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Research Article

Relevance of the Environmental Kuznets Curve (EKC) Theory in the Context of Urban Waste Generation

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Abstract

This study examines the empirical relationship between economic growth and municipal solid waste (MSW) generation in Bali, Indonesia, within the framework of the Environmental Kuznets Curve (EKC) hypothesis. Employing a quantitative ex post facto design, the research utilizes panel data regression to analyze historical data from nine districts over a five-year period, assessing whether increasing income levels contribute to reduced waste generation after a certain threshold. Model diagnostics, including the Chow, Hausman, and Lagrange Multiplier (LM) tests, were conducted using EViews 12 to ensure robustness. The findings reveal a U-shaped relationship, contrary to the traditional inverted-U pattern predicted by the EKC. The coefficient for GRDP per capita is negative but statistically insignificant, whereas the squared GRDP term is positive and significant, suggesting that waste generation rises after reaching an income threshold of approximately IDR 15.7 million per capita per year. To enhance model precision, population and hotel room variables were included as proxies for demographic and tourism pressures, respectively. Model selection tests identified the Random Effects Model (REM) as the most appropriate specification. Interestingly, both additional variables exhibited negative relationships with waste generation, implying that districts with higher population density and tourism intensity may possess more efficient waste management systems. Overall, the results suggest that the EKC hypothesis does not fully apply to Bali's waste dynamics, emphasizing the need for policy-driven, evidence-based waste management strategies-particularly in regions where economic and tourism growth remain major environmental stressors.

Keywords

Environmental Kuznets Curve (EKC), Municipal Solid Waste (MSW), Economic Growth, Decoupling, Sustainable Development, Bali

1. Introduction

Bali faces an increasingly acute challenge in managing municipal solid waste (MSW), a consequence of rapid urbanization, sustained economic growth, and intensified tourism activity. According to the Indonesian Ministry of Environment and Forestry (Sistem Informasi Pengelolaan Sampah Nasional [1], national waste generation exceeded 43 million tons in 2022, coinciding with a population of approximately 278 million people and an urbanization rate of 57.44%. De-

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spite stable national economic growth averaging 5.03% in 2024, expanding consumption and urban sprawl have imposed substantial strain on local waste management systems. In Bali, the majority of waste continues to end up in final disposal sites (Tempat Pembuangan Akhir or TPA), leading to landfill saturation, leachate contamination, and inefficiencies in waste handling and treatment. This condition highlights an urgent need to explore the economic and policy mechanisms underpinning waste generation in this tourism-dependent region, where economic expansion and environmental degradation are increasingly intertwined.

The relationship between economic growth and environmental degradation has been widely debated and is often analyzed through the Environmental Kuznets Curve (EKC) hypothesis. First developed by [2] in the context of income inequality and later extended to environmental studies, the EKC suggests an inverted U-shaped relationship between income per capita and environmental pressure. During early development stages, environmental degradation tends to rise with economic expansion; however, beyond a certain income threshold, the so-called turning point-further growth is expected to facilitate environmental improvement through technological innovation, effective governance, and greater public awareness [3, 4]. Yet, recent evidence increasingly questions the universality of this pattern. Studies such as [5] in Vietnam and [6] in Colombia demonstrate that the EKC outcome is highly dependent on institutional capacity, governance quality, and technological readiness, particularly in developing economies.

In Indonesia, empirical results are equally mixed. [7] found that the EKC relationship does not hold in Java and Bali, suggesting that economic structure plays a decisive role: regions dominated by services and tourism display environmental stress linked to consumption rather than industrial emissions. At the national level, studies by [8, 9] show that CO_2 emissions continue to rise with income, challenging the notion that economic growth alone can lead to improved environmental quality. Similarly, [10] observed no clear decoupling between income and MSW generation in India, concluding that in developing countries, waste accumulation tends to persist even as income levels increase. These findings suggest that the EKC's predictive power diminishes when applied to waste-related contexts, where the driving forces are behavioral and infrastructural rather than purely industrial.

The concept of decoupling-the separation of economic growth from environmental degradation-serves as a critical extension of the EKC framework. According to [11], relative decoupling occurs when waste generation grows more slowly than income, while absolute decoupling takes place when waste declines despite continued economic growth. Studies in multiple contexts reveal that achieving decoupling in waste management requires strong policy enforcement and investment in circular economy systems. For example, [12] found that municipalities in Australia's New South Wales exhibited only relative decoupling, with local socioeconomic conditions determining the extent of divergence between income and waste generation. Similarly, [13] demonstrated that the City of Cape Town achieved partial decoupling during periods of economic slowdown but failed to sustain it over the long term due to population growth and limited landfill capacity.

