

Conference Proceedings-Paper Collection

Building a Just and Climate-Resilient Future: Youth Innovation for People, Nature, and Climate





The 1st International Young Environmental Scientists Conference

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Hendrika Wulandari Samosir
Sri Noor Chalidah

Paper Collection Contributors

Bimario Eka Bhaskara, Resinthia Rachmanda
Sherlly Rossa
Wira A. Swadana, Fahri Santosa, Fachriy Mungkasa, Farizal Arrafisena
Devana Tsintaniarsy Iskandar
I Putu Arisgunarta, Arrozaq Ave, Nasya Augusta, Qory Salsabilla
Ida Bagus Oka Agastya, Putu Diyan Diwyastira, Anak Agung Gde Brahmantya Murti, I Gusti Ngurah Krisna Dana, Jessica Andrea
Muhammad Novan Prasetya, Tini Adiatma, Tutik Yuliatun, Ilham Majid, Guntur Arafah
Kristanto Irawan Putra
Yulia Sukma Supriatna, Arief Sabdo Yuwono
Ni Putu Ayu Eka Sundari¹, You One Van Tomi Lumbanraja, and Citra Septiani
Hosiana Simamora, Romauli Panggabean, Bergita Gusti Lipu, Peter Xandya Rudyan, Sri Noor Cholidah, Sarah Gracia Keinamada, Talitha Fauzia Chairunnisa
Peter Xandya Rudyan, Bergita Gusti Lipu, Hosiana Simamora, Lisandy Arinta Suryana, Muchammad Gumilang Pramuwidyatama, Romauli Panggabean, Sri Noor Cholidah
Indry Chahyana, Hari Novar, Amy Jesscia Pakpahan, Veronika Lestary Silaen
Dikara Maitri Pradipta Alkarisyah
Aulia Izzah Azmi
Mhd Wahyu Riandani, Agus Purnomo, Maniah

Publication:

Jejek Dari Santoso, Publication Coordinator
Septika Sihite, Design and Layout
Bimo Chaderi, Design and Layout

Editorial note for YES Conference proceedings' paper collection

The paper collection in these conference proceedings present selected works from the first YES Conference under the broader agenda of strengthening young scientists' contributions to environmental and climate policymaking. The collection reflects diverse research interests across climate-resilient urban planning, waste management innovation, food loss and waste prevention, local ecological knowledge, and energy transition. Of all the papers presented during the conference, 17 authors agreed to publish their work in these proceedings, making this collection a curated representation of the conference's knowledge-sharing process rather than a complete record of all presentations.

Climate-resilient urban planning, as the first theme, comprises eight papers that examine how cities can respond to climate risks through more inclusive, adaptive, and justice-oriented planning. The papers discuss household greening as climate justice, critical planning issues around Yogyakarta International Airport in Indonesia, participatory transport planning for urban slum communities in Jakarta, active transport integration in South Tangerang, youth digital engagement for climate action, community advocacy after the 2025 Denpasar flash flood, AI-driven emission control systems, and Jakarta's urban food system adaptation challenges. Together, these papers highlight the need to connect spatial planning, mobility, digital innovation, disaster advocacy, food systems, and environmental justice in shaping climate-resilient cities.

The second theme, innovations in waste management, includes five papers that explore waste governance, circularity, and pollution challenges across diverse ecological and social contexts. The papers examine South Papua's Indigenous Malind women's local wisdom and socioecological resilience; community-led waste-working groups in Central Maluku; black soldier fly larvae techniques for waste management; and circularity pathways in the shrimp aquaculture of Banyuwangi, East Java—all in Indonesia.

This theme shows that waste management is not only a technical issue, but also a governance, livelihood, health, and justice concern that requires locally grounded innovation and community participation.

The third theme, preventing food loss and waste, brings together four papers on household behavior, surplus food donation, post-harvest technology, and food demand forecasting. These papers discuss food waste reduction in Bandung, hotel staff intentions to participate in surplus food donation, and ARIMA-based rice demand forecasting for the government's Free Nutritious Meal Program (MBG, from its initials in Bahasa Indonesia). Collectively, this theme highlights the importance of behavioral change, institutional participation, technological intervention, and data-driven planning in reducing food loss and waste while supporting more sustainable and equitable food systems.

Local ecological knowledge, as the fourth theme, includes one paper on local wisdom and sustainable livelihoods in the Subayang River landscape of Riau province in Indonesia. The paper provides insights from Terusan, Pangkalan Serai, and Subayang Jaya Villages, showing how community knowledge, livelihood practices, and landscape-based experience can contribute to climate resilience.

Updates on energy makes the fifth theme, which includes one paper that discusses Indonesia's adoption of palm oil-based biodiesel for ships in relation to the energy trilemma and marine air pollution. Although represented by fewer papers, these two themes add important perspectives on place-based ecological knowledge and emerging energy policy debates.

This collection of papers demonstrates the breadth of young researchers' contributions to environmental and climate discussions in Indonesia and beyond. The papers vary in topic, methodology, and scale, ranging from local community practices to urban policy, technological innovation, circular economy, food systems, and energy governance. While each paper stands as an independent contribution, the collection reflects a shared concern: the need to produce research that is not only academically relevant but also socially meaningful, policy-oriented, and responsive to real environmental défis.

Disclaimer

The papers included in this collection represent the views, arguments, and analyses of their respective authors. They do not necessarily reflect the official position, opinion, or endorsement of WRI Indonesia, YES Conference organizers, moderators, reviewers, or affiliated institutions. The responsibility for the accuracy, originality, interpretation, and overall quality of each paper rests entirely with the authors. The organizers have compiled these papers as part of a knowledge-sharing platform and do not guarantee the quality of language, including English grammar, style, or academic writing standards, in each submitted manuscript.

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Beyond Parks: Household Greening as Climate Justice in Urbanizing Indonesia

Bimario Eka Bhaskara^{1,*}, Resinthia Rachmanda¹

¹ Department of Urban Design, Monash University Indonesia, Tangerang, Indonesia

* Corresponding author: bbha0007@student.monash.edu

Abstract

Urban heat island (UHI) poses an emerging threat to environmental justice in rapidly urbanizing cities, including South Tangerang, Indonesia. This study focuses on Keranggan Subdistrict, where disparities in land use and vegetation cover between *kampung* (informal) settlements and formal housing have contributed to spatial inequalities in thermal comfort. Using Landsat and Sentinel-2 imagery, we analyzed the spatiotemporal changes in land surface temperature (LST) and enhanced vegetation index from 2014 to 2024. Results show a notable rise in LST and inequitable access to green space, with informal settlements exhibiting limited exposure to cooling infrastructure. To address this, we propose a vernacular nature-based solutions (NbS) framework leveraging household-scale greening, such as potted plants, vertical gardens, and community-driven shading strategies. These interventions are coordinated through local institutions, such as local tourism organizations (Kelompok Sadar Wisata, or Pokdarwis), and embedded in ecotourism activities to foster cultural relevance and intergenerational participation. This model offers a micro-scale yet scalable intervention strategy to promote thermal equity and localized climate resilience in space-constrained urban areas. Findings emphasize the need for bottom-up climate adaptation strategies that integrate ecological function with social inclusion.

Keywords: urban heat island (UHI); nature-based solutions (NbS); spatial justice

Introduction

Background

Urban heat island (UHI) is not just an environmental issue but a matter of spatial justice, disproportionately affecting low-income and vulnerable communities. Restricted access to green spaces and cooling infrastructure increases health risks and reinforces urban inequality (Mitchell and Chakraborty 2015; Hsu et al. 2021). South Tangerang City in Banten, Indonesia, is experiencing rising temperatures due to land-use changes, indicating the presence of a UHI phenomenon. The loss of vegetation and the increase in built-up areas have contributed to higher land surface temperatures (LST), with an average increase of 2°C recorded between 2011 and 2019. The research confirms a strong correlation between dense urban development and UHI effects, emphasizing the need for green infrastructure and climate adaptation strategies to mitigate further temperature rise (Setyaningrum et al. 2021).

Keranggan Subdistrict in Setu District, South Tangerang City, has a unique character as an area that still preserves its rural atmosphere amid urban development. In addition to being known for its home industries producing traditional snacks, Keranggan also serves as a hub for local economic activities with numerous small and medium-sized businesses (Lubis et al. 2018; Kalalo and Setiawan 2023). Existing studies indicate that South Tangerang City faces stark disparities between formal housing complexes built by major developers and *kampung* settlements that emerged organically. These informal villages are often isolated enclaves within elite residential areas, such as Bumi Serpong Damai (BSD), Alam Sutera, and Bintaro Jaya, and are struggling with limited access to infrastructure, public services, and green spaces (Wihadanto et al. 2024). In contrast, most formal housing complexes enjoy better facilities, wider roads, and more accessible green spaces, which reinforce socio-spatial



inequalities. Physical barriers further widen this divide, limiting interaction and deepening urban fragmentation, which may affect long-term urban sustainability (Ischak et al. 2017; Wihadanto et al. 2024).

In this context, Keranggan also shows signs of urbanization and faces disparities between formal and informal settlements, which may intensify the UHI effect. Some areas remain traditional villages, while others have developed into housing complexes. Following the broader development trend in South Tangerang, there is a risk that certain parts of Keranggan may experience limited access to green spaces, particularly in denser or constrained settlement areas.

This study will explore LST conditions in Keranggan and its surroundings to identify UHI presence and distribution patterns, while assessing whether green spaces are accessible to all or only certain groups. Using the nature-based solutions (NbS) approach, this research aims to propose interventions that can serve as inputs for local governments, academics, and stakeholders to improve ecological balance and spatial equity in the area.

Integrating NbS: A pathway to equitable cities

NbS are widely promoted in urban planning to address environmental challenges, including stormwater management, air quality improvement, and UHI mitigation. By integrating green and blue infrastructures such as parks, tree canopies, green roofs, rivers, and lakes, NbS can reduce surface temperatures and improve urban thermal comfort (Kabisch et al. 2017; Hsu et al. 2021). UHI is driven by artificial materials and dense urban forms that trap heat, intensifying thermal stress and reducing human well-being (Khorrami, Heidarlou, and Feizizadeh 2021; Zhang, Shi, and Chang 2022). However, NbS are not inherently inclusive and may exacerbate environmental injustice through green gentrification, privatization, and unequal access to green spaces, often benefiting affluent communities while marginalizing vulnerable groups (Bauer 2023; Rigolon et al. 2024). NbS frameworks may also lack sensitivity to local ecological conditions and social practices, resulting in standardized interventions that fail to address place-specific needs (Lemes de Oliveira 2025).

This highlights the need to reconceptualize NbS as vernacular—meaning locally grounded, socially inclusive, and ecologically contextualized. Vernacular NbS emphasize localization, adapting design, vegetation, governance, and use to local climate, culture, and community needs while integrating spatial justice and biodiversity concerns. Without such localization, NbS risk functioning as technocratic tools rather than equitable and resilient urban solutions (Pineda-Pinto et al. 2022; M. Li et al. 2025).

Methodology

Assessing LST

LST is utilized as a primary indicator of UHI because surface temperatures directly influence heat distribution patterns in urban areas. Regions with high LST often indicate areas experiencing elevated temperatures due to urbanization, particularly in areas with extensive hard surfaces, such as asphalt and concrete, which absorb and release heat more slowly than vegetation (Bhaskara and Pratomo 2023; Pratomo et al. 2024). The LST analysis in this paper follows a step-by-step remote sensing approach using processed Landsat 8 satellite imagery (obtained on September 13, 2014, and October 26, 2024, at <https://earthexplorer.usgs.gov/>).

Assessing enhanced vegetation index

Enhanced vegetation index (EVI) was used to extract the distribution of green areas from Sentinel-2 satellite imagery (acquired on October 25, 2024) from the Copernicus Data Space Ecosystem (<https://browser.dataspace.copernicus.eu/>). The extracted green areas were then classified based on their size to assess how far a green space can effectively cool its surroundings (cooling effect).



A buffer analysis was subsequently applied to evaluate the spatial extent of cooling and to identify areas with limited exposure to vegetation-based cooling. Green spaces differ in their effectiveness at reducing temperatures (Table 1).

Table 1. Cooling effect of green space

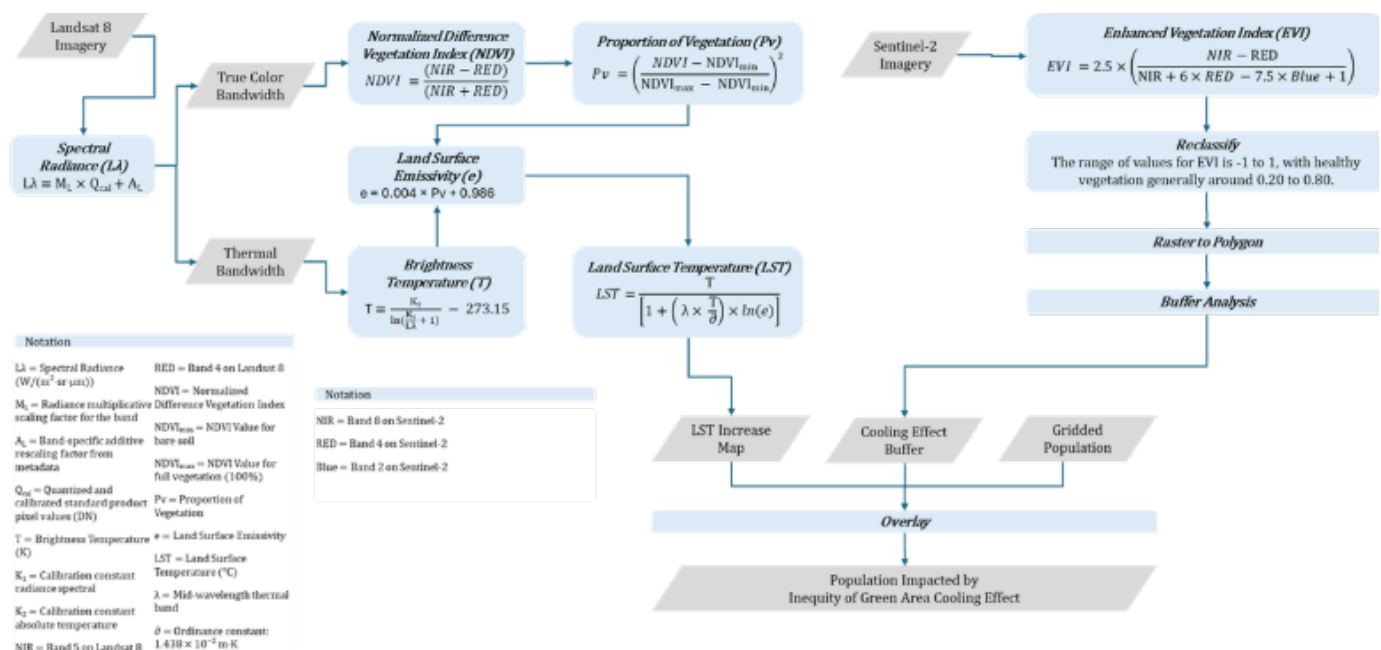
No.	Typology	Cooling effectiveness (m)
1.	Large green spaces (>1 ha)	90
2.	Medium-sized green spaces (0.1–1 ha)	60
3.	Small green spaces (<0.1 ha)	30

Source: Gally et al. 2023.

Assessing the population impacted by the inequity of the green area cooling effect

After analyzing LST and the buffer cooling effect of green spaces/vegetation, the next step is to assess the affected population using estimated demographic data based on pixel values from <https://data.humdata.org/dataset/indonesia-high-resolution-population-density-maps-demographic-estimates>. See Figure 1 for details.

