decreased to a negative value of -1.641. This change of direction shows that the existence of Jakstrada has succeeded in reducing the sensitivity of waste generation to GRDP per capita.

To complete the interpretation of the interaction coefficient and marginal effect, an analysis was carried out predictive margins as shown in Figure 4. In contrast to average marginal effects which focuses on changes in the slope of the relationship, predictive margins show how the prediction of waste generation changes at several levels of GRDP per capita according to the policy status of the Jakstrada. Thus, this graph provides a more intuitive picture of the substantive implications of the moderation results obtained in Model 3.

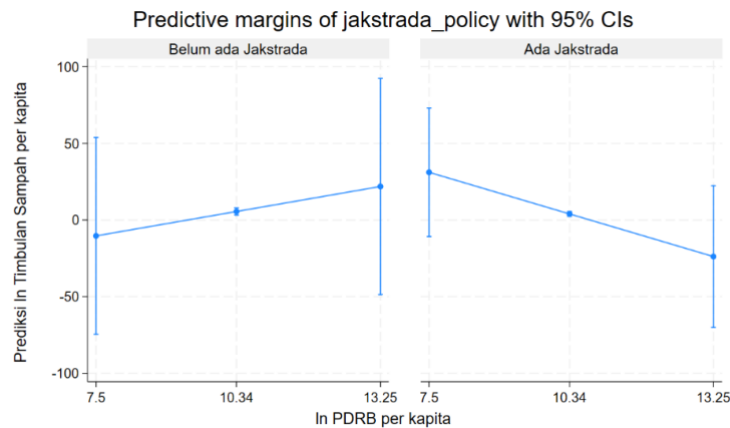


Figure 4. Prediction of the Relationship between GRDP per Capita and Waste Generation in Conditions Before and After Jakstrada

Source: Author's Edited Results, 2026

On the left panel, it can be seen that when the ln (GRDP per capita) increases from around 7.5 to 13.25, the prediction of ln (per capita waste generation) increases from around -9 to about 18, meaning that in areas that do not have a Jakstrada, the increase in economic activity is still related to a considerable increase in waste generation. Visually, the positive slant of the line shows that the increase in GRDP per capita still translates into increased pressure on the regional waste system. The higher the level of regional income, the greater the prediction of waste generation produced when the region does not have adequate waste management policy instruments.

The right panel shows a different pattern. When ln (GRDP per capita) increases from about 7.5 to 13.25, the prediction of ln (per capita waste generation) decreases from about 10 to close to 0. In areas that already have a Jakstrada, the increase in economic activity is no longer followed by an increase in waste generation in the same amount. The existence of Jakstrada changes the relationship between GRDP per capita and waste generation so that the increase in income no longer results in additional waste generation as much as that occurs in areas without Jakstrada.

Overall, the results of the study show that GRDP per capita does not automatically result in an increase in waste generation with the same pattern in all regions. The insignificance of the relationship in the basic model indicates that the relationship between the economy and waste generation is conditional and influenced by regional characteristics. When regional policy factors are considered through the Jakstrada, the relationship changes significantly, suggesting that regional waste management policies play a role as a conditioning factor that affects how GRDP per capita translates into environmental pressures. Thus, the findings of this study provide empirical evidence that the existence of Jakstrada not only functions as a waste management instrument,

but also as an institutional mechanism that is able to weaken the relationship between GRDP per capita and waste generation. These findings are an important basis for the formulation of policy recommendations that will be discussed in the next chapter.

Robustness Check

In Model 1, the GRDP coefficient per capita of the mean-centering result remained positive at 0.409, while the coefficient squared of GRDP per capita remained negative at -0.046. Although the value of the linear coefficient changes compared to the main model, the direction of the relationship formed remains the same. These results show that the mean-centering transformation does not change the basic pattern of the relationship between GRDP per capita and waste generation. Substantively, the relationship still leads to a nonlinear pattern in the shape of an inverted-U, i.e. the increase in income in the early stages of development tends to be followed by an increase in waste generation, while at higher income levels the rate of increase begins to slow down. This consistency shows that the initial indication of the existence of the EKC pattern found in the main model is not due to the measurement scale of the GRDP per capita variable, but rather comes from the relationship structure contained in the data.

In Model 2, the estimation results also show a pattern that is identical to the main model. The GRDP coefficient per capita remained positive at 0.388, the squared coefficient remained negative at -0.072, while the Jakstrada coefficient remained negative at -0.031. There was no change in the direction of the coefficient or a change in substantive conclusions after mean-centering was carried out. These findings show that the relationship between GRDP per capita, Jakstrada's policies, and waste generation remains stable even though the reference points of economic variables are changed to their average values. In other words, the results of the estimates in Model 2 are not sensitive to independent variable scale transformations.

In Model 3, the moderation model is the focus of the research. After mean-centering, the interaction coefficient between Jakstrada and GRDP per capita remained negative and significant at -0.311, while the interaction coefficient between Jakstrada and the square of GRDP per capita remained positive and significant at 0.298. The consistency of the direction and significance of the two interaction coefficients showed that the main conclusions of the study did not change after the variable transformation was performed. Thus, the finding that Jakstrada moderates the relationship between GRDP per capita and waste generation persists in both the main model and the mean-centered model.