In Bali, where tourism constitutes more than 50% of regional GDP, the link between income and MSW generation is complex. Economic prosperity drives consumption-based waste-plastic packaging, food residues, and hospitality waste-that increases nonlinearly with tourism volume. [14] highlighted similar dynamics in Sweden, where income growth in high-income municipalities correlated positively with per capita waste generation despite advanced recycling systems. These insights reinforce that wealth alone does not guarantee waste reduction; institutional design and policy coherence are decisive. Furthermore, recent works such as [15, 16] emphasize that financial stability, governance efficiency, and institutional resilience are key determinants of sustainable growth. In this sense, Bali's waste management challenges are not merely environmental but institutional-echoing findings by [15-18], who argue that effective environmental governance must accompany economic expansion to achieve sustainability.

Furthermore, [5] demonstrated that green governance, measured through the Provincial Green Index (PGI), plays a significant role in accelerating the EKC turning point by enhancing institutional performance and encouraging sustainable practices. Applying this framework to Bali implies that improving intergovernmental coordination, regulatory enforcement, and public participation could lower the income threshold required for environmental improvement. However, Bali's waste management remains fragmented, with decentralized district-level policies and inconsistent data reporting systems. As noted by [13], effective waste decoupling depends on the integration of economic and environmental data to guide adaptive policy design.

Cross-country comparisons further suggest that the EKC for waste is far from universal. [6] confirmed the EKC pattern for landfill waste in Colombia, though the turning point varied significantly across regions due to socioeconomic disparities. In contrast, [10, 19] found no such relationship for India and OECD nations, respectively. These disparities reveal that waste management outcomes depend more on governance efficiency and behavioral adaptation than on economic thresholds. The precision of identifying these turning points, as emphasized by [20], also influences the robustness of EKC estimations, particularly when applied to short or regionally heterogeneous datasets such as those in Bali.

Against this backdrop, Bali's waste problem represents not just an environmental challenge but an institutional one. Despite initiatives like community-based waste banks (bank sampah), composting programs, and emerging waste-to-energy projects, these efforts have yet to scale adequately. Moreover, the seasonal fluctuations in tourism create sharp variations in waste volume, complicating capacity

planning and policy evaluation. The experience of Vietnam analyzed by [5] illustrates that integrating green governance mechanisms at the provincial level-through environmental performance indices, data-driven oversight, and private-sector engagement-can meaningfully accelerate the transition toward sustainable waste management.

Therefore, examining the EKC hypothesis within Bali's MSW context is both timely and critical. By empirically evaluating the relationship between income, population, tourism intensity, and waste generation across Bali's nine districts, this study seeks to determine whether the region exhibits evidence of relative or absolute decoupling. The analysis also aims to identify whether tourism growth and demographic factors exacerbate or mitigate waste pressure, providing insight into the dynamics of sustainability in a service-based economy.

Ultimately, this research contributes to the global discourse on sustainable development by addressing whether economic growth can coexist with environmental preservation in a rapidly urbanizing, tourism-intensive economy. In line with Sustainable Development Goals (SDG) 6 (Clean Water and Sanitation), 8 (Decent Work and Economic Growth), 11 (Sustainable Cities and Communities), and 12 (Responsible Consumption and Production), this study underscores the need for integrative policy approaches. Strengthening institutional coordination, promoting circular economy strategies, and embedding environmental governance within economic planning are essential to achieving both economic resilience and ecological sustainability in Bali's development trajectory.

2. Materials and Methods

2.1. Research Design

This study adopts a quantitative ex post facto case study design to empirically test the relationship between economic growth and municipal solid waste (MSW) generation in Bali within the framework of the Environmental Kuznets Curve (EKC) hypothesis. The expost facto approach was chosen because the variables under investigation such as gross regional domestic product (GRDP), population, and waste generation are naturally occurring phenomena that cannot be experimentally manipulated.