Figure 1. Assessing LST



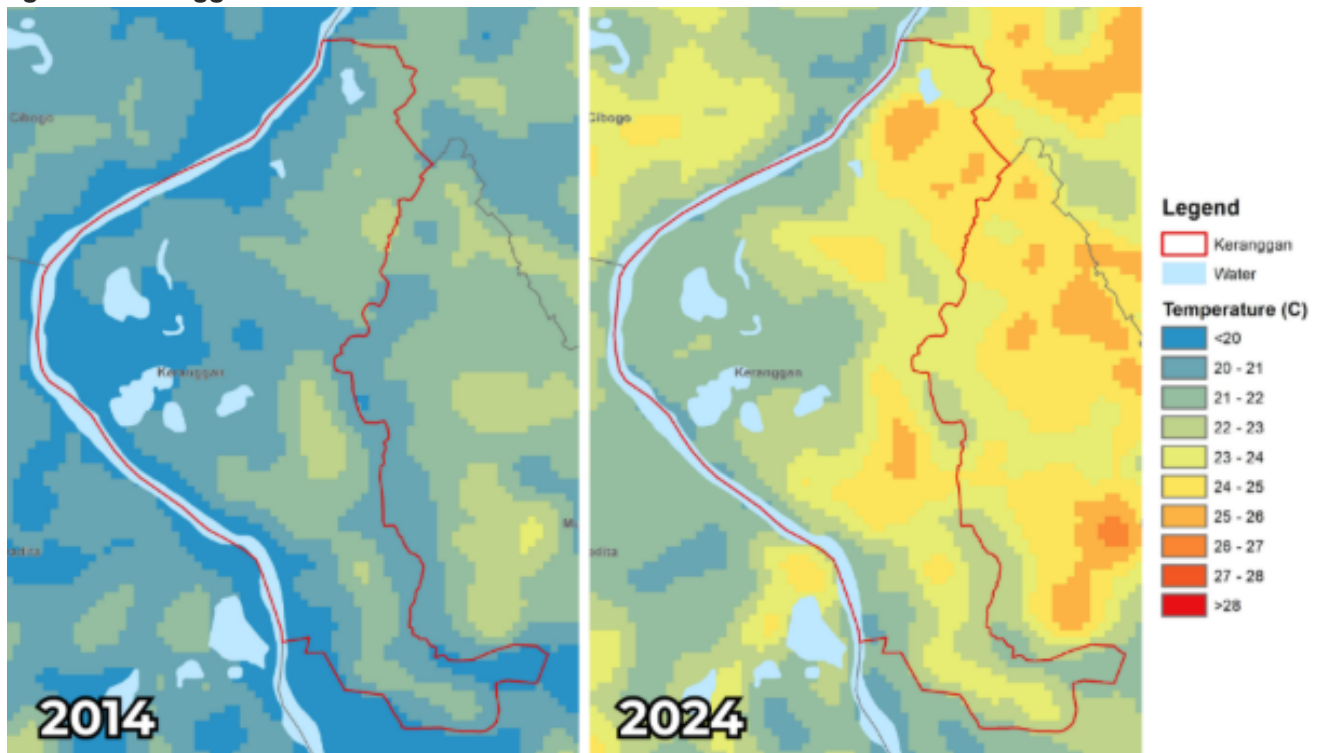
Source: Authors' analysis.

Results and discussion

Assessing UHI through LST

The analysis of LST in Keranggan shows a significant increase in temperature over the past decade (Figure 2). In 2014, the average LST was 20.52°C, with the dominant temperature class being 20–21°C, covering 100.91 hectares (42.86 percent of the total area). By 2024, the average LST had risen to 22.76°C, shifting the dominant class to 21–22°C, covering 80.46 ha (34.24 percent). Extreme increases were detected in the 4–5°C range (2.81 ha), 3–4°C (8.18 ha), and 2–3°C (27.94 ha), with the 1–2°C range being the most widespread (161.21 ha), followed by 0.1–1°C (30.81 ha), while 6.01 ha showed no significant change.

Figure 2. Keranggan's LST in 2014 and 2024



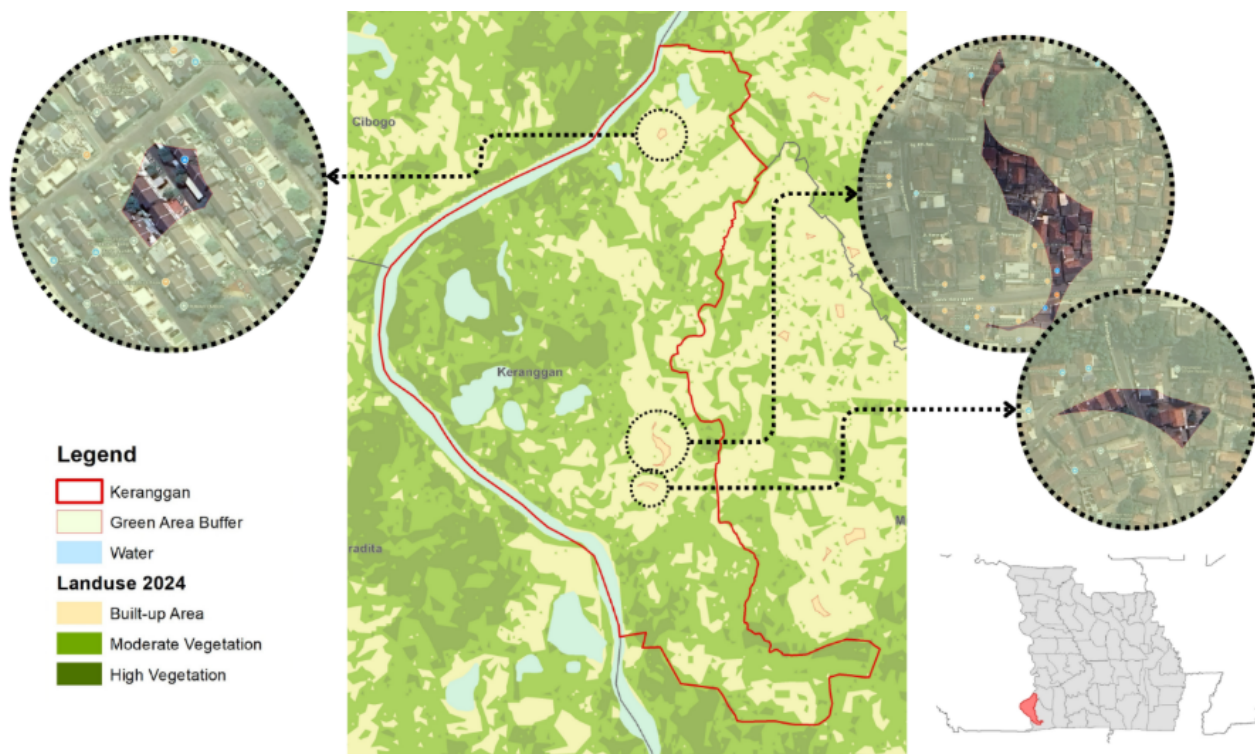
Source: Authors' analysis.

The 2014 map already indicated early signs of UHI formation, reflecting an uneven temperature distribution due to urban development. By 2024, this trend had intensified, particularly in residential areas, which may be associated with increased building density and reduced vegetation cover, as widely discussed in previous studies on urban heat dynamics (Setyaningrum et al. 2021; Bhaskara and Pratomo 2023). Recent studies on tropical cities show that rapid urbanization correlates with extreme increases in temperature (Lee et al. 2020). Specifically, a 1–2°C temperature rise is the dominant range for UHI formation (Zezzo et al. 2025). Additionally, the rising extreme temperatures in tropical cities can lead to higher health risks and increased energy consumption (Peng et al. 2012). This study reinforces the critical need for climate-conscious urban planning, particularly through the strategic integration of green spaces to mitigate UHI effects in rapidly urbanizing areas.

Assessing equity in green area distribution

Based on the analysis, three categories of green spaces were identified. Large green spaces (>1 ha) are widely distributed, covering a total of 834.82 ha, followed by medium-sized green spaces (0.1–1 ha) with 110.53 ha, and small green spaces (<0.1 ha) covering 57.89 ha. After applying a buffer analysis, it was found that 0.55 ha of the total area, including in both developer-built residential areas and informal settlements, fell outside the cooling effect coverage. However, this condition is predominantly concentrated in informal settlements (approximately 0.45 ha), compared to only about 0.1 ha in formal residential areas, indicating a higher risk of limited cooling access in informal areas.

Figure 3. Keranggan's green area buffer



Source: Authors' analysis.

This spatial inequality resonates with broader evidence showing that urban green space distribution is often uneven, leaving low-income or marginalized communities unable to fully benefit from cooling effects, health improvements, and other ecosystem services (Koprowska 2020; dos Santos Facundes et al. 2024). Koprowska emphasizes that environmental justice is not only about exposure to environmental “bads” but also about equitable access to environmental “goods”, such as parks and green areas, which are frequently distributed inequitably across socioeconomic groups (Koprowska 2020). In Belém, Brazil, for example, more than half of urban units have insufficient vegetation cover. Affluent central neighborhoods have less than 5 m² of green space per inhabitant, while peripheral vulnerable areas contain remnant vegetation with poor accessibility (dos Santos Facundes et al. 2024). Such findings reinforce the concept of environmental justice, which underscores equal access to urban amenities and warns that even well-intentioned greening initiatives can reproduce inequality through processes like ecological gentrification (Koprowska 2020; Ufaira et al. 2023; Y. Li et al. 2024).

This pattern aligns with broader findings on environmental inequality, where dense, low-income neighborhoods are more exposed to cooling deficits. Addressing this imbalance requires deliberate planning to expand and equitably distribute green spaces to ensure that cooling benefits reach vulnerable communities.

How much is impacted?

Based on gridded population estimation, approximately 87 residents (about 0.99% of Keranggan's total population) live within zones experiencing temperature increases of 1–5°C without effective cooling vegetation coverage. While relatively small in proportion, these residents are spatially concentrated in built-up pockets across both *kampung* and formal housing complexes, signaling early micro-level inequities in thermal exposure.

Table 2. Keranggan's population impacted by the inequity of the green area cooling effect

	LST increase (°C)	Unserved area (m ²)	Population estimate (residents)
1.	4–5	1,008.4	± 16
2.	3–4	3,236.7	± 53
3.	1–2	1,136.7	± 18
Total		~5,381	± 87

Source: Authors' analysis.

Mitigating UHI through the NbS framework

This analysis suggests that Keranggan generally maintains a relatively balanced spatial distribution of green areas at the macro level. However, a closer examination reveals localized disparities, particularly in informal settlements, where limited vegetation buffers create higher exposure to thermal risk. These zones represent early warning signals, especially in highly built-up kampung cores, where, without intervention, urban infill or further densification may exacerbate heat vulnerability. Even though no extreme heat zones were detected in 2024, the rising LST trend signals an urgent need for proactive urban greening strategies to prevent further intensification of heat exposure in the future. Furthermore, reports from the World Resources Institute (2019) and analysis by the United Nations Environment Programme (UNEP) emphasize that, without effective mitigation measures, extreme temperature increases and the UHI effect will exacerbate negative impacts on public health and urban infrastructure (UNEP 2020).

In terms of mitigation, implementing urban green space systems and increasing vegetation cover can lower surface temperatures by up to 2°C, helping to reduce UHI intensity and extent in tropical cities while improving outdoor thermal comfort (M. Li et al. 2025). Analysis of vegetation distribution reveals that the effectiveness of urban greening for UHI mitigation depends not only on its presence but also on its spatial structure. Larger, continuous vegetation patches are more effective in disrupting thermal zones. This aligns with findings that strategic green space planning can reduce UHI effects without requiring significant expansion of green areas (Zhou et al. 2023). However, achieving such configurations remains challenging in high-density kampung settlements and even in formal housing developments. This spatial limitation underscores the need for flexible, small-scale interventions tailored for urban environments with constrained space.

While large-scale urban greening is ideal in theory, spatial limitations in high-density kampung settlements and many formal housing developments make such interventions impractical. Despite spatial proximity to green areas, these neighborhoods often lack the vegetative density or connectivity necessary for effective thermal relief. This underscores a form of ecological inequity where the physical presence of greenery does not translate into equal cooling benefits.

To address this, a shift towards small-scale, decentralized greening efforts becomes essential. One such approach is through vernacular NbS, including locally adapted, low-cost practices such as household gardening using potted plants, climbing vegetation, or simple shading devices (Humaida et al. 2023). Studies by Priya and Senthil (2024) demonstrate that potted greenery in homes can reduce indoor temperatures by up to 3°C. Similarly, Gallay et al. (2023) highlights that even limited vegetation, when spatially distributed, contributes meaningfully to urban cooling.

In the Indonesian context, this practice is not entirely new. During the COVID-19 pandemic, there was a documented surge in household gardening, especially among women (Mubarok et al. 2023). Moreover, comparative studies on youth perspectives in Indonesia and Japan show that while awareness of the environmental benefits of home gardens is high, active participation among the younger generation remains limited, indicating untapped potential for engagement if supported through community-led, inclusive programs (Mao et al. 2020). In the Keranggan village itself, although not predominant, several houses have potted plants in front of their homes, indicating a positive step towards implementing this solution.

This opens a strategic opportunity to position community-based greening efforts as a platform not only for climate adaptation but also for cultivating intergenerational environmental stewardship.

Figure 4. Houses in Keranggan



Source: Authors' documentation.

When strategically supported, such community-driven greening can evolve from a passive domestic habit into an active resilience strategy. Keranggan, with its strong community networks and local tourism organizations (Kelompok Sadar Wisata/Pokdarwis), is well-positioned to serve as a pilot site for climate-resilient urban living. In Keranggan, Pokdarwis plays a key role in managing ecotourism activities and promoting the village's identity as an environmentally preserved area. This vision aligns with broader greening efforts, as Pokdarwis actively encourages community participation in maintaining vegetation, managing local landscapes, and supporting small-scale environmental initiatives. By integrating vernacular greening and ecotourism, the village can demonstrate how household gardening can evolve into a visible, participatory model of grassroots climate action, inviting not only residents but also the younger generation to help shape a cooler, greener future.

How is this intervention managed?

Keranggan is a well-known destination for community-based tourism, i.e., Keranggan Ecotourism, located near the Cisadane River in the subdistrict in South Tangerang (Juliana et al. 2024). Local initiatives have long demonstrated the value of protecting the environment and of harnessing local wisdom sustainably (Ritonga 2023).

In this context, local ecotourism groups, such as Pokdarwis, are proposed to act as the main actors in the intervention. As intermediaries, they can effectively bridge institutional support with community capacity while promoting an environmentally friendly identity rooted in active community participation. Under this framework, the target group is the local community that will directly benefit from improved access to and a more even distribution of green spaces to mitigate the UHI effect. Simultaneously, government bodies and the private sector will serve as funders, providing the necessary resources to implement these green interventions (Figure 5).

Figure 5. Actor-based model for equitable urban greening through vernacular NbS



Source: Authors' analysis.

This collaborative model aligns with the principles of environmental justice, which emphasize equitable access to urban environmental goods such as public parks (Koprowska 2020; Ufaira et al. 2023; Y. Li et al. 2024). By prioritizing Pokdarwis in Keranggan, the framework not only addresses cooling inequality but also leverages local cultural heritage and community-driven innovation to achieve sustainable urban greening in dense, rapidly urbanizing areas.

Conclusion

This study emphasizes the pressing need for micro-scale climate action to address rising urban temperatures and spatial environmental inequality. Through spatiotemporal analysis of LST and EVI, it becomes evident that even moderate temperature increases in Keranggan Subdistrict reflect patterns of UHI intensification, particularly in built-up *kampung* areas with limited vegetation. Despite the absence of extreme heat zones, the trend suggests future risks if no intervention is pursued. Furthermore, while green areas are relatively well distributed at the macro level, localized disparities in cooling access raise environmental justice concerns, with informal areas (*kampung*) experiencing more limited cooling benefits than formal settlements.

The proposed vernacular NbS framework, centered on household-level greening supported by local actors like Pokdarwis, offers a low-cost, context-sensitive approach to mitigating UHI while building local capacity and agency. By harnessing existing social structures and embedding greening into community culture and tourism, Keranggan has the potential to pioneer a scalable, inclusive climate resilience model.

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The Agro-Aerotropolis: A Critical Analysis of Planning at Yogyakarta International Airport

Sherlly Rossa^{1,*}

¹ Department of Politics and Government, Faculty of Social and Political Sciences, Universitas Gadjah Mada, Yogyakarta, Indonesia

*Corresponding author: sherlly.workspace@gmail.com

Abstract

The emergence of airport-led urbanization has catalyzed a complex spatial transition that systematically devalues local agrarian sectors in favor of global connectivity. As Yogyakarta International Airport (YIA) commenced operations within a dynamic and vulnerable coastal zone, the local government initiated the "agro-aerotropolis" plan to integrate the existing agrarian economy with global aviation connectivity. Drawing on Henri Lefebvre's theory on the production of space, this study highlights the political dimensions of the aerotropolis as a new spatial regime, linking macro-level land finance strategies, specifically land value capture (LVC) and land readjustment, with micro-level social inequality outcomes. The investigation reveals that the project is fundamentally hampered by a profound authority gap between central mandates and local autonomy. Driven by the command-and-control framework of National Strategic Projects, the prioritization of immediate economic interests has subordinated local community demands. Consequently, aggressive land conversion has systematically devalued the agrarian sector, triggering forced shifts from farming to a vulnerable industrial workforce and resulting in fragmented housing patterns. The article contends that while the agro-aerotropolis model holds potential for long-term growth, its current implementation contradicts the concept of democratic space production. To achieve equitable development, the study advocates a transition from technocratic domination to participatory governance, which requires fiscal rebalancing and the institutionalization of social impact financing to protect the region's socioeconomic fabric.