Substantively, these results have an important meaning. In the main model, the existence of Jakstrada has been proven to change the relationship between GRDP per capita and waste generation. The same result appears again after the economic variable is changed to a centered form. Since the moderation effect remains significant in both model specifications, it can be concluded that the role of Jakstrada is not a result that arises due to certain mathematical characteristics of the GRDP variable, but rather reflects the empirical relationship that is contained in the data. In the context of this study, these results strengthen the argument that the existence of regional waste management policies does indeed play an institutional role as an institutional factor that affects how GRDP per capita is translated into waste generation.

Overall, robustness checks using mean-centering showed that the entire model maintained the same relationship pattern as the main estimate. In Model 1 and Model 2, the direction of the relationship between variables remained consistent after the transformation. In Model 3, the Jakstrada interaction coefficient remained significant in the same direction as in the main model. Therefore, the results of the study can be stated to be robust to changes in model specifications, so that the main conclusion regarding the role of Jakstrada as a moderator variable that weakens the relationship between GRDP per capita and waste generation remains valid and reliable.

Analysis of Regency and City Heterogeneity

The results of estimating the influence of GRDP per capita on capita waste generation by separating the analysis between regencies and cities. In the model without moderation, it was found that GRDP per capita in urban areas has a positive and significant coefficient, while the quadratic variable of GRDP per capita has a negative and significant coefficient. These results indicate that the increase in GRDP per capita in urban areas is still going hand in hand with the

increase in household consumption and the use of consumer goods that produce waste and the relationship between GRDP per capita and capita waste generation in cities is nonlinear in the shape of an inverted U-shape.

Overall, the results of the heterogeneity analysis show that the relationship between GRDP per capita and waste generation is more pronounced in urban areas than districts. Cities with higher rates of urbanization, consumption, and economic activity show a positive and nonlinear relationship between GRDP per capita and capita waste generation. On the other hand, in the districts the relationship is not significant due to the more diverse economic characteristics and the dominance of the primary sector. On the other hand, this study has not found evidence that the existence of Jakstrada is able to moderate the relationship between GRDP per capita and waste generation in both cities and districts. The findings indicate that the existence of policies does not necessarily reflect the effectiveness of implementation and shows that economic and urbanization factors are still the main determinants of waste generation at the regional level. The existence of policy documents is not necessarily followed by the provision of waste management infrastructure, institutional strengthening, and effective changes in community behavior.

CONCLUSION

This study confirms that GRDP per capita does not automatically result in an increase in waste generation by the same amount in all regions. What determines precisely how this growth is managed through public policy, institutional capacity, and regional context. In this case, Jakstrada has been proven to play a role as a conditioning factor that weakens the relationship between GRDP per capita and waste generation.

ACKNOWLEDGEMENT

The authors sincerely express their gratitude to all institutions and individuals who contributed to the completion of this study. Special appreciation is extended to the institutions responsible for providing access to regional statistical and waste management data, including publicly available data from Statistics Indonesia (BPS), the National Waste Management Information System (SIPSN), and other relevant government agencies whose datasets made this analysis possible. The authors also acknowledge the valuable insights and constructive feedback from colleagues and academic reviewers that helped improve the quality of this manuscript throughout the research and writing process.

The authors are grateful to Universitas Indonesia for providing academic support and a conducive research environment during the preparation of this study. Although this research did not receive any specific grant from funding agencies in the public, commercial, or not-for-profit sectors, the authors appreciate all forms of institutional and professional support that contributed to the successful completion of this research.

AUTHOR CONTRIBUTION STATEMENT

Aristawidya Dwi Putri contributed to the conceptualization of the study, research design, data collection, data curation, formal analysis, interpretation of results, visualization, and preparation of the original manuscript draft. Widyono Soetjipto contributed to the research supervision, methodological refinement, validation of the analytical approach, interpretation of findings, critical review of the manuscript, and editing of the final version. Both authors discussed the results, contributed substantially to the intellectual content of the manuscript, approved the final version for publication, and agreed to be accountable for all aspects of the work.

REFERENCES

- Abae, I., Royali, A. S., & Pustaka, D. (2025). *Ekonomi Regional: Dinamika Ketimpangan, Integrasi Daerah, dan Inovasi Daerah*. Detak Pustaka.
- Akther, A., Tahrim, F., Voumik, L. C., Esquivias, M. A., & Pattak, D. C. (2025). Municipal solid waste dynamics: Economic, environmental, and technological determinants in Europe. *Cleaner Engineering and Technology*, 24, 100877. <https://doi.org/10.1016/j.clet.2024.100877>
- Aqilah, N. S. (2025). *Dinamika Urbanisasi dan Dampaknya terhadap Kondisi Sosial Ekonomi dan Lingkungan di Kota Palembang*. SOSIAL DEMOGRAFI.
- Ari, I., & Şentürk, H. (2020). The relationship between GDP and methane emissions from solid