The study analyzes historical secondary data covering multiple years and multiple administrative regions (nine districts/cities in Bali Province). By employing a panel data regression framework, the research captures both cross-sectional and temporal variations [21], providing a more comprehensive understanding of the dynamics between economic growth and generation of waste overtime. The analytical framework follows the EKC hypothesis, which posits a nonlinear relationship between income per capita and environmental degradation, initially increasing and later declining after reaching a turning point.

2.2. Data Collection

Table 1. *The dataset consists of four main categories of variables.*

Data Category	Variables Included	Source
Municipal Waste Data	Annual municipal solid waste generation (tons/year), waste composition (organic, inorganic, plastic, paper, metal), recycling and disposal rates	DLHK Bali, SIPSN (https://sipsn.menlhk.go.id), Local TPA reports
Economic Indicators	GRDP per capita (million Rp/person/year), sectoral GRDP (tourism, industry, agriculture)	BPS Bali, Bank Indonesia Regional Office
Demographic and Urbanization Data	Population, population density, urbanization rate, number of hotel rooms (as a proxy for tourism intensity)	BPS Bali, Bali Tourism Office
Policy and Waste Management Data	Implementation of local waste management regulations (e.g., Bali Governor Regulation No. 97/2018 on single-use plastic reduction), investment in waste infrastructure, community-based waste programs	DLHK Bali, Regional Government Reports

The study relies on secondary data obtained from reputable national and regional sources, including the Bali Provincial Environmental Agency (DLHK), Central Bureau of Statistics (BPS), and the National Waste Management Information System (SIPSN, Ministry of Environment and Forestry). Additional supporting data were drawn from government reports, academic publications, and policy documents relevant to waste management and regional development (Table 1).

This panel dataset covers a period of five consecutive years across nine administrative regions, forming a balanced panel suitable for econometric modeling.

2.3. Econometric Analysis

To test the Environmental Kuznets Curve hypothesis, the study employs a panel regression model estimated using both Fixed Effects Model (FEM) and Random Effects Model (REM) frameworks. The general EKC specification can be expressed as (1):

$$E_{it} = \beta_0 + \beta_1 Y_{it} + \beta_2 Y_{it}^2 + \beta_3 Y_{it}^3 + \gamma X_{it} + \epsilon_{it} \quad (1)$$

Where:

1) E_{it} = Environmental indicator (municipal solid waste generation per capita in district *i* at time *t*),
2) Y_{it} = GRDP per capita (economic indicator),
3) Y_{it}^2, Y_{it}^3 = Squared and cubic income terms to capture nonlinearity,
4) X_{it} = Control variables (population, urbanization rate, tourism intensity, and waste management policy factors),
5) ϵ_{it} = Error term.

The model allows for testing different shapes of the income–waste relationship:

1) Inverted U-shape (EKC) when $\beta_1 > 0$ and $\beta_2 < 0$;
2) U-shape when $\beta_1 < 0$ and $\beta_2 > 0$;
3) N-shape when the cubic term (β_3) alternates in sign.

The turning point (TP) - the income level at which waste generation transitions from decreasing to increasing (or vice versa)-is calculated as (2):

$$TP = -\frac{\beta_1}{2\beta_2} \quad (2)$$

This provides a quantitative estimate of the income threshold where economic growth begins to influence waste generation dynamics differently.

2.4. Diagnostic and Specification Tests

To ensure the robustness and validity of the econometric results, several diagnostic and specification tests were performed:

1) Chow Test – To determine whether the Fixed Effects Model (FEM) is preferable to the Pooled OLS model.
2) Hausman Test – To decide between FEM and REM by testing whether random effects are correlated with the regressors.
3) Lagrange Multiplier (LM) Test (Breusch–Pagan) – To confirm the presence of random effects when comparing REM and pooled models.
4) Multicollinearity Test – Variance Inflation Factor (VIF) was used to check for high intercorrelations among independent variables.
5) Heteroskedasticity Test – White's or Breusch–Pagan tests were applied to detect non-constant variance in residuals; robust standard errors were used when needed.
6) Serial Correlation Test – Durbin–Watson and Breusch–Godfrey tests were conducted to detect autocorrelation across time periods.
7) Normality Test – The Shapiro–Wilk and Kolmogorov–Smirnov tests assessed residual normality, complemented by Q–Q plots.
8) Model Specification Test – Ramsey RESET test was employed to detect potential model misspecification.