Keywords: aerotropolis; land conversion; land value capture (LVC); production of space; Yogyakarta International Airport

Introduction

Airports have emerged as pivotal catalysts for economic growth within the spatial development landscape (Kamruzzaman et al. 2021). This phenomenon drives 21st-century urbanization through the aerotropolis model, in which airport-centered logistics and integrated networks shape spatial planning (Baker et al. 2015; Kamruzzaman et al. 2021; Pereira et al. 2023; Frétiigny et al. 2024). While local governments often adopt airport corridor strategies to foster sustainable economic development, such a market-led urbanization often results in a fragmented landscape and ecological impacts (Pereira et al. 2023). Global cases, such as the Suvarnabhumi International Airport in Thailand, demonstrate how such megaprojects can disrupt local livelihoods, particularly for farmers, and threaten environmental stability (Swangjang and Iamaram 2011).

The spatial challenges posed by airport development are vividly evident in Kulon Progo, Special Region of Yogyakarta, Indonesia. The construction of Yogyakarta International Airport (YIA), mandated by the Master Plan for the Acceleration and Expansion of Indonesia's Economic Development (Masterplan Percepatan dan Perluasan Pembangunan Ekonomi Indonesia; MP3EI), was designed to strengthen global connectivity (Ahmad 2018). However, this new spatial regime has fundamentally reoriented local livelihoods from agrarian to service industries. Consequently, affected communities face a high risk of transient poverty due to employment uncertainty during this transition (Gunawan and Winarno 2020).

To mitigate these risks, the local government adopted the agro-aerotropolis vision, which is explicitly operationalized through District Head Regulation (Peraturan Bupati; Perbup) No. 47 of 2023 concerning the Detailed Spatial Plan (Rencana Detail Tata Ruang; RDTR) for the Area Surrounding Yogyakarta International Airport 2023–2043, specifically in Article 4. Furthermore, the "agro" prefix is derived from Kulon Progo's Regional Development Planning Agency's (Badan Perencanaan Pembangunan Daerah; Bappeda) strategic planning documents for the southern coast, which aim to bolster the competitiveness of the Special Region of Yogyakarta. These documents outline five priority programs, including smart agriculture, as the foundational pillars for a sustainable and productive agro-aerotropolis.

Despite this vision, the development of the Kulon Progo aerotropolis has precipitated significant conflicts of interest between the government and local communities (Ardi 2021; Effendi 2022). The development relies on complex market-driven mechanisms to fund infrastructure and organize space, often neglecting community needs. This approach has led to fragmented housing patterns and deepened social inequality among the displaced populations (Effendi 2022).

This article aims to complement the study of the aerotropolis concept by applying Henri Lefebvre's theory of the production of space to scrutinize the political dimensions of this spatial regime. It investigates two main questions: first, the dynamics of power relations shaping the spatial transformation at YIA; and second, how the consensus on the aerotropolis concept evolves during its implementation amid competing interests between the state and communities.

Methodology

This research integrates the aerotropolis concept, as theorized by John Kasarda, with Henri Lefebvre's theory of the production of space to examine the potential of the Kulon Progo District in Yogyakarta, Indonesia, as an emerging aerotropolis. Kasarda (2019) defines an aerotropolis as a region centered around an airport, emphasizing integrated transportation networks and efficient logistics. The aerotropolis model offers a solution by focusing on integrated planning that minimizes these costs and fosters a more efficient, interconnected logistics network (Kasarda 2008). Lefebvre's (2000) production of space theory provides a complementary lens for understanding the social and spatial implications of aerotropolis development. Lefebvre introduced a triad comprising spatial practices, representations of space, and representational spaces.

This qualitative study scrutinizes YIA's aerotropolis governance through in-depth interviews conducted between January and August 2024. Using purposive sampling, the research engaged nine high-level stakeholders, including the Regional Secretary of the Special Region of Yogyakarta and the Former District Head of Kulon Progo (2017–2022), to capture strategic policy insights.

Furthermore, secondary data, including spatial planning documents, feasibility matrices, and land conversion statistics, were analyzed to triangulate the interview findings within Lefebvre's framework. These official documents reflect the state's technocratic vision (representations of space). This data was critically correlated with interview and socioeconomic data, which illustrate the community's lived realities and disruptions (spatial practices and representational spaces), thereby exposing the power imbalances between the idealized agro-aerotropolis and the actual agrarian experience.

Table 1. Relevance triad of social space production and aerotropolis development

Component	Description	Relevance to aerotropolis
Spatial practice	Daily routines and social cohesion	The patterns of movement, consumption, and social interaction within the aerotropolis
Representations of space	The mental concepts, images, and discourses about space	The planning and design concepts of the aerotropolis, as well as public perceptions and their representations
Representational spaces	Space as directly lived and experienced	The quality of life, sense of community, and identity of residents and workers in the aerotropolis

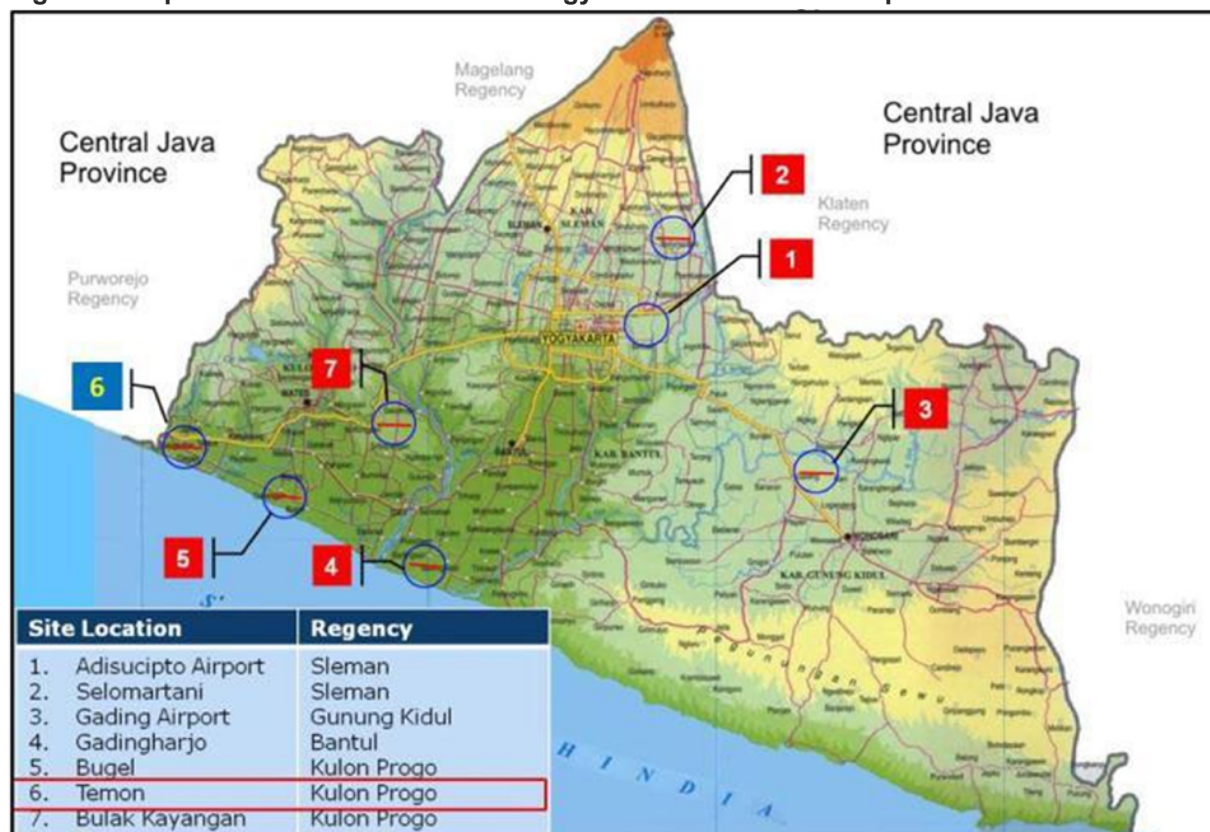
Source: Adapted from Lefebvre (2000).

Results

Transforming Kulon Progo: An agro-aerotropolis vision

The establishment of YIA is deeply embedded in the national strategic agenda, explicitly designated as a National Strategic Project under the MP3EI 2011–2025, with nationwide investment projected at approximately USD275 billion, 35 percent of which is expected to come from the private sector. The government positioned YIA as a critical corridor to strengthen Indonesia's global connectivity (Ahmad 2018). This strategic expansion was further necessitated by the critical saturation of the existing Adisutjipto Airport, which had long exceeded its operational capacity. The limitations of Adisutjipto hindered the development of the tourism and education sectors, the region's economic lifelines, prompting the urgent need for a new facility capable of accommodating 20 million passengers annually to support internationalization (Angkasa Pura I 2014).

Figure 1. Map of alternative locations for Yogyakarta International Airport



Source: Angkasa Pura I 2014.

This grand vision demanded a rigorous, technocratic site-selection process to justify transforming the coastline of Kulon Progo. As outlined in the feasibility study by GVK India, Landrum, and Brown (Australia), and Angkasa Pura I (2014), seven potential locations were initially identified based on spatial planning and operational criteria. Following a screening process, two sites were shortlisted: Gadingharjo in Bantul District and Temon in Kulon Progo District. To justify the selection, an evaluation matrix (Table 2) showed that Temon scored 81%, while Gadingharjo scored 68%. Temon's superiority was largely attributed to its land availability and perceived economic benefits, despite the high social cost for displacing existing communities.

Table 2. Evaluation matrix and sensitivity analysis of the two final alternative locations for YIA

No.	Evaluation categories	Weighting criteria	Evaluation criteria	Gadingharjo	Temon
1.	Regional development	8.6	Compliance with the Provincial Spatial Plan	2	3
			Compliance with the Transportation Plan	3	2
2.	Land availability	40	Land available for long-term expansion	2	1
			Ease of obtaining land use rights	1	2
			Ability to relocate vital infrastructure	3	2
3.	Operational sustainability	8.6	Surface clearance obstacles	2	2
			Air navigation	2	2
			Hazards/risks	3	3
4.	Socioeconomic and cultural	8.6	Minimizing disruption to the community	1	2
			Minimizing impact on social structure	1	2
			Economic benefits	2	3
5.	Natural environment	8.6	Aircraft noise	2	2
			Impact on flora and fauna	3	3
			Impact of construction equipment	2	3
			Natural disaster risks	2	2
			Impact on water quality	2	3
6.	Airport access	8.6	Travel time	3	2
			Ability to widen roads	1	3
			Rail access	2	3
7.	Technical aspects	8.6	Soil bearing capacity	2	3
			Topography (cut and fill)	2	3
			Infrastructure (needs)	2	3
			Hydrology (drainage)	3	3
8.	Financial feasibility	8.6	Maximizing potential for flight growth	2	2
			The weighting of main cost differential factors	1	2
		100%	TOTAL	51	61
			Score (%)	68	81
			Weighted average	2.01	2.16
			Weighted average score (%)	67	72

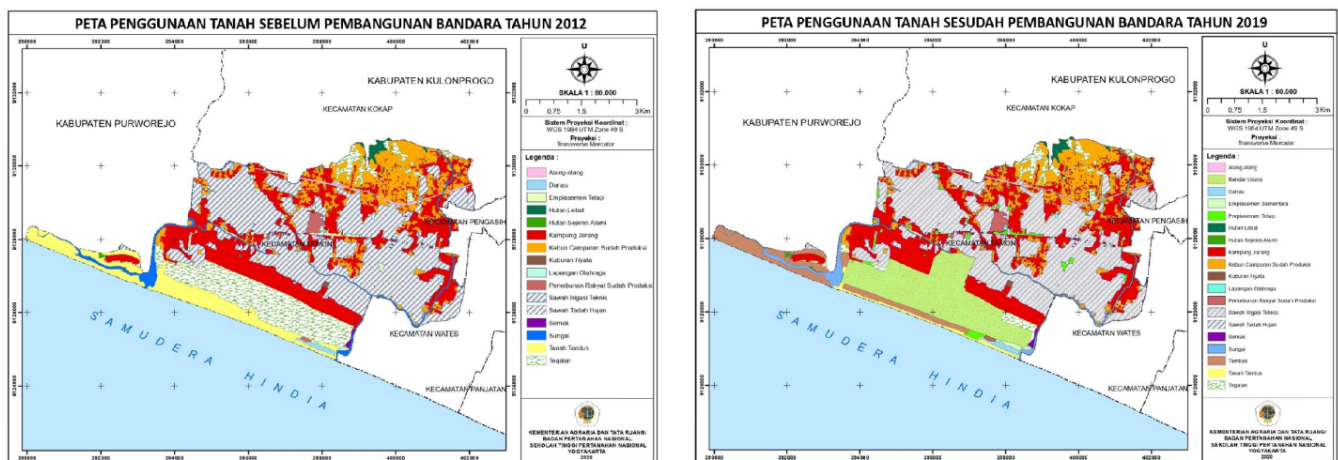
Source: Angkasa Pura I 2014.

Following this selection, the Kulon Progo District Government integrated the airport into its spatial plan through the agro-aerotropolis concept. Ideally, this framework envisioned a symbiotic relationship, in which modern airport infrastructure coexists with agricultural preservation. Saryono, Secretary of the Land and Spatial Planning Agency of Kulon Progo Regency, emphasized that the local government has initiated programs to expand agricultural land to mitigate conflicts and ensure food security (interview, June 26, 2024). Geographically, Kulon Progo is strategically positioned along the southern Java transportation corridor and served by national highways and a double-track railway connecting five provinces, making it an ideal candidate for an integrated hub (Restiyadi 2018).

However, the physical implementation reveals a stark contradiction to the “agro” narrative. The government’s focus has predominantly shifted towards hard infrastructure, often at the expense of the agricultural landscape. The spatial encroachment is evident in the drastic land-use changes observed between 2012 and 2019. Figures 2 and 3 provide visual evidence of this radical spatial reorganization. The maps illustrate how productive green zones in Temon Subdistrict were extensively converted into grey infrastructure for residential and industrial areas, particularly around the airport in the southern area. This conversion incurs a high economic cost, undermining the region’s agrarian potential.

Data on economic land valuation reveals that the agricultural sector suffered the most severe blow. The conversion of 99.75 hectares (ha) of productive agricultural land resulted in a monetary loss of IDR387.76 billion (Merdekawati 2021). In comparison, other land uses, such as poundland, saw significantly smaller losses (IDR2.27 billion from 37.41 ha). This empirical evidence suggests that the aerotropolis development has systematically devalued the agrarian sector it claimed to protect, prioritizing short-term infrastructure gains over the long-term value of food security.

Figure. 2 Land use area before airport construction in 2012 (left); and land use area after airport construction in 2019 (right)



Source: Setiowati et al. 2020.

Further, the land acquisition process for over 500 ha, which cost the state IDR4.1 trillion in compensation, triggered a fundamental shift in housing patterns (Hanafi 2018). The high cost of land acquisition was driven by the gap between market prices and the compensation residents demanded (Restiyadi 2018). While the government secured the land, subsequent independent relocation of residents led to fragmented settlements. According to Setiowati et al. (2020), displaced communities, particularly from villages such as Glagah and Palihan in Temon Subdistrict at the center of the project area (see Figures 2), rebuilt their lives using compensation funds but without a cohesive spatial plan. This resulted in scattered housing typologies that severed the social cohesion that previously defined the village structure. Moreover, tenant farmers who received little to no land compensation were the most vulnerable, often falling into transient poverty as their livelihoods vanished without adequate replacement assets (Gunawan and Winarno 2020).



Analysis of this transition through Lefebvre's (2000) theory of the production of space reveals the underlying power dynamics. Lefebvre's triad demonstrates how physical spaces influence social, economic, and political behaviors. The agro-aerotropolis master plan functions as a dominant *representation of space* (the conceived space of planners and state elites), which often clashes with the *representational spaces* (the lived reality and cultural heritage) of the local agrarian community. This conflict over spatial control is evident in the resistance displayed in Glagah and Palihan villages. As documented by Susanto (2020), villagers' opposition to the airport was a counter-narrative to the state's vision of progress, reflecting a distinct understanding of space that values ecological sustainability and social cohesion over capitalist accumulation.

This spatial transformation has triggered a drastic shift in *spatial practices*, particularly in the community's daily routines, housing patterns, and livelihoods. Land readjustment, a critical component of the aerotropolis, physically alters the region's typology. Setiowati et al. (2020) note that communities affected by the YIA construction were relocated to village lands (*tanah kas desa*) and Pakualaman ground (PAG). Table 3 details the relocation of 383 households across various villages, including heavily affected areas such as Glagah and Palihan. While the government provided relocation sites of approximately 100 m² to 200 m² per plot, residents had to rebuild their homes independently using compensation money. This process disrupted the cooperative atmosphere and bonds that had previously characterized the agrarian community's social interactions. The resulting settlements display fragmented housing typologies: wealthy residents built two-story houses, while vulnerable tenant farmers, who received little to no land compensation, relied on subsidized housing from the Ministry of Public Works and Housing or faced displacement.