- waste: A panel data analysis for the G7. *Sustainable Production and Consumption*, 23, 282–290. <https://doi.org/10.1016/j.spc.2020.06.004>
- Blagoeva, N., Georgieva, V., & Dimova, D. (2023). Relationship between GDP and Municipal Waste: Regional Disparities and Implication for Waste Management Policies. *Sustainability*, 15(21), 15193. <https://doi.org/10.3390/su152115193>
- Fauzi, A. R., Putra, F. A., Alfajar, R., Afdallah, M. F., Purwaningsih, V. T., & Aida, N. (2025). Pengaruh Kependudukan, Perekonomian Regional, dan Pembangunan Manusia terhadap Lingkungan: Tantangan dan Peluang bagi Pembangunan Kota Berkelanjutan. *Diponegoro Journal of Economics*, 14(1), 53–65. <https://doi.org/10.14710/djoe.50691>
- Hartoyo, H., Putra, A., Fahmi, A., & Nurkodri, M. S. (2025). Analysis of the Effect of Gross Regional Domestic Product and Regional Expenditure on Local Own-Source Revenue in Jambi City. *Jurnal Prajaiswara*, 6(2), 540–553.
- Iacovidou, E., Gerassimidou, S., Ebner, N., Webster, M., Whyte, A., Jobling, S., ... & Cordova, M. R. (2025). System-wide analysis of the plastics value chain in Indonesia: The five levels of information. *Journal of Circular Economy*, 3(1).
- Jovanca, A. W. A., & Shara, A. R. I. D. (2025). Pengaruh Pertumbuhan Ekonomi dan Urbanisasi terhadap Krisis Sampah di Daerah Istimewa Yogyakarta. *Media Komunikasi Geografi*, 26(1), 137–148. <https://doi.org/10.23887/mkg.v26i1.96363>
- Kaza, S., Yao, L. C., Bhada-Tata, P., & Woerden, F. Van. (2018). What a Waste 2.0: A Global Snapshot of Solid Waste Management to 2050. In *Urban Development, World Bank*. Washington, DC: World Bank. <https://doi.org/10.1596/978-1-4648-1329-0>
- Lu, M., Zhou, C., Wang, C., Jackson, R. B., & Kempes, C. P. (2024). Worldwide scaling of waste generation in urban systems. *Nature Cities*, 1(2), 126–135.
- Maalouf, A., & Mavropoulos, A. (2023). Re-assessing global municipal solid waste generation. *Waste Management & Research: The Journal for a Sustainable Circular Economy*, 41(4), 936–947. <https://doi.org/10.1177/0734242X221074116>
- Mazzanti, M., & Zoboli, R. (2009). Municipal Waste Kuznets curves: Evidence on socio-economic drivers and policy effectiveness from the EU. *Environmental and Resource Economics*, 44(2), 203–230. <https://doi.org/10.1007/s10640-009-9280-x>
- Maskun, M., Naswar, N., Normiati, N., Mukhlis, M. M., & Wiranti, W. (2025). Harmonization between National Policy and Regional Regulations in Solid Waste Management in Indonesia: A Normative-Empirical Legal Analysis. *Jambura Law Review*, 7(2), 726–765.
- Nugroho, S. S., Dewi, R. C. K., Yitawati, K., & Chairani, M. A. (2026, January). PENGELOLAAN SAMPAH BERBASIS FILOSOFI ENVIRONMENTAL ETHIC MEWUJUDKAN ZERO WASTE. In *Prosiding Seminar Nasional Multidisiplin Merdeka (SEMMAR) Tahun 2025* (Vol. 2, No. 1, pp. 143–151).
- Ratnadewati, A., & Juvitasari, D. A. (2024). Adaptasi Ekonomi Sirkular Terhadap Reduksi Timbulan Sampah di Kapanewon Kabupaten Bantul: Analisis Data Panel dan Spasial. *Jurnal Riset Daerah*, 24(2), 64–76. <https://doi.org/10.64730/jrdbantul.v24i2.114>
- Voukkali, I., Papamichael, I., Loizia, P., & Zorpas, A. A. (2024). Urbanization and solid waste production: prospects and challenges. *Environmental Science and Pollution Research*, 31(12), 17678–17689.
- Wikurendra, E. A., Csonka, A., Nagy, I., & Nurika, G. (2024). Urbanization and benefit of integration circular economy into waste management in Indonesia: A Review. *Circular Economy and Sustainability*, 4(2), 1219–1248.
- Yudhartha, I. P. D., Suwitri, S., & Yuwono, T. (2026). Dinamika Implementasi Kebijakan Pengaturan Pengelolaan Sampah di Kota Denpasar Provinsi Bali. *Bina Hukum Lingkungan*, 10(3), 495–515.
- Zambrano-Monserrate, M. A., Ruano, M. A., & Ormeño-Candelario, V. (2021). Determinants of municipal solid waste: a global analysis by countries' income level. *Environmental Science and Pollution Research*, 28(44), 62421–62430. <https://doi.org/10.1007/s11356-021-15167-9>