All estimations were conducted using EViews 12 software, which supports advanced panel data modeling and diagnostic testing. The selection of the final model was based on statistical significance, theoretical consistency, and goodness-of-fit indicators such as R ², F-statistic, and p-values.

2.5. Analytical Interpretation

The model interpretation focused on determining whether the EKC hypothesis holds for municipal waste generation in Bali. A U-shaped result indicates that economic growth initially reduces waste generation but later increases it beyond a certain income level, implying that decoupling has not yet occurred. Conversely, an inverted U-shaped or flattening relationship would suggest progress toward relative or absolute decoupling. Further, the roles of population and tourism intensity were examined to identify whether socio-demographic and sectoral pressures amplify or mitigate waste generation trends.

3. Results

3.1. Overview of Model Estimation

Table 2 delineates the descriptive statistics of the primary variables employed in the study, specifically waste per capita (Y), GDP per capita (X1), and the squared term of GDP per capita (X2). The substantial range between the minimum and maximum values, coupled with the elevated standard deviations, indicates considerable variability among observations across districts and years. The variables demonstrate pronounced positive skewness and exceptionally high kurtosis, indicating non-normal distributions with heavy tails. The results of the Jarque-Bera test ($p < 0.01$) confirm that all variables significantly deviate from normality. This finding supports the application of robust estimation techniques in subsequent regression analyses to address heteroskedasticity and non-normal error distributions.

Table 2. Descriptive Statistics of Research Variables.

Statistic	Y (Waste per Capita)	X1 (GDP per Capita)	X2 (GDP ²)
Mean	824.1435	45.03253	3199.115
Median	111.3800	36.11550	1304.356
Maximum	130921.4	201.3160	40528.13
Minimum	12.97700	11.05300	122.1790
Std. Dev.	9590.998	34.31495	6410.159
Skewness	13.52692	2.614374	3.893698
Kurtosis	183.9870	10.10832	18.77439
Jarque-Bera	259533.5	603.4777	2398.429

The econometric estimation was conducted using panel data from nine districts and cities in Bali over multiple years, applying both Fixed Effects Model (FEM) and Random Effects Model (REM) specifications. To ensure model validity, three specification tests were performed-Chow, Hausman, and Lagrange Multiplier (LM) tests-whose results are summarized in Table 3.

Table 3. Summary of Model Selection Tests.

Test	Statistic	d. f.	p-value	Decision
Chow Test	20.8095	(8, 50)	0.0000	FEM preferred over Pooled OLS
Hausman Test	4.9626	4	0.2912	Fail to reject H_0 → REM preferred
LM Test (Breusch–Pagan)	83.6981	-	0.0000	REM preferred over Pooled OLS
Test	Statistic	d. f.	p-value	Decision

The Chow test indicates that cross-sectional fixed effects are statistically significant ($p < 0.05$), supporting the FEM structure. However, the Hausman test result ($p = 0.2912$) fails to reject the null hypothesis, implying that the random effects are uncorrelated with the regressors. This is confirmed by the significant LM test, which supports the Random Effects Model (REM) as the most appropriate specification for the extended model.

3.2. Estimation of the Environmental Kuznets Curve (EKC)

Table 4 presents the results of the Fixed Effects Model (FEM) estimation using robust standard errors to correct for heteroskedasticity across districts.

Table 4. Fixed Effects Model (FEM) with Robust Standard Errors.

Variable	Coefficient	Robust Std. Error	t-Statistic	p-Value
Constant (C)	187.232	171.301	1.093	0.3062
X_1 (GRDP per capita)	-6.587	7.816	-0.843	0.4238
X_2 (GRDP ²)	0.2095	0.0587	3.569	0.0353

Dependent Variable: Waste generation per capita (kg/person/year)

The results reveal a U-shaped relationship between GRDP per capita and municipal waste generation in Bali, rather than the inverted-U pattern predicted by the Environmental Kuznets Curve (EKC) hypothesis. The coefficient for GRDP per capita (X_1) is negative but statistically insignificant (p = 0.4238), suggesting that income alone does not directly reduce waste generation. In contrast, the squared term (X_2) is positive and statistically significant (p = 0.0353), indicating that after a certain income level, waste generation increases with continued economic growth.

This implies that economic development in Bali may initially be associated with minor efficiency gains or improved waste management systems, but beyond a threshold level of income (around Rp 14.5–15.7 million per capita per year), higher consumption, increased tourism, and intensified urban activities lead to greater waste accumulation.