Table 3. Relocation of residents affected by YIA construction

No.	Village (<i>desa</i>)	Subdistrict (<i>kecamatan</i>)	Number of land parcels and household	Description
1.	Jangkaran	Temon	4	On village land, about 200 m ² per plot
2.	Kebonrejo	Temon	24	
3.	Janten	Temon	54	
4.	Palihan	Temon	99	
5.	Glagah	Temon	102	
6.	Kedundang	Temon	50	On Pakualaman ground, about 100 m ² per plot
7.	Kaligintung	Temon	50	
Total			383	

Source: Setiowati et al. 2020.

The loss of land equates to the severance of employment relations in an agrarian society, forcing a reorientation of livelihoods that pushes many into transient poverty (Gunawan and Winarno 2020). This phenomenon of "depeasantization" illustrates how economic power drives a decline in rural farmers, leading them to adopt an urban mindset as they abandon agriculture to survive (Haekal 2020).

Despite this pressure, community resilience remains high. As shown in Table 4, local efforts to survive the YIA development environment indicate that 63.3 percent of affected communities sought suitable business opportunities, while 51.7 percent attempted to continue farming on the remaining land (Gunawan and Winarno





2020). The fact that all of the respondents chose not to sell their land to move outside the area underscores how land remains a deeply rooted representational space and a vital productive asset for daily livelihoods.

Table 4. Community efforts to survive in the YIA development environment

No.	Description	Yes		No		Total	
		F	%	F	%	Total	%
1.	Selling land and buying land outside the area	0	0	60	100	60	100
2.	Finding suitable business opportunities	38	63.3	22	36.7	60	100
3.	Continuing to use the land for farming or business	31	51.7	29	48.3	60	100
4.	Business development	4	6.7	56	93.3	60	100

Source: Gunawan and Winarno 2020.

To mitigate the social fallout of this capitalist mode of production, the government and PT Angkasa Pura I implemented corporate social responsibility and community empowerment programs. Throughout 2018, the Human Development Agency carried out numerous initiatives, managed in collaboration with the Kulon Progo Training Center. These programs ranged from English-language courses to electromechanical training (Susanto 2020).

While these programs aim to provide welfare, Haekal (2020) critiques this model, arguing that it essentially commodifies local labor. The trainings create a vulnerable working class or an industrial reserve army designed to replace existing industrial labor as needed. Indirectly, displaced farmers serve as a reserve for the active proletariat engaged in the productive accumulation of capital (Habibi 2016). With Angkasa Pura projected to hire around 3,000 workers aged 17 to 35 (Pradana 2018), surplus labor that cannot compete in the formal market is diverted to the informal sector, such as opening souvenir shops. Competition becomes tighter with the influx of newcomers, leaving locals in the shadow of being reserves on the very land they sacrificed for public infrastructure.

This socioeconomic polarization highlights the governance paradox within the aerotropolis development. While the aerocity concept, globally, successfully integrates airports with business districts, as seen in Schiphol in the Netherlands, Piedmont Triad in the US, and Incheon in South Korea (Kasarda 2008; Chung and Feng 2016; Caritra 2019), its replication in Kulon Progo faces unique local constraints.

One major constraint is financing. The scale of development requires massive investment, leading the government to employ land value capture (LVC) and land readjustment mechanisms, which were initially conceived to finance infrastructure from the increased land value created by transportation access (Rybeck 2004; Pujianingsih and Setiawan 2021). In practice, LVC often prioritizes economic viability over spatial justice. Property appraisers play a crucial role here, but soaring land values prompt the government to use passive value capture systems, levying taxes on land that appreciates (Lee and Locke 2020).

Further, implementing land readjustment to reallocate public-space boundaries often disadvantages local landowners. Subjective community demands for justice complicate negotiations, lowering the government's bargaining position (Jibril et al. 2020). In reality, state entities such as the Ministry of Agrarian Affairs and PT Angkasa Pura I dominate these processes, reflecting a centralization of power (Wang et al. 2020). This hegemony often leads to neglect of public participation and the marginalization of minority groups, contradicting Lefebvre's vision of the production of democratic social space.

Local governance seeks to counter these structural inequalities through policies such as "Bela Beli Kulon Progo," which promotes local economic circulation. However, the former District Head of Kulon Progo (2017–22) acknowledged its limitations, stating that, "Relying heavily on large traders to distribute goods to people experiencing poverty has limitations. A more equitable approach would directly involve farmer groups and other





producers in the procurement process.” (Sutedjo, interview, July 13, 2024). The local government’s aspirations for inclusive development often clash with the top-down mandates of National Strategic Projects. High-level interviews revealed that local governments were overwhelmed by the delegation of authority from the central government; they were made responsible for implementation but severely constrained by limited funds. This imbalance in urbanization highlights a critical trade-off between the three pillars of sustainability: economic, climate, and social (Syaifuddin et al. 2021).

Finally, the aviation industry’s heavy reliance makes the aerotropolis vulnerable to global economic shocks. A lack of economic diversification leaves the region vulnerable to a single point of failure. If demand for air transportation declines due to pandemics or geopolitical shifts, the entire ecosystem could collapse. In spatial planning, an overemphasis on idealistic visions, such as the digital agro-aerotropolis, can hinder practical integration if the inevitable power dynamics are ignored (Yamamoto 2018). Power dynamics in this planning process predominantly benefit elite groups and state agencies, relegating the wider community’s interests to the periphery. Consequently, the evolving consensus on the aerotropolis in Kulon Progo has calcified into a relationship of domination rather than partnership. Without a fundamental restructuring of financing mechanisms and a genuine commitment to participatory governance, the agro-aerotropolis will remain a utopian representation of space. In contrast, the lived space of Kulon Progo becomes increasingly fragmented and unequal.

Conclusion

The development of the Kulon Progo Aerotropolis represents a pivotal shift in Indonesia’s strategic economic landscape. However, its success remains constrained by a profound authority gap between the central and regional governments. While the agro-aerotropolis framework was envisioned as a symbiotic integration of modernization and agriculture, its implementation has been hampered by a command-and-control model for National Strategic Projects. This study reveals that the regional government, while technically autonomous, has been reduced to an administrative executor of top-down mandates. This lack of genuine independence has created an “institutional overload,” in which the Kulon Progo District must manage the complex social and environmental fallout, such as depeasantization and housing fragmentation, without the sovereign fiscal or legal tools required to do so effectively.

Ultimately, the failure to maximize the potential of the aerotropolis is a symptom of the fiscal dependency trap. Because the project is driven by central funding and national interests, local spatial sovereignty has been subordinated to the dictates of global capital connectivity. The loss of 99.75 ha of productive land and the subsequent social displacement are the direct results of a governance structure that prioritizes national infrastructure targets over regional agrarian protection. For the Kulon Progo Aerotropolis to evolve into a truly sustainable and inclusive urban model, the relationship between the state levels must move from subordination to a power-sharing partnership that recognizes the district as a sovereign stakeholder in its own transformation.

To achieve a more inclusive and just regional transformation, the government must move beyond technocratic land readjustment toward a participatory, negotiation-based governance model that formally incorporates social and cultural heritage into land valuation. Finally, true regional autonomy requires a fiscal rebalancing where National Strategic Projects are accompanied by mandatory social impact financing from the central government, allowing local authorities to effectively manage long-term social costs without exhausting their limited regional budgets.





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Participatory Urban Transport Planning to Raise the Social Mobility of Urban Slum Communities in Jakarta, Indonesia

Wira A. Swadana^{1,*}, Fahri Santosa¹, Fachriy Mungkasa¹, Farijzal Arrafisena¹

¹ World Resources Institute (WRI) Indonesia, Jakarta, Indonesia

* Corresponding author: wira.swadana@gmail.com

Abstract

Jakarta has a population of over 10 million, but slum areas still account for more than 6 percent of the city's total area and lag in terms of social mobility. For example, the expansion of highways and gradual contraction of pedestrian networks have reduced transport accessibility, especially for marginalized communities and low-income households. This illustrates that economic and infrastructure development does not clearly correspond to improvements in people's livelihoods, partly because they are located on the city's periphery, making formal jobs in the city center inaccessible. This research addresses the question of how to alleviate poverty stemming from a lack of social mobility in Jakarta's slum areas, driven by limited transport options. Using qualitative research methods, this study employs a case study design to gather data and draw conclusions. The analysis shows that better approaches are needed to improve social mobility for slum populations. These improvements should consider participatory planning and implementation processes involving the slum communities to improve their transport mobility. Further, as Jakarta's emissions mostly come from the transportation sector, particularly private vehicles, an improved inclusive transport system could also stimulate efforts to reduce emissions, benefitting the environment and the planet. This research shows that the current government's approach to inclusive participatory transport planning, particularly in urban slum areas, is lacking. Participatory transport planning will support improvements in environmental quality and the socioeconomic conditions of underrepresented local communities in slum areas.

Keywords: participatory urban policy planning; slum; transportation; social mobility

Introduction

Rapid urbanization in Asian developing megacities has exacerbated long-standing inequalities in access to economic opportunities and social services (Bai and Krumdieck 2020). In Jakarta, rapid urban population growth has led to a sharp increase in the urban poor population in slum areas (Batubara and Rachman 2022; Batubara et al. 2024). They reside in densely populated areas on the outskirts of the city, far and disconnected from service centers and employment opportunities (Majocchi 2009; Winarso et al. 2015; Kusno 2019). Mobility systems play a pivotal role in tipping the scale for the urban poor to access the plethora of opportunities and services offered by a megacity, such as Jakarta (Muchlisin et al 2025). However, when public transport is inaccessible, unaffordable, unsafe, or poorly integrated, mobility constraints translate directly into limited livelihood choices and perpetuate cycles of urban poverty (Kong et al. 2021; Buchholz 2023).

The past decade has observed massive overhauls to Jakarta's mobility system, driven primarily by government-led investments. Changes include expanding coverage of Jakarta's bus rapid transit (BRT) system (BPK Republik Indonesia 2017; Transjakarta 2025) as well as the incorporation and currently ongoing service extension for both light rapid transit (LRT) and mass rapid transit (MRT) (Government of Jakarta 2023; LRT Jakarta 2025; Tempo 2025). Additionally, Jakarta has improved non-motorized mobility options, including by renovating sidewalks in certain areas and installing dedicated bike lanes in major arteries (Gewati 2016; Government of Jakarta n.d.).

Despite recent advancements in mobility systems, much of Jakarta's urban poor population remains underserved (Janssen et al. 2022). For example, Hidayati et al. (2020) highlighted that poor and discontinuous pedestrian





networks have discouraged the urban poor from walking to educational facilities. Additionally, limited public transport availability near urban poor settlements and the government's tendencies to favor vehicle-oriented street networks further constrain the mobility of urban poor (Hidayati et al. 2019; Janssen et al. 2022). This spatial configuration has forced the urban poor to rely on private vehicles, predominantly motorcycles (Janssen et al. 2022). Although motorcycles can benefit most of Jakarta's population, those living in extreme poverty cannot afford one—and even if they could, it would only diminish much of their financial resources (Hidayati et al. 2019). Altogether, these gaps in Jakarta's transport planning policies highlight the limitations of relying on predominantly top-down planning approaches, which are insufficient to capture the lived realities of marginalized communities (Hidayati et al. 2019; Hidayati et al. 2020; Janssen et al. 2022).

Participatory urban transport planning offers an inclusive pathway to address these shortcomings by actively involving affected communities (Linovski and Baker 2023). By using this method, planning processes can surface local knowledge derived from the community's daily mobility struggles, constraints, and concerns that are often overlooked in top-down planning approaches (Nared 2019). More importantly, participatory processes can shift planning objectives beyond network efficiency toward broader social outcomes, including enhanced access to jobs, education, and services (Fouracre et al. 2006; Manaugh et al. 2015).

This paper examines the use of participatory approaches in urban transport planning to improve the social mobility of urban slum communities in Jakarta. It does so by mapping the distribution of public transport services against the spatial concentration of slum settlements, integrating transit-oriented development (TOD) principles into participatory planning processes, and exploring the mechanisms through which participation-oriented approaches influence planning outcomes and mobility-related opportunities. By linking participatory planning to social mobility outcomes, this paper contributes to debates on inclusive urban infrastructure and provides policy-relevant insights for cities seeking to align transport investments with equity and poverty reduction objectives.

Literature review

Participatory urban planning

Participatory urban planning has many forms, guided by a multitude of goals and differing power redistributions. There is a strong correlation between how planners engage citizens, how planning problems are defined, and how the decision-making process is contextualized (Lok 2023). Within the urban planning context, there are three purposes to highlight:

- Public participation puts emphasis on the emotional bonds that people have with the neighborhoods they live in. This approach appreciates the connections people have with a place's attachment and identity (Inch 2014).
- Participatory planning aims to provide distributional justice and democratize decision-making (Fainstein 2014). This ensures a more equal distribution of public resources by giving voice to individuals affected by macro-level planning decisions and who previously lacked representation in planning processes (Lok 2023).
- This participatory approach helps identify the political and social impact of planning beyond the spatial and technical aspects to avoid resistance and opposition to planning decisions (Smith 1973).

By comparing the ideal conditions of participatory urban planning with the current transportation master plan for Jakarta Metropolitan, we identify the deficiencies in current development and provide recommendations to better represent slum areas in Jakarta.





Mobility and the urban poor

Low-income communities are often scattered far from major economic centers (Kain 1992; Gobillon et al. 2007). As such, they must travel longer distances, which translates into higher commuting costs (Banister 2008). Further, the long travel time and unreliable transport services exacerbate economic loss by reducing work productivity (Blumenberg and Pierce 2014). Adding on to the unreliability of transport facilities, there is also a weak first- and last-mile connectivity, such as missing or broken sidewalks (Boarnet et al. 2017). Overall, these factors form a regressive yet perpetuating cycle whereby distance, cost, time, and land-use patterns restrict social mobility for the urban poor. For example, these factors limit the availability of feasible socioeconomic opportunities and lower job stability. This highlights how mobility is a critical precondition for breaking these barriers and unlocking numerous socioeconomic opportunities (Ferreira et al. 2012). By defining the barriers to equitable mobility for the urban poor, we utilize spatial data to estimate the accessibility of transit facilities and provide recommendations for mobility-related indicators to be included in participatory planning.

TOD as a mean to reduce social inequity

In many cities, a shortage of affordable housing options results in lower-income and marginalized people being pushed or displaced to underserved outlying areas. These areas often lack access to jobs, educational opportunities, and basic services, or long commutes to reach them. TOD can be a strategy to help alleviate the socioeconomic impacts of reduced social mobility and inequity. According to the World Bank (2017), TOD is a planning and design strategy that promotes more compact urban development and easy access to transit by clustering jobs, housing, services, and amenities around public transport stations. TOD provides several benefits, including

- prioritization of modes that many low-income people, marginalized groups, women, and caregivers can use daily;
- reduction of time burden to travel to destinations, especially for time-constrained caregivers; and
- the ability of people of all income levels to live within walking distances of basic services, jobs, and transit (ITDP 2019).

By defining the main values of TOD, recommended indicators were formulated using a framework developed by Wan et al. (2023), contextualized to the problem of inequitable social mobility in urban slum areas. They also highlight the benefits of increasing transport accessibility.

Methodology

This research uses a qualitative approach for data collection and analysis. Using a case study approach, the authors attempted to answer questions about the case description and the issues that it raised and to explore the processes within the study's theme (Creswell and Creswell 2018). In this regard, the study addresses the research theme that has emerged from urban transport planning in Jakarta's slum areas. The urban transport planning process reveals that the current approach produces limited participatory planning, particularly in slum areas. Based on this finding, the authors further explore two potential discussion points, namely the integration of TOD into urban transport planning and the use of participatory urban transport planning to improve social mobility in slum areas.

This research collected qualitative data by selecting documents and materials to answer the research questions. These materials include Jakarta's main transport planning documents, as well as literature on the importance of participatory urban transport planning and social mobility. The research also conducted a qualitative spatial overlay between urban transport planning documents for the city and socioeconomic statistical data. This process would determine the status of urban mobility in Jakarta's slum communities.



The qualitative case study method facilitates the generalization of the findings by replicating the logic of previous research (Creswell and Creswell 2018). In this study, generalization stems from the status of participatory urban transport planning and social mobility in urban slum residential areas.