3.3. Interpretation of the Curve Shape

Visually, the relationship between income and waste generation forms a convex upward curve (∩-shape segment)-a rising parabola that represents only one portion of the theoretical U-curve. Because the observed data do not extend far below the turning point, the curve does not exhibit the full "U" shape. Instead, it appears as a continuously increasing function, suggesting that Bali's economic growth remains in the pre-decoupling phase.

This means that waste generation continues to rise with economic development, and no evidence of absolute or relative decoupling is yet observed. Decoupling would imply that waste generation stabilizes or decreases even as economic growth continues, a condition that, according to the data, has not been achieved in Bali's current development trajectory.

3.4. Model Refinement with Socioeconomic and Tourism Variables

To improve explanatory power and capture the socio-economic complexity of Bali's regional development, two additional variables were introduced:

1) X_3: Population (proxy for demographic pressure)
2) X_4: Number of hotel rooms (proxy for tourism intensity).

After including these variables, the model was re-estimated using the Random Effects Model (REM), as justified by the model selection tests. The resulting regression equation is:

$$Y = 205.14 - 5.20X_1 + 0.179X_2 - 0.00095X_3 - 0.00000203X_4$$

Where:

1) Y= Waste generation per capita (kg/person/year)
2) X_1= GRDP per capita (million Rp/person/year)
3) X_2= GRDP ²
4) X_3= Population
5) X_4= Number of hotel rooms

The negative coefficients for population and hotel rooms are noteworthy. They suggest that regions with larger populations or higher tourism activity may exhibit lower per capita waste generation, potentially due to better-developed waste management systems, stronger infrastructure, or stricter regulations in high-pressure districts such as Badung and Denpasar. This aligns with findings from [22], who noted that urban and tourism-heavy regions often adopt more efficient waste systems as economic and environmental pressures intensify.

4. Discussion

The empirical findings of this study contribute to a critical reevaluation of the Environmental Kuznets Curve (EKC) hypothesis within the context of municipal solid waste (MSW) generation in Bali, Indonesia. The evidence demonstrates that the conventional EKC framework-predicting an inverted U-shaped relationship between income and environmental degradation-does not hold for Bali's waste dynamics. Instead, the relationship exhibits a persistent upward trajectory, underscoring that rising income levels and economic expansion continue to amplify waste generation rather than mitigate it. This pattern aligns with emerging critiques in the environmental economics literature, which argue that the EKC's presumed self-correcting mechanism is neither universal nor applicable to all forms of environmental degradation, particularly in consumption-driven and service-oriented economies.

In Indonesia, the empirical literature presents mixed and often contradictory results concerning the EKC hypothesis, revealing that its validity is highly contingent upon the specific environmental indicator, regional economic structure, and methodological approach employed. (Setiawan & Anwar, 2022) found an "open U-shaped" rather than an inverted-U relationship between GDP per capita and CO_2 emissions, using a long-term Vector Error Correction Model (VECM) covering 1974–2020. Their findings indicate that Indonesia remains in an immature post-industrial phase where fossil energy dependence and weak environmental governance continue to drive emissions upward despite economic growth [23]. Similarly, [24] applied the Autoregressive Distributed Lag (ARDL) methodology for Indonesia over the period 1971–2007 and concluded that the EKC hypothesis did not hold. Their study revealed that foreign trade and energy consumption, rather than income, were the primary determinants of CO_2 emissions. The results highlighted that the Indonesian economy's structural reliance on carbon-intensive energy sources and global trade patterns undermines the possibility of spontaneous environmental improvement through

income growth [24]. These findings mirror the Balinese experience, where economic expansion-largely driven by tourism and services-exerts environmental pressure primarily through waste production and consumption, rather than industrial pollution.