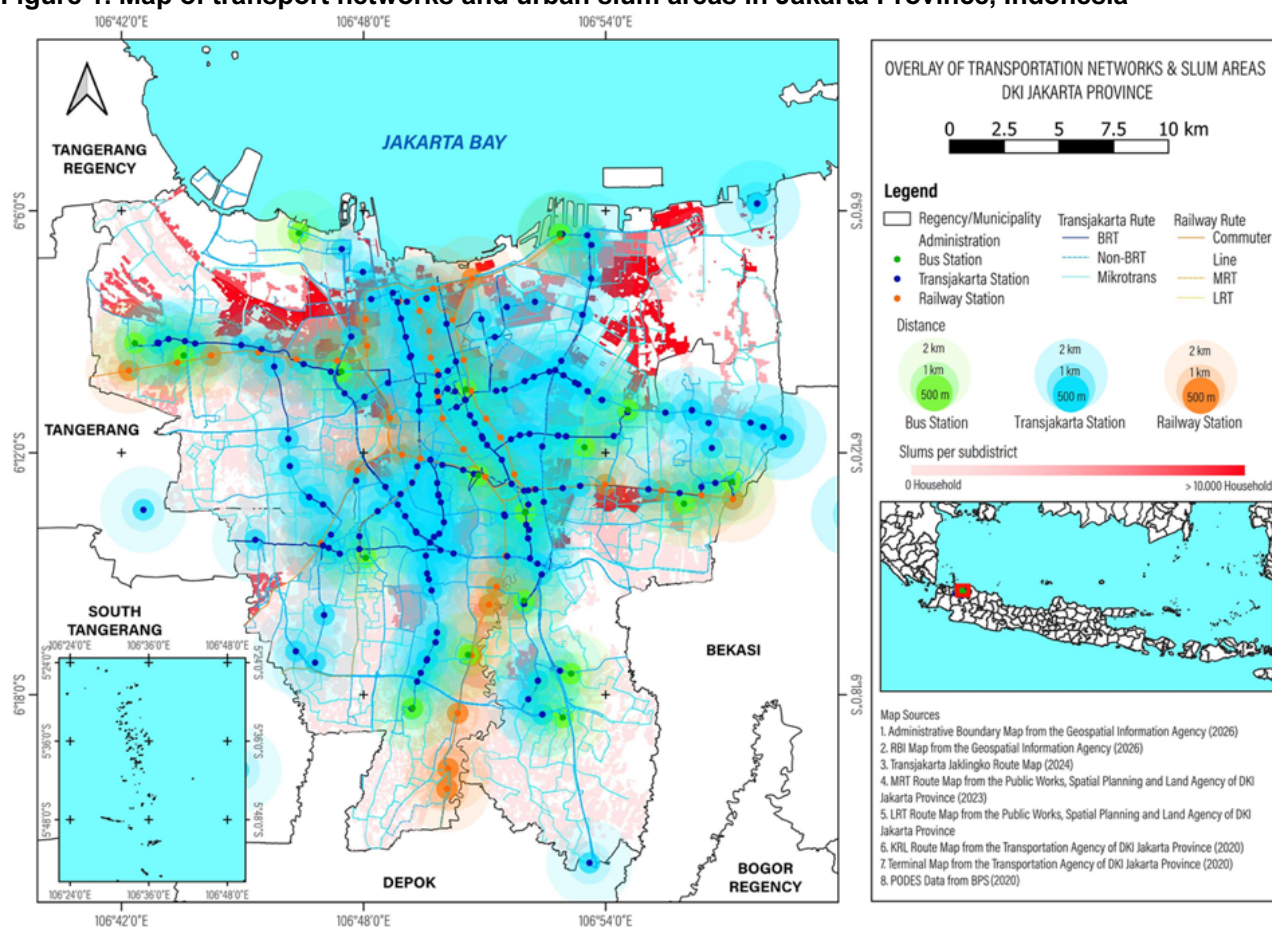
Results and discussion

Status of participatory urban transport planning in slum areas

According to Satu Data Jakarta (2025), slum areas accounted for 6 percent of the Jakarta area in 2024, with the majority located in the province's northern parts, as illustrated in Figure 1. The figure also shows that the current urban transport networks in Jakarta do not reach the slum areas. Overlaying transport network data with slum area spatial distribution indicates that many northern neighborhoods lack access to government-facilitated mass transportation services and are primarily served by paratransit, including Mikrotrans or minibuses (angkot).

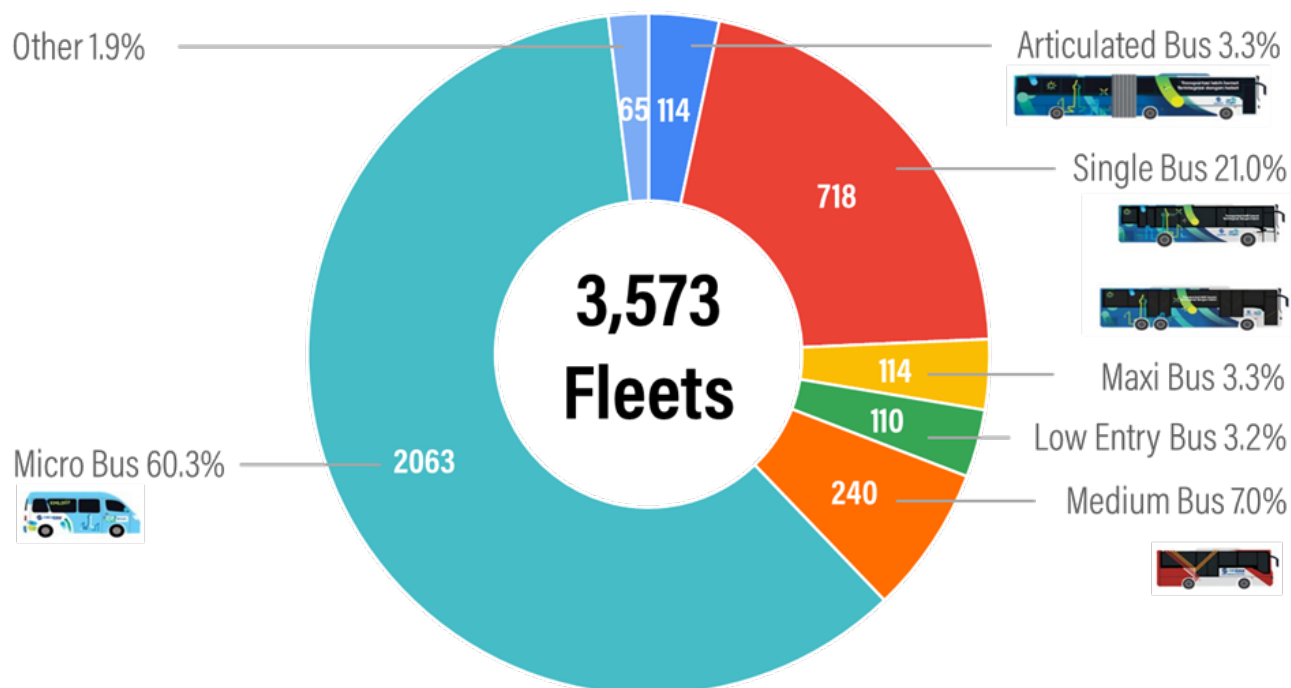
Mikrotrans, launched by the Jakarta government in 2018, aims to extend public transport to narrow roads and densely populated urban villages using four-meter minibuses with a capacity of up to 11 passengers (ITDP 2021). The formalization of paratransit into Transjakarta's system has significantly expanded coverage from 42 percent in 2017 to 82 percent in 2022, with Mikrotrans now accounting for over 60 percent of the network (C40 Cities Climate Leadership Group 2023). Nevertheless, important concerns regarding access and inclusivity remain.

Figure 1. Map of transport networks and urban slum areas in Jakarta Province, Indonesia



Source: Authors' analysis.

Figure 2. Number of fleets in the Transjakarta service as of November 2019



Source: ITDP 2022.

Key challenges include limited micro bus (Mikrotrans) size compared to regular buses, circuitous routes, the requirement to use a transportation card, and safety concerns (Tommy et al. 2026). At bus stops, issues persist, including unclear stopping points that hinder visually impaired users, ambiguous queue flows for priority groups, and the absence of clear audio and visual information about arriving services (ITDP 2025). These shortcomings raise concerns about the ability of Jakarta's slum communities to access economic centers in the city's central and southern areas.

On the other hand, the government has tried to adopt participatory approaches in formulating the provincial and metropolitan urban transportation master plan (Rencana Induk Transportasi Jabodetabek) 2018–2029 to improve community mobility in Jakarta. This has been done through the involvement of national and local governments, as well as the private sector. However, it is unclear how communities could participate directly in the development of the master plan (Government of Indonesia 2018). Through JakLingko¹, the Jakarta government also integrated wayfinding systems across public transport modes, with signage developed in collaboration with civil society organization Forum Diskusi Transportasi Jakarta (ITDP 2021). Yet, these initiatives have not sufficiently translated into improved outcomes for slum communities, which continue to face challenges related to last-mile access, inclusivity, and service quality.

As a result, while Jakarta's transport planning demonstrates incremental progress toward participatory governance, it remains closer to tokenistic or consultative participation rather than the empowered, justice-oriented participation envisioned in the literature. Bridging this gap would require more direct, inclusive, and continuous engagement with marginalized communities, ensuring that their needs shape not only design elements but also core policy decisions.



Integrating TOD in participatory planning

As most current urban transport networks in Jakarta are inaccessible to citizens in slum areas, integrating TOD into participatory planning is essential to addressing the aforementioned issues. Given TOD's ability to increase social mobility, several recommended indicators for integrating TOD into participatory planning, targeting underserved communities, were developed based on Wan et al. (2023) (Table 1). These indicators, divided into node, place, and economic values, have the potential to serve as quantified targets to be communicated to a variety of stakeholders, specifically affected communities within slum areas. The impacts of planning decisions are targeted towards increasing inclusivity, specifically in marginalized communities.

Table 1. Recommended indicators to be integrated in urban participatory planning

Dimension	Aspect	Recommended indicator within participatory planning
Node value	Transfer capacity	Facilitation of public transport/transfers (number)
		Convenience in-between transit facilities (walking transfer distance from exit station to nearest transit) (m)
	Accessibility	Average walking distance from stations to underserved communities' neighborhoods (i.e. slums) (m)
		Average walking distance from neighborhoods to employment facilities (m)
		Average walking distance from neighborhoods to recreational and commercial facilities (m)
Place value	Land use diversity	Proportion of residential land area accessible to marginalized communities (ratio of affordable residential land area divided by total area in %)
	Land development intensity	Ratio of employment and recreational facilities to the total number of facilities (%)
Economic value	Job-housing feature	Weekday commuting population density per income class (%)
		Weekend commuting population per income class (%)
		Employed population density within catchment radius (%)
	Balance of economic activity	Unevenness in the distribution of enterprises (Gini index)

Source: Authors' analysis based on Wan et al. (2023).

The node value dimensions will reflect whether marginalized communities can enter, transfer, and use planned transport networks. This will show whether stations can truly serve as multimodal transit facilities or only benefit certain users. Node value indicators in transport planning can inform marginalized residents' ability to reach jobs, schools, and services without long or costly transfers. Exemplified in a case study in Windhoek, Namibia, by Cui et al. (2026), node value indicators offer planning authorities diagnostic tools for targeted interventions to improve transport facility accessibility and provision of employment, thereby increasing social mobility. For example, areas with low node values indicate a lack of transport facility accessibility, meaning they would need the development of transit facilities such as bus stops, particularly when land use intensity is high.

Place value indicators can indicate whether TOD development will serve people or displace them. Land-use diversity parameters are used to prevent displacement and allow marginalized groups to live near opportunities rather than being pushed away. Finally, the economic value dimension ensures TOD provides shared prosperity through spreading economic and employment opportunities across all income classes. Zhao et al. (2024) highlighted that the incorporation of indicators representing vulnerable people into TOD planning will mitigate potential negative impacts, such as displacement, by measuring income-class representation in relation to commuting, employed populations, and distribution of enterprises using the Gini index.





Participatory urban transport planning to increase the social mobility of slum communities in Jakarta

Recent interest in expanding public participation in transport planning has led to a wide range of participation strategies and modes of collaboration (Carteni et al. 2022; Giuffrida and Pira 2025). Nevertheless, prevailing approaches agree that addressing power relations and elite capture is of utmost importance and that marginalized communities need to be involved throughout the planning process, with the early stages, i.e., goal formulation, being the most critical (Brown 2022).

During the early stages, it has been noted that inviting as many marginalized communities as possible is necessary (Bickerstaff et al. 2002; Gil et al 2011). This enables the governing entity to identify the concerns of different urban poor communities, with each community represented by a group representative (Nared 2019). Such an approach is necessary because the urban poor are composed of different age groups and, across different parts of the city, exhibit different travel patterns and mobility concerns. Having as many urban poor as possible, with diverse spatial characteristics and demographics helps provide granularity and useful insights for transport planning formulation (Bickerstaff et al. 2002). Most importantly, this approach reduces the risk that lived experiences from the urban poor will be discounted as not expert knowledge or drowned out by special interests (Linovski and Baker 2023).

Additionally, when formulating a goal, priority must be given to equity concerns (Brown 2022). This can be done by examining indicators across multiple groups over time and combining them with the perspectives of marginalized groups. These indicators encompass changes in accessibility to desired destinations for marginalized groups over the years, differences in journey times between the affluent and the marginalized, and the number of fatalities among car users and non-motorized users in traffic accidents (Manaugh et al. 2015). Accommodating these indicators will anchor the concerns of marginalized groups in actual data, reinforcing the rationale for advancing equity objectives.

Multiple studies (e.g., Fouracre et al. 2006; Linovski and Baker 2023) have shown that when driven by marginalized communities, transport planning produces more satisfactory proposed mobility solutions that better reflect the needs of marginalized communities than business-as-usual, top-down approaches. Additionally, other studies have suggested that incorporating participatory approaches into transport planning yields better investment targeting in slum areas, thereby improving access to essential services conducive to poverty alleviation (OECD 2019; Hrelja et al. 2024). Going beyond access to essential services and poverty alleviation, Camilleri et al. (2023) found that participatory planning was fundamental to building consensus and designing low-emission transportation systems.

Taken together, these findings imply that participatory transport planning serves as a key enabler of both socially responsive service design and longer-term structural transitions toward inclusive, low-emission urban mobility systems.

Conclusions

Our analysis shows that physical mobility is related to social mobility, as evidenced by the limited transport options available to urban slum communities in Jakarta. This is particularly evident when slum communities have less access to public transport than other communities in different parts of the city. Providing more transport options to underserved communities could help Jakarta alleviate poverty more effectively, particularly through participatory transport planning. This would also align with the city's interest in transforming its transport system to be more participatory and inclusive.

The government and other relevant stakeholders should consider TOD principles in urban transport development. By integrating TOD principles into participatory transport planning, the city could maximize the benefits of improving the socioeconomic conditions of underserved communities while minimizing the risk of further marginalization.





For further research, we suggest developing two studies. The first should focus on the methodology for developing a participatory approach to urban transport planning in Jakarta's slum areas. This would address the limitations of this research in answering the question of how participatory planning should be carried out. Secondly, research into defining meaningful participation in participatory urban transport planning would benefit the government and other stakeholders. In particular, it would help stakeholders improve their approach to participatory urban transport planning, moving beyond surveys and focus group discussions.

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A Study on Potential Areas for Active Transport Integration with Public Transport in South Tangerang, Indonesia

Devana Tsintaniarsy Iskandar^{1,*}

¹ Independent researcher

* Corresponding author: devanatsintaniarsy@gmail.com

Abstract

In 2023, South Tangerang, Indonesia, had 18.5 percent of commuters in a total of residents aged over 5 years old in the city, making it the third-largest commuter in Greater Jakarta. Ironically, among these commuters, only 15.7 percent use public transport, while 83 percent rely on private vehicles—and about 92 percent of commuters who do not use public transport are reluctant to switch to public transport. As a result, the city is now the most polluted in Indonesia. To reduce air pollution caused by commuting, the research aims to identify potential areas to develop to integrate active transport into public transport. The research focuses on five train stations and their surrounding areas in South Tangerang: Pondok Ranji, Jurangmangu, Sudimara, Rawa Buntu, and Serpong. The analytic hierarchy process (AHP) was used to determine the priority of these alternatives. To do this, the research defines four criteria: 500-meter walkability (criterion 1, weight 0.278), population density (criterion 2, weight 0.057), the availability of feeder services (criterion 3, weight 0.181), and the condition of the pedestrian areas (criterion 4, weight 0.484). The study finds that Rawa Buntu and Sudimara train stations are potential areas to be prioritized for development, with AHP composite weights of 0.249 and 0.161, respectively. The research can therefore support the government's strategy to reduce air pollution by revitalizing priority areas to encourage people to walk and cycle. However, the government must focus on expanding and upgrading existing public transport systems to make them more comfortable and safer, thereby encouraging their use.

Keywords: South Tangerang; polluted city; the highest number of commuters; analytic hierarchy process; location selection

Introduction

Seeking jobs in Jakarta, Indonesia's capital, has become common, as the megapolis serves as the country's primary economic hub. Consequently, the number of migrants has increased, leading to the development of surrounding areas known as the Greater Jakarta (also known as Jabodetabek, the acronym for Jakarta, Bogor, Depok, Tangerang, and Bekasi). Historically, Jakarta was inhabited by many migrants from rural areas, and had increased rapidly especially in 1942, when the Japanese started to occupy Indonesia (Rustiadi et al. 2015, 425). Population growth led to the expansion of slum areas in Jakarta, and as such, the idea of satellite cities for residential areas was discussed as part of Jakarta's development plan as the national capital. Tangerang, Bekasi, and Bogor were identified as satellite cities, a concept aimed to avoid overcrowding in Jakarta (Silver 2008, quoted in Rustiadi et al. 2015, 425). Jakarta's population growth reached its peak in the periods of 1961-1971 (55%) and 1971-1981 (42%), with growth much greater than that of the surrounding cities or Bodetabek (Rustiadi et al. 2015, 429-430). However, after 1981, the population growth has shifted to Bodetabek and has remained higher than in Jakarta (Rustiadi et al. 2015, 430). Jabodetabek has become a magnet for migrants, with South Tangerang among the affected cities.

South Tangerang recorded a population of approximately 1.4 million with a population density of 8,506 people per km² in 2025 and an increase of 4 percent over the five years from 2020 to 2025 (BPS South Tangerang City 2025b). This growth has heightened demand for housing, leading to massive land-use changes. Housing areas accounted for the largest share of land use in the city in 2018 at 65.76 percent (South Tangerang City Government 2021, 14-15). This phenomenon is largely inevitable, as residents prefer landed houses over vertical housing,





which is less culturally common. Data from Satu Data Tangsel (2023) show that in 2022, the total number of apartment buildings in South Tangerang was only 47. A 2020 study in Indonesia that included Millennials and Generation Z found that 62 percent, or 111 respondents, preferred to live in landed houses outside the city, while 38 percent, or 68 respondents, preferred vertical housing in city centers (Tang et al. 2022, 89). Interestingly, this survey by Tang et al. (2022, 90-93) found that the main reasons young people prefer a landed house were comfort, property/land ownership, a peaceful environment, and the flexibility to design their own house. Further, the social culture is also part of the reasons (Tang et al. 2022, 95), especially for the Millennials, as they prefer to live in their parents' house, which is typically a landed house (Nadiya 2017, quoted in Tang et al. 2022, 93).

However, landed houses consume vast areas of land at the expense of green spaces. Fitri et al. (2022, 122) found that South Tangerang lost 30 percent of its green space between 2010 and 2020, leaving only 28.7 percent remaining. This depletion of green areas reduces the ability to absorb hazardous particles from air pollution generated by industry and transportation, putting public health at risk (Izzatuljannah and Zakiah 2021, 70-73).

Notably, in 2023, South Tangerang was the third-largest source of commuters in Greater Jakarta, contributing 18.5 percent of commuters in a total of residents aged over 5 years old in the city (BPS 2024, 11). Within that group, there is a significant gap between those using private transport (83 percent) and public transport (15.7 percent) (BPS 2024, 46). Ironically, about 92 percent of commuters who do not use public transport in South Tangerang are reluctant to switch to public transport due to inefficiency, discomfort, safety issues, and accessibility challenges (BPS 2024, 50-54). Consequently, the city has become one of the most polluted in Indonesia. Data from IQAir Indonesia (2025) shows that from August 22 to September 20, 2025, the average PM_{2.5} level was 65.17 µg/m³, which is significantly higher than the World Health Organization (WHO) (2021) standard of 5 µg/m³.

Walking and cycling are modes of transportation that do not produce air pollution and are also known as active transport. A study by Woodcock et al. (2009, 1930) finds that increases in active transport and decreases in motor vehicle usage have reduced carbon dioxide emissions in London and Delhi. Aside from reducing air pollution, active transport also improves public health by increasing physical activity. Xu et al. (2013, 311) did a systematic review to understand the link between active transport and public health and found that the health impacts of active transport vary. Cardiovascular health was the most impacted, while the impact on body weight was moderate, and on mental health and cancer was the lowest.

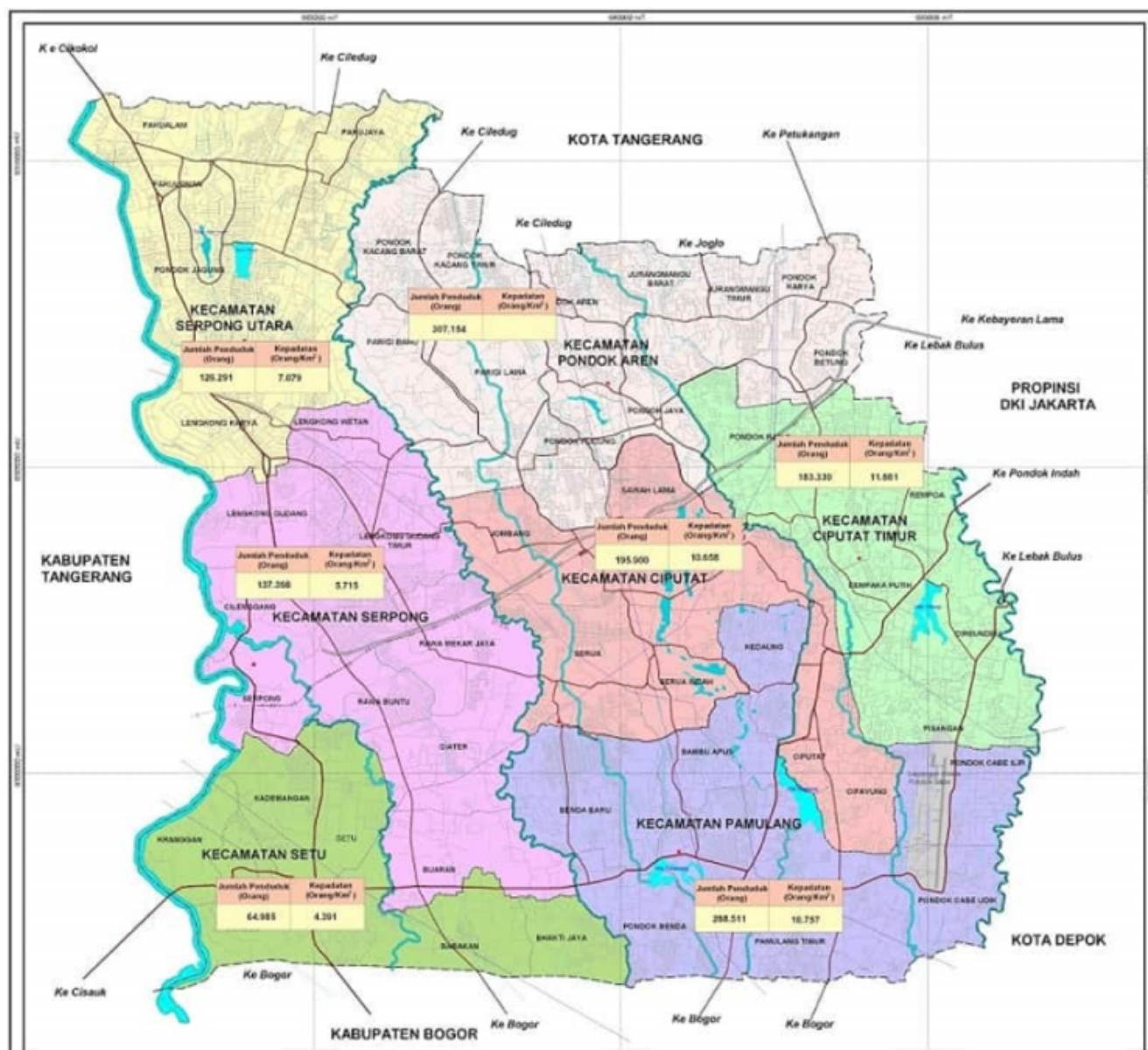
To reduce air pollution from commuting and improve public health, this research aims to analyze potential areas for developing active transport that is integrated with public transport. The two potential areas have been selected, which can be the first pilot project to revitalize the transit environment to promote active transport in South Tangerang.

Study Area

South Tangerang was established as an official city on November 26, 2008, with seven subdistricts (*kecamatan*), including Serpong, Serpong Utara, Pondok Aren, Ciputat, East Ciputat, Pamulang, and Setu, all of which were previously parts of Tangerang District (Republik Indonesia 2008, 4-5). The city is strategically positioned, as it borders Tangerang City to the north, South Jakarta to the east, Depok to the south, and Tangerang to the west (Figure 1).



Figure 1. Map of South Tangerang administrative area



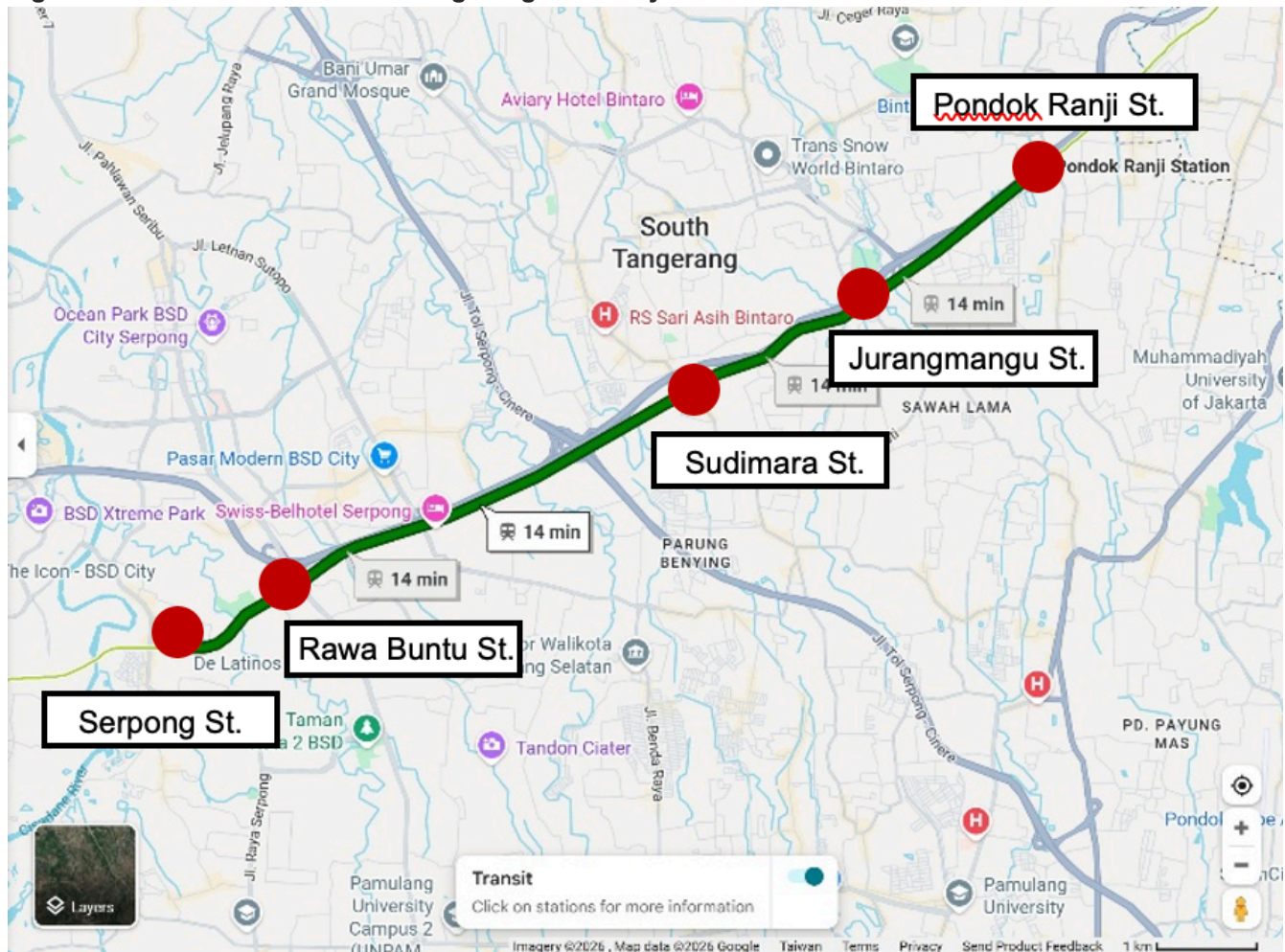
Source: Peta-hd 2022.

South Tangerang's position, directly adjacent to Jakarta, has made it attractive as a residential area. Rustiadi et al. (2015, 425) found that the development plan for the Greater Jakarta area required immense investment that could not be met with public funds alone. As such, the housing has been predominantly developed by the private sector, such as Jaya Real Property, Sinar Mas Land, and Alam Sutera. Jaya Real Property—one of the biggest and oldest private housing developers in Indonesia—is worth underlining as it has shifted the branding of its flagship Bintaro Jaya complex from “The Garden City” to “The Professional’s City” as the majority of its residents, who come from diverse professional backgrounds, commute daily to their workplaces in Jakarta (Tarigan and Rukmana 2025, 12). According to Statistics Indonesia (BPS) (2024, 12-14), commuters residing in South Tangerang mostly travel to the city itself (71%) and to South Jakarta (13%).

Figure 2. Map of commuter train lines in the Greater Jakarta and Merak



Figure 3. Train stations in South Tangerang served by the commuter trains



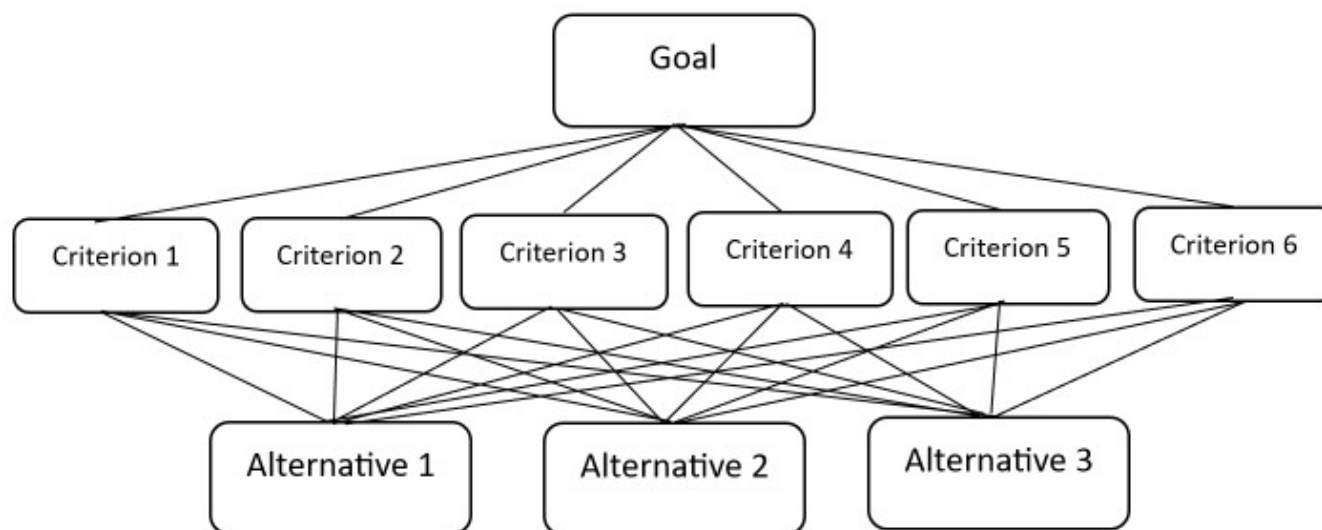
Source: Google Maps 2026.

Methodology

According to Saaty and Vargas (2012, 1), the analytic hierarchy process (AHP) is a basic approach to decision-making, designed to cover both the rational and the intuitive, for selecting the best among several alternatives evaluated based on several criteria. Susila and Munadi (2007, 985) explain that AHP is a multi-criteria decision-making tool to determine priority levels among alternatives, helping decision-makers choose among options based on a diverse set of criteria.

Before conducting AHP, the alternatives to be analyzed should be selected through a structured, logical process (Susila and Munadi 2007, 985). In doing so, a hierarchy decomposition is formulated. A hierarchy consisting of three levels is used to structure the decision problem, with the goal as the first level, the criteria the second, and the alternatives the third (Saaty and Vargas 2012, 2). The goal is what a decision-maker intends to achieve, while the criteria support the consideration process, and the alternatives are specifically selected options to achieve the goal (Figure 4).