Theoretically, the EKC hypothesis rests on three mechanisms: the scale effect, the composition effect, and the technique effect. The scale effect implies that environmental degradation increases during early growth stages due to expanding production and consumption; the composition effect refers to structural shifts toward less polluting sectors as economies mature; and the technique effect embodies technological and regulatory improvements that eventually reduce pollution [3]. However, these mechanisms are conditional upon institutional capacity, regulatory enforcement, and technological readiness. As [25, 26] emphasize, the existence and magnitude of these effects vary across contexts, particularly in developing regions where governance structures remain fragmented. In Bali, the service-based economy has not undergone the compositional transformation envisioned in EKC theory. Waste continues to increase due to consumer behavior, weak segregation practices, and limited recycling infrastructure. Moreover, the absence of coherent institutional mechanisms prevents the emergence of the technique effect that could otherwise decouple growth from degradation. This resonates with [27], who argued that Indonesia's green industrialization remains hindered by a lack of inter-sectoral policy coherence, resulting in the predominance of the scale effect that perpetuates environmental deterioration.

On a broader scale, recent global analyses question the universality of the EKC. [28] examined 158 countries using a cross-correlation coefficient (CCC) method to analyze the dynamic relationship between income and CO_2 emissions from 1990 to 2020. Their findings revealed strong heterogeneity across income groups: while some high-income countries exhibited partial decoupling, low- and middle-income nations-such as Indonesia-continued to display positive correlations between economic growth and emissions [28]. These results underscore the argument that EKC behavior is not an inevitable outcome of economic development, but rather a reflection of institutional maturity, technological innovation, and governance effectiveness. In this light, Bali's continued growth in waste generation despite rising income indicates that it has yet to achieve the structural and institutional transformations required for environmental improvement.

The characteristics of Bali's economy amplify the limitations of the EKC hypothesis. As a tourism-dominated region, Bali's economic expansion is consumption-driven, resulting in large quantities of single-use materials, food waste, and packaging. Unlike emissions, which can be mitigated through cleaner production technologies, waste generation requires systemic interventions involving behavioral change, infrastructure investment, and regulatory enforcement. The increase in tourism-related waste has been particularly pronounced in Denpasar and Badung, where annual waste growth has averaged over 5% since 2015. This situation echoes [29], who found that economic and demographic expansion on Java Island improved GDP but negatively affected environmental quality in the absence of integrated environmental management. In both cases, economic prosperity has not translated into ecological sustainability because policy responses have lagged behind economic and population growth.

Institutional fragmentation is a central factor exacerbating Bali's waste management challenge. The province's decentralized administrative structure grants local governments autonomy in waste collection and disposal, leading to disparities in policy enforcement, budget allocation, and data consistency. These governance gaps parallel the national pattern identified [23], who argued that Indonesia's post-Kyoto environmental commitments failed to produce tangible outcomes due to weak regulatory implementation and coordination across agencies. Furthermore, [30] emphasize that cross-country differences in EKC trajectories are closely linked to governance quality and the presence of robust monitoring systems. Bali's lack of a unified data management framework prevents the systematic integration of waste statistics with economic and demographic data. The establishment of a centralized, interoperable waste data system connected to the national Sistem Informasi Pengelolaan Sampah Nasional (SIPSN) could support evidence-based policymaking and strengthen accountability while aligning with the Sustainable Development Goals (SDG 11 and SDG 12).

Transitioning toward a circular economy offers a more viable pathway to sustainability than reliance on income-driven environmental corrections. [31] underscores that sustainable growth in Indonesia requires not only reductions in resource intensity but also institutional mechanisms that promote equitable participation in environmental governance. For Bali, this implies moving beyond linear waste management toward closed-loop systems emphasizing reuse, recycling, and resource recovery. The tourism sector, which accounts for a significant portion of waste, can play a pivotal role by adopting circular practices such as zero-waste certifications, sustainable packaging, and waste segregation programs. Comparative cases such as Kamikatsu in Japan and the Balearic Islands in Spain demonstrate how community engagement, strict sorting rules, and circular tourism frameworks can drastically reduce waste generation. Implementing similar strategies in Bali could help institutionalize sustainability practices and align the province's tourism industry with global sustainability standards.

The experiences of other ASEAN economies further contextualize Bali's deviation from the EKC hypothesis. [32] tested the EKC across six ASEAN countries between 1971 and 2013 and found that while Singapore, Thailand, and Vietnam exhibited inverted-U patterns, Indonesia showed no evidence of EKC behavior. The results implied that countries with more advanced institutional capacity and stronger policy frameworks were more successful in decoupling growth from environmental degradation [32]. Similarly, [33] observed that

Indonesia's forest management outcomes followed a U-shaped rather than an inverted-U trajectory, reflecting that environmental improvement is contingent upon targeted policy reform rather than passive income effects. Bali's continued increase in MSW thus mirrors a national and regional trend in which economic growth outpaced environmental adaptation.