Figure 4. A hierarchy decomposition

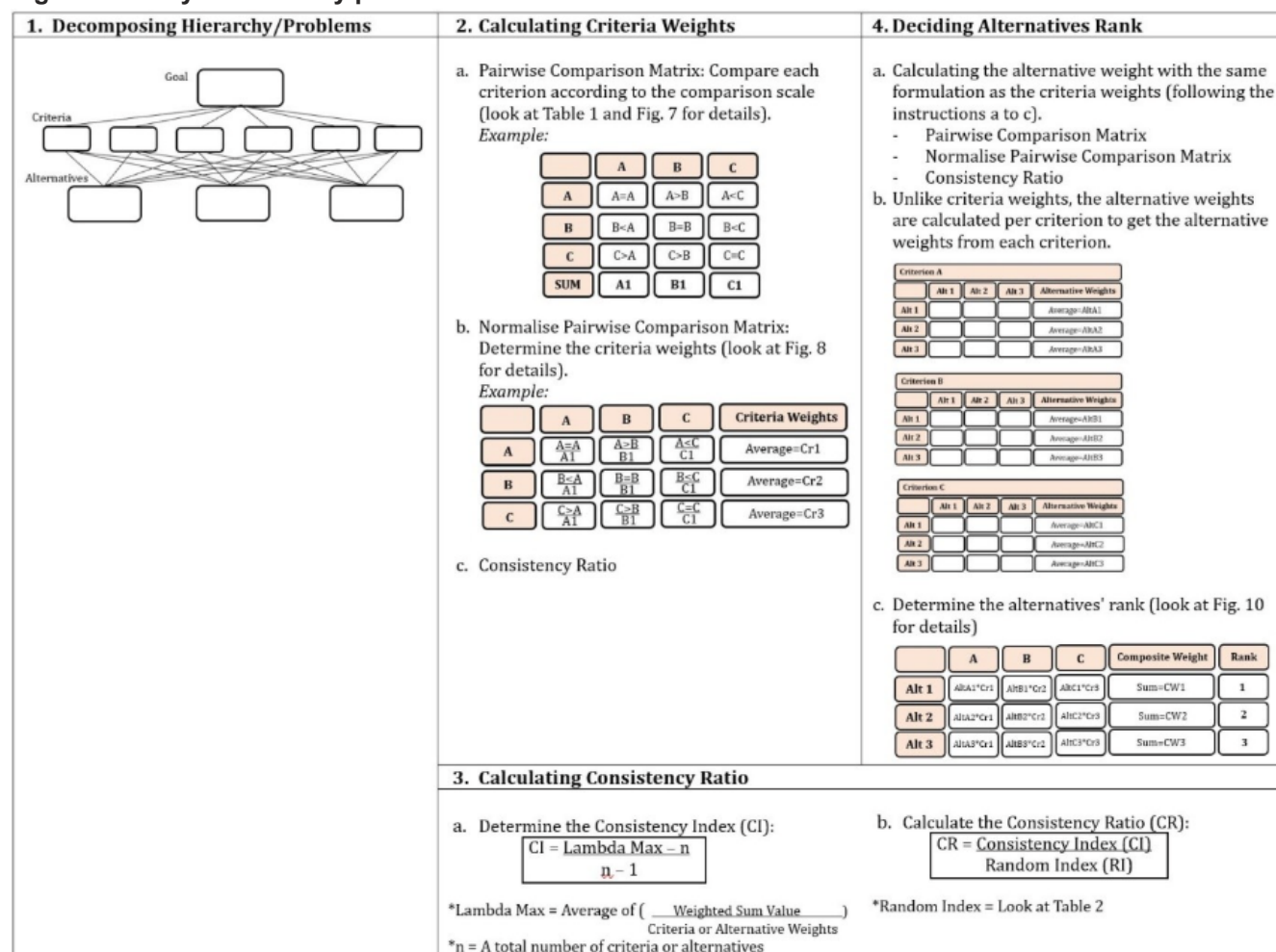


Source: Saaty and Vargas 2012.

Marbun and Sulianta (2024, 7-8) illustrated the use of AHP to determine the optimal location for public infrastructure development in Bandung, Indonesia. The three criteria used were location size, cost, and facilities, while the alternative locations were in Braga, Cibiru, and Bojongsoang. It should be underlined that the alternatives being compared should be homogeneous (Saaty and Vargas 2012, 2), as shown in Marbun and Sulianta's (2024, 8) research, which used locations as their alternatives.

The calculation continues with an evaluation/appraisal to compare alternatives in the composition, the results of which are synthesized for prioritization (Susila and Munadi 2007, 986). It is important to note that the AHP should verify that the calculations across criteria and alternatives are consistent (Marbun and Sulianta 2024, 6). In this study, the AHP was divided into four steps: decomposing the hierarchy/problems, calculating criteria weights, calculating consistency, and ranking the alternatives. The detailed process of AHP calculation was explained by Mathew (2018) in his video tutorials as a supporting guide for this research. Therefore, Figure 5 is an AHP structure with a detailed calculation process.

Figure 5. Analytic hierarchy process



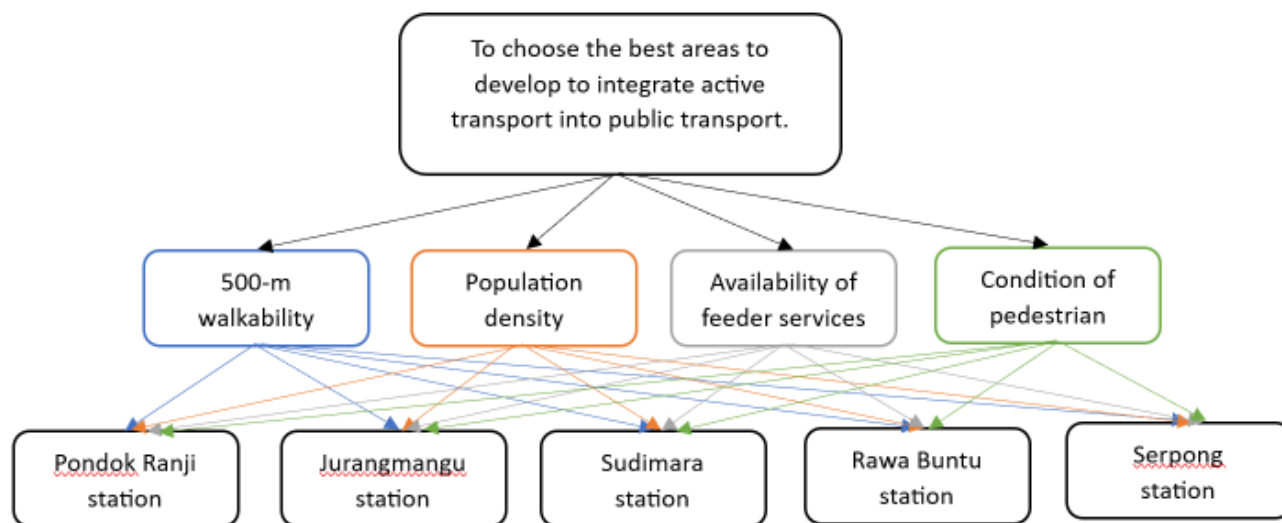
Source: Marbun and Sulianta 2024; Mathew 2018; Saaty and Vargas 2012; and Susila and Munadi 2007.

Decomposing problems

The problem is decomposed into a three-level hierarchy consisting of the goal, criteria, and alternatives. First, the goal must be clearly defined. In this research, the goal is "to choose the best areas to develop to integrate active transport into public transport" (Figure 6).

Based on this goal, four key criteria were selected: 500-meter (m) walkability, population density, the availability of feeder services, and the condition of the pedestrian areas.

Figure 6. Problem decomposition



Source: Author's analysis.

Five-hundred-meter walkability

A critical factor in developing active transportation is ensuring that public transportation is accessible within a short time and distance. A 500-m walking radius is considered the ideal distance for commuters willing to walk or cycle. According to Presidential Regulation Number 55 of 2018 concerning the Transportation Master Plan for Jabodetabek, the maximum walking distance to public transit is 500 m (Government of Indonesia 2018, 2). Further, the walking time to the nearest transit node should ideally range between five and 10 minutes, or within a 400- to 800-m radius (Ministry of Agrarian Affairs and Spatial Planning/National Land Agency 2017, L-4). Therefore, evaluating the walkability potential of each location is a vital step in selecting the best alternatives.

Population density

Population density is an essential indicator for public transportation planning, as higher population levels correlate with greater demand for accessibility and mobility. Population growth strongly correlates with the number of urban trips and travel demand (Aljoufie et al. 2011, 324).

In densely populated areas, people move in massive volumes. Consequently, integrated accessibility and mobility facilities are primary necessities in rapidly growing cities and their surrounding areas, directly impacting the regional economy. Conversely, a lack of such infrastructure leads to severe traffic congestion and rising carbon emissions, which detract from public health and cause environmental damage. An imbalance between travel demand and transport infrastructure supply consequently increases congestion (Aljoufie et al. 2011, 325). Therefore, identifying high-population-density areas is a crucial step in selecting the most suitable transport integration alternatives.

Availability of feeder services

Another critical indicator for developing an integrated active and public transportation system is the availability of local transport to the main transit hubs. Local feeder services offer diverse routes for commuters, effectively expanding the service area and providing more people with access to the public transport network. By providing feeder services, people living more than 500 m from transit areas can access public transport, reducing the need for private transport. Longer distances to access or egress transit stations discourage individuals from using transit services (Park et al. 2015, quoted in Ha et al. 2023, 15).



Indonesia's regulation also requires the presence of at least one local feeder in the design of transit-oriented development (Ministry of Agrarian Affairs and Spatial Planning/National Land Agency 2017, L6-L7). Consequently, the availability of feeder services in public transport must be prioritized to integrate main hubs and local residential or commercial areas.

Condition of the pedestrian areas

Pedestrian infrastructure is a vital supporting facility for transport planning and improvement, and high-quality pedestrian environments are essential to promoting a shift toward active transport modes. As this paper aims to integrate active transport into public transport systems, it evaluates three key dimensions related to pedestrian areas: the presence of pedestrian pathways, the physical quality of the infrastructure, and user safety.

A study in the Delhi Metro Rail found that the most significant index of pedestrian environment affecting the users' choice to walk is the route quality and placemaking (safety & security, aesthetics, liveliness, and activity), while for infrastructure availability, infrastructure condition & quality, and route continuity & connectivity, exhibited low/moderate correlation and were not statistically significant; the reason of this, probably, because the station had poor infrastructure, but the route environment exceptionally good (Chidambara 2019, 192-193).

Chidambara's study may not significantly align with this study, as infrastructure availability, condition, and quality were not significantly correlated with people's willingness to walk, yet this study aligned with Chidambara's findings by underscoring the importance of pedestrian safety and security, which can promote walkability. Venter (2020, quoted in Ha et al. 2023, 2) also highlights that transit users prioritize safety and a pleasant environment, but in contrast, Venter's study finds that transit users also highlight sidewalk quality. Thus, assessing the condition of pedestrian areas is a fundamental consideration when determining the most suitable alternatives for integrating active transport with public transport.

Finally, the alternatives must be identified by defining the potential areas (Susila and Munadi 2007, 985). To achieve the objective, five train stations in South Tangerang were selected as alternatives: Pondok Ranji, Jurangmangu, Sudimara, Rawa Buntu, and Serpong.

Calculating criteria weights

Criteria weights are calculated from a pairwise comparison matrix, in which each criterion is compared with the others on a standardized scale (Mathew 2018). This process determines the relative importance of each criterion in achieving the overall goal.

Table 1. Comparison scale

Intensity of Importance	Definition	Explanation
1	Equal importance	Two activities contribute equally to the objective
2	Weak	
3	Moderate importance	Experience and judgment slightly favor one activity over another
4	Moderate plus	
5	Strong importance	Experience and judgment strongly favor one activity over another
6	Strong plus	
7	Very strong or demonstrated importance	An activity is favored very strongly over another; its dominance demonstrated in practice



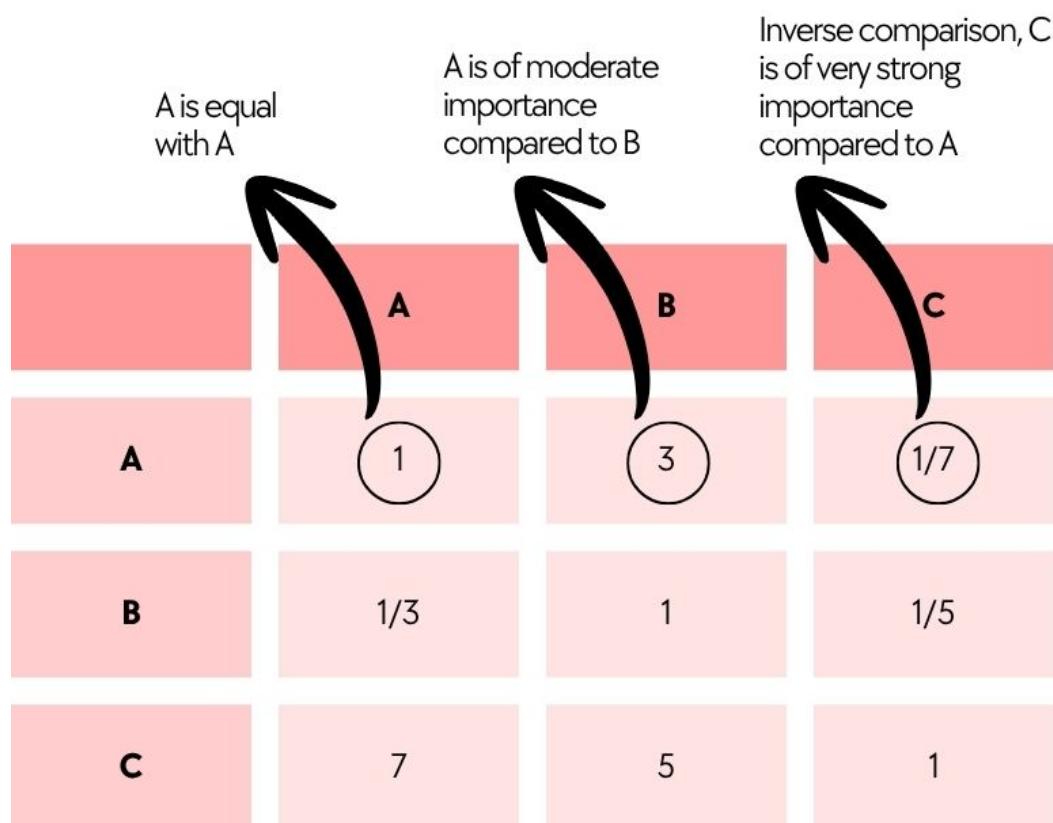


8	Very, very strong	
9	Extreme importance	The evidence favoring one activity over another is of the highest possible order of affirmation
Reciprocals of above	If activity i has one of the above nonzero numbers assigned to it when compared with activity j , then j has the reciprocal value when compared with i	A reasonable assumption
Rationals	Ratios arising from the scale	If consistency were to be forced by obtaining n numerical values to span the matrix

Source: Saaty and Vargas 2012.

The comparison scale is used to assess the relative importance of one criterion over another (Ishizaka and Labib 2011, quoted in Cremades and Ponsich 2024, 4) (Figure 7). In this scale, a value of 1 signifies that both criteria are equally important, while 3 indicates a moderate level of importance and 5 a strong level of importance. A value of 7 denotes a very strong importance relative to another criterion, and 9 represents absolute importance (Marbun and Sulianta 2024, 6).

Figure 7. Illustration of pairwise comparison matrix



Source: Author's analysis.

Subsequently, the criterion weights are determined by summing each column of the matrix and dividing each cell by its respective column total. Finally, the average of each resulting row is calculated (Mathew 2018). This average represents the priority weight for each criterion, defining which factors are most or least significant in influencing the ranking of the alternatives.



Figure 8. Illustration of a normalized pairwise comparison matrix

	A	B	C		A	B	C	Average
A	1	3	1/7	A	1 / T1	3 / T2	1/7 / T3	A1
B	1/3	1	1/5	B	1/3 / T1	1 / T2	1/5 / T3	B1
C	7	5	1	C	7 / T1	5 / T2	1 / T3	C1
Total	T1	T2	T3					

Source: Author's analysis.

This process is also required for calculating the alternative weights. However, these weights must be calculated separately for each criterion to determine the comparison scale.

Calculating consistency

Measuring consistency is essential for validating the reliability of pairwise comparisons and ensuring that they are not based on inconsistent judgments (Marbun and Sulianta 2024, 6). To demonstrate that the values in the comparison matrix are consistent, its consistency ratio (CR) should be less than 0.1. If the CR exceeds 0.1, it indicates inconsistent judgments, and the pairwise comparison must be repeated.

To calculate the CR, the first step is to determine the consistency index (CI) using the following formula:

$$CI = \frac{\text{Lambda max} - n}{n - 1}$$

In this formula, lambda max is the principal eigenvalue, calculated as the average of the weighted sum values divided by the criteria weights, while “n” represents the number of criteria.

Figure 9. Illustration of the calculation of lambda max

Criteria Weight	A1	B1	C1
	A	B	C
A	1	3	1/7
B	1/3	1	1/5
C	7	5	1

	A	B	C	Weighted SUM Value	Criteria Weights	Weighted SUM Value Criteria Weight
A	1 / A1	3 / B1	1/7 / C1	W1	A1	W1 / A1 = D1
B	1/3 / A1	1 / B1	1/5 / C1	W2	B1	W2 / B1 = D2
C	7 / A1	5 / B1	1 / C1	W3	C1	W3 / C1 = D3
Lambda Max						$\frac{D1 + D2 + D3}{3} = L1$

Source: Author's analysis.

After obtaining the lambda max value, the CI is determined using the previously mentioned formula. Subsequently, the CR is calculated as follows:

$$CR = \frac{CI}{RI}$$

The random index (RI) is a standard constant developed by Thomas L. Saaty (1980) (Figure 9). The appropriate RI value depends on the number of elements (n) being compared. In this study, to check the consistency of the criteria (n=4), an RI value of 0.90 is used. For the alternatives (n=5), an RI value of 1.12 is applied. The standard RI values are presented in Table 2.

Table 2. Random index

n	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
RI	0	0	0.58	0.90	1.12	1.24	1.32	1.41	1.45	1.49	1.51	1.48	1.56	1.57	1.59

Source: Saaty 1980, quoted in Piantanakulchai and Saengkhao (2003).

Ranking the alternatives

The final step involves determining the overall ranking of the alternatives by calculating their composite weights (Figure 10). The areas with the highest resulting values are the most suitable for developing active transport integration into public transport. The procedure is

- consolidate the weights of each alternative under each criterion;
- calculate the composite weights by multiplying the criteria weights by the corresponding alternative weights and adding the results to obtain a final score for each alternative; and
- rank the alternatives in descending order based on their composite weights.

Figure 10. Illustration of ranking the alternatives

Criteria Weight	A1	B1	C1		
	Criterion 1	Criterion 2	Criterion 3	Composite Weight	Rank
A	CrA1	CrA2	CrA3	$(CrA1 \cdot A1) + (CrA2 \cdot B2) + (CrA3 \cdot C1) = CW1$	3
B	CrB1	CrB2	CrB3	$(CrB1 \cdot A1) + (CrB2 \cdot B2) + (CrB3 \cdot C1) = CW2$	1
C	CrC1	CrC2	CrC3	$(CrC1 \cdot A1) + (CrC2 \cdot B2) + (CrC3 \cdot C1) = CW3$	2

Source: Author's analysis.

Ultimately, this process identifies the alternative that holds the highest potential to achieve the goal, based on the selected criteria. In the context of this research, this result pinpoints the area(s) most in need of attention and strategic investment to develop an integrated active and public transport system in South Tangerang.



Results and discussion

Criteria weights

The criteria weights were successfully calculated, with a CR of 0.05. The resulting criteria weights are presented in Table 3.

Table 3. Criteria weights calculated in the study

Number	Criterion	Criteria weight
1	500-m walkability	0.278
2	Population density	0.057
3	Availability of feeder services	0.181
4	Condition of the pedestrian areas	0.484

Source: Author's analysis.

Clearly, this paper focuses on supporting active transport to phase out the use of private transport, thereby impacting environmental value. As such, the condition of pedestrian areas had the highest weight, as it is the primary factor supporting active transport planning. This criterion is followed by the ideal walking distance to public transit areas.

Gradually, as pedestrians are well served and walking distances to public transport hubs are short, people's behavior will shift toward active transport. According to Gan et al. (2021, quoted in Ha et al. 2023, 3), based on previous studies, better built-environment features for walking behavior can facilitate a longer acceptable walking distance. They suggested that improving the walkability of residential areas can motivate individuals to walk more near their homes and encourage them to use public transport.

However, the acceptable walking distance for transit can vary across regions (Olszewski and Wibowo 2005; El-Geneidy et al. 2014; Jun et al. 2015, quoted in Ha et al. 2023, 2). As discussed in the previous section, South Tangerang is one of the most polluted cities in Indonesia, with the average PM_{2.5} level was 65.17 µg/m³ from August to September 2025, which was higher than the WHO standard of 5 µg/m³. It can affect the city's temperature conditions, where the heat can influence people's willingness to use active transport. Typically, people prefer walking a longer distance with minimal sun exposure to a shorter but hotter path (Melnikov et al. 2022, 6).

This study aims to encourage the selection of the best option among the alternatives, which should be located closest to the transit environment, because most of the surrounding areas are residential with supporting activities such as local/traditional markets that experience high movement during peak hours. This factor must be supported by the availability of feeder services to facilitate more people to travel across wider areas. While population density has the lowest weight, this criterion is influential due to the need for accessibility and mobility.

Ranking the alternatives

After comparing five train stations in South Tangerang, this study identified the two best alternatives for integrating active transport with public transport. These train stations are Rawa Buntu, with a composite weight of 0.249, and Sudimara, with a composite weight of 0.161 (Table 4). They are supported by different levels of criterion strength. Rawa Buntu station ranks highly in criteria 3 (0.346) and 4 (0.341). Notably, criterion 4—condition of pedestrian areas—is the most important factor in the model, significantly influencing the overall ranking of the alternatives. Conversely, Sudimara station demonstrates strong performance in criteria 1 (0.376) and 2 (0.562).



Table 4. Ranks of alternatives in the study

Alternative (stations)	Local weight (criterion)				Composite weight	Rank
	1 500-m walkability	2 Population density	3 Availability of feeder services	4 Condition of pedestrian areas		
Pondok Ranji	0.160	0.083	0.122	0.081	0.111	4
Jurangmangu	0.033	0.173	0.058	0.160	0.107	5
Sudimara	0.376	0.562	0.031	0.038	0.161	2
Rawa Buntu	0.062	0.077	0.346	0.341	0.249	1
Serpong	0.307	0.028	0.097	0.038	0.123	3

Note: Figures in bold indicate the highest values for the specific criterion among the alternatives.

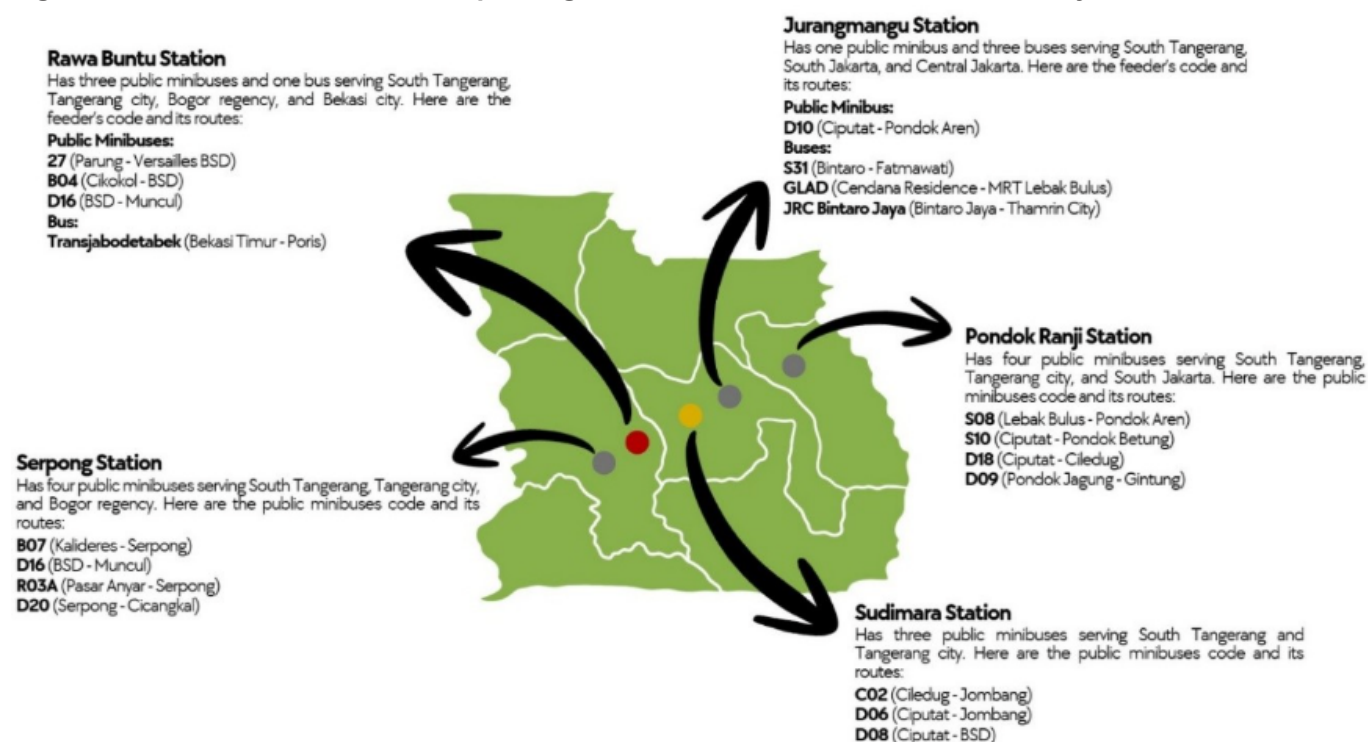
Source: Author's analysis.

Compared to other alternatives, Rawa Buntu station has an extensive feeder service, served by three public minibuses (locally known as *angkot*) and one bus line, covering four regions: South Tangerang City, Tangerang City, Bogor District, and Bekasi City. Wide service routes indicate more diverse coverage, allowing more people to reach public transit hubs and potentially reducing private transport use.

However, to improve this service, the government should expand and upgrade public minibus services, as in the 21st century we have been facing an explosive growth in new-age forms of mobility, including the rise of ride-hailing, which has utilized technology (Cervero 2020, 138-139). Rayle et. al (2016, quoted in Cervero 2020, 139) find that the reason people used Uber and Lyft was due to the ease of payment, ride request using a smartphone, and short waiting time. Another study by Rozin and Yugopuspito (2022, 1440) also finds that customers' switching behavior from traditional motorcycle taxis to ride-hailing due to their better service. Further, the low quality of public minibus services and crime risks often cause discomfort and safety concerns. As mentioned briefly in the Introduction, commuters in South Tangerang are reluctant to switch to public transport, citing safety, discomfort, inefficiency, and inaccessibility as reasons (BPS 2024, 51-54).

Because public minibuses' income depends directly on the number of passengers, they often wait long periods for passengers to fill their vehicles, resulting in inconsistent departure times and longer travel times for passengers. The public minibuses also often cause traffic congestion as they stop and go whenever passengers need to be picked up or dropped off along their routes (Rahayu 2021, 202-203). Another potential disadvantage for users is the transport fee, which depends on the driver's judgment. Although the fee is usually based on the distance covered, drivers can charge different amounts (Rahayu 2021, 202-203). Therefore, improving the quality and service of public minibuses remains a critical issue for transport integration.

Figure 11. Routes of feeder services passing the train stations selected for this study



Source: Moovit 2025.

Rawa Buntu station has the best pedestrian infrastructure, characterized by well-maintained sidewalks and vegetation that provides natural shade. However, the lower section of the road leading to the station entrance is quite narrow and is frequently used as a pick-up and drop-off point for vehicles, posing a safety risk to pedestrians. To maximize its function, the sidewalk needs to be optimized by adding pedestrian features and road facilities, such as zebra crossings, street lights, traffic signs, and traffic lights to support active transport.

In contrast, the Sudimara and Serpong stations lack sidewalks entirely, as many buildings protrude into the road, leaving no space for pedestrians. Where sidewalks do exist, they are often occupied by feeder minibuses and food stalls, making it difficult for commuters to pass. This forces pedestrians to walk on the main road, putting them at risk from the constant flow of vehicles. While Pondok Ranji and Jurangmangu stations also lack sidewalks, both have successfully integrated their facilities with nearby malls through connecting walkways. However, these walkways do not reach the residential areas in the opposite direction.

Figure 12. Comparison of the conditions of pedestrian areas at the stations



Source: Google Earth 2024



Sudimara station scores the highest in criterion 2 (population density) and criterion 1 (walkability). Sudimara station is located in Jombang urban village (*kelurahan*), which has the largest population of 46,684 residents, followed by Jurangmangu station in *kelurahan* Sawah, with 34,668 residents (Table 5). Both stations are situated within Ciputat subdistrict, which is the most densely populated among the studied sites, with a population density of 11,062 people per km² (Table 6). Moreover, due to its large population, Sudimara station is directly surrounded by residential areas, allowing more people to reach the station by walking or cycling within a 500-m radius. Consequently, Rawa Buntu and Sudimara stations should be prioritized for development.

Table 5. Population by urban village (*kelurahan*)

Station	Kelurahan	Population
Pondok Ranji	Pondok Ranji	31,961
Jurangmangu	Sawah	34,668
Sudimara	Jombang	46,684
Rawa Buntu	Rawa Buntu	30,113
Serpong	Serpong	22,536

Source: South Tangerang City Population and Civil Registry Office 2025.

Table 6. Population density by subdistrict

Station	Subdistrict	Population	Area (km ²)	Density (people/km ²)
Pondok Ranji	East Ciputat	175,673	17.81	9,864
Jurangmangu	Ciputat	233,528	21.11	11,062
Sudimara	Ciputat	233,528	21.11	11,062
Rawa Buntu	Serpong	172,931	28.27	6,117
Serpong	Serpong	172,931	28.27	6,117

Source: Author's analysis based on data from the demographic statistics dashboard of the South Tangerang City Population and Civil Registry Office and the BPS of South Tangerang City.

As a heavily polluted city, South Tangerang should implement various strategies to reduce pollution, given its negative effects on people's health and well-being. One long-term strategy this study offers is to encourage the government to promote a walkable city by improving active-transport infrastructure and ensuring its integration with public transport systems. Implementation of this strategy could begin by revitalizing the built transit environment, represented by train stations in this study.

Promoting a walkable city (active transport) and its connection with public transport will bring various benefits, including improved physical health and well-being and reduced air pollution. Individuals who took part in physical activities, including walking and cycling, have shown less frequent depression, as diagnosed by doctors, than those who did not (Paffenbarger et al. 1994, quoted in Woodcock et al. 2009, 1936).

The study by Woodcock et al. (2009, 1936-1937) found that in London and Delhi, the scenarios with lower-carbon-emission motor vehicles, increased active travel, and sustainable transport could reduce the disability-adjusted life years (DALYs) and premature deaths caused by air pollution. In 1 year, in London and Delhi, the lower-carbon-emission motor vehicles scenario saved 160 DALYs and 17 premature deaths per million population, and saved a total of 1,696 DALYs and 74 premature deaths per million population, respectively; increased active travel saved 7,332 DALYs and 530 premature deaths per million population, and saved 12,516 DALYs and 511 premature deaths per million population, respectively; and the sustainable transport saved 7,439 DALYs and 541 premature deaths per million population, and saved 12,995 DALYs and 532 premature deaths per million population, respectively (Woodcock et al. 2009, 1936-1937). Similarly, Fransen et al. (2023, 104) show that current transportation approaches are unsustainable as they will generate three to six times more greenhouse gas emissions by 2050 than in scenarios consistent with Paris Agreement and cost roughly 1.35 million lives in road fatalities every year (WHO 2018a, quoted in Fransen et al. 2023, 104). The current transportation approaches in





Indonesia have pushed people to choose private transport over public transport. It has been proven by BPS records in 2024 that the number of motorcycle and car users in Indonesia had reached 84% and 12%, respectively, which were higher than the number of buses as a public transport, at only 0.17% (BPS 2025). A predominance of private transport users can increase the risk of road fatalities as the most significant factor of this incident due to human error (77%) as compared to defects in vehicles, roads, or weather conditions (Singh et. al 2016, 54). Pedestrians, comprising the elderly and children, are the most commonly affected group of road accident victims (Singh et. al 2016, 54). Besides road fatalities, the current transportation approaches can harm human from air pollution that is expected to cause nearly 4.2 million premature deaths (WHO 2018b, quoted in Fransen et al. 2023, 104), of which a tenth is from air pollution generated by transport (Anenberg et al. 2019, quoted in Fransen et al. 2023, 104), and a lack of physical activity accounts for 5.3 million more (Lee et al. 2019, quoted in Fransen et al. 2023, 104).

Fransen et al. (2023, 104) offer the “Avoid-