Effective environmental governance in Bali must therefore prioritize integration and coordination across administrative levels. [28] highlight that environmental policies should be differentiated by income level and development stage, recognizing that one-size-fits-all models like the EKC are insufficient. Bali requires a cohesive waste governance framework that harmonizes provincial and district policies, strengthens regulatory oversight, and promotes private sector participation through fiscal incentives and public-private partnerships. Additionally, [29] emphasize the importance of embedding environmental indicators within economic planning frameworks to ensure policy coherence and sustained monitoring. Establishing a centralized, data-driven system for tracking waste generation, collection, and treatment would allow policymakers to identify spatial and temporal trends, particularly in relation to seasonal tourism peaks.

Given these insights, Bali's environmental trajectory illustrates the need to reconceptualize the EKC as a context-dependent, policy-mediated relationship rather than a deterministic curve. Several authors, including [34, 35], have proposed N-shaped or monotonic relationships between income and environmental degradation to account for rebound effects and technological obsolescence. In Bali, a similar N-shaped trajectory may be plausible, where waste generation initially rises, stabilizes due to temporary policy interventions, and increases again as tourism expands. This cyclical pattern reflects the structural volatility of tourism economies and their sensitivity to external shocks. As [28] argue, environmental performance is inherently path-dependent, shaped by historical, institutional, and cultural variables. Hence, achieving sustainability in Bali will require deliberate policy-driven decoupling rather than reliance on spontaneous market corrections.

In conclusion, the case of Bali challenges the central premise of the EKC hypothesis by demonstrating that economic growth in service-based, consumption-oriented economies can exacerbate rather than alleviate environmental degradation. The findings affirm that institutional capacity, governance coherence, and behavioral transformation are the critical determinants of sustainable outcomes. Bali's future sustainability depends on integrating waste management into its broader economic and spatial planning framework, developing equitable infrastructure across districts, and embedding circular economy principles within tourism and local industries. The province's environmental future will not hinge on reaching an abstract income threshold but on the deliberate, coordinated effort to align economic prosperity with ecological preservation.

5. Conclusions

This study examined the Environmental Kuznets Curve (EKC) hypothesis in the context of municipal solid waste (MSW) generation in Bali, Indonesia, using panel data from nine districts and cities. The initial Fixed Effects Model (FEM) indicated a U-shaped relationship between waste generation per capita and Gross Regional Domestic Product (GRDP) per capita, with a turning point estimated at approximately Rp 15.7 million per capita per year. Contrary to the traditional EKC hypothesis, which predicts an inverted-U pattern, the results reveal a convex upward curve, implying that economic growth beyond a certain threshold contributes to increased waste generation rather than environmental improvement.

To enhance model accuracy, additional variables-population and number of hotel rooms-were included as proxies for demographic and tourism pressures. Model specification tests (Chow, Hausman, and Breusch-Pagan LM) confirmed that the Random Effects Model (REM) was the most appropriate. Interestingly, both population size and tourism intensity were found to have a negative and significant relationship with waste generation, suggesting that more urbanized and tourism-focused areas benefit from better waste management infrastructure and policy attention.

Overall, these findings corroborate the broader evidence that the Environmental Kuznets Curve (EKC) hypothesis is not applicable to Indonesia, particularly in the context of Bali. This underscores the necessity for proactive, policy-driven waste management strategies to accompany economic growth. The implications of the study extend to the advocacy of circular economy strategies, emphasizing waste minimization, recycling, and resource recovery as essential components of regional economic planning. Furthermore, it highlights the significance of evidence-based policymaking in tourism-driven regions, where sustainable waste management must be integrated within broader development frameworks to ensure that economic prosperity aligns with environmental resilience and long-term sustainability.

Abbreviations

zEKC	Environmental Kuznets Curve
GRDP	Gross Regional Domestic Product
FEM	Fixed Effects Model
REM	Random Effects Model
MSW	Municipal Solid Waste

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Author Contributions

I Made Gunuamantha: Conceptualization, Data curation, Methodology, Pr Resources, Software, Supervision, Writing – original draft

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Ni Wayan Yuningrat: Formal Analysis, Investigation, Writing – review & editing

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Conflicts of Interest

The authors declare no conflicts of interest.

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Biography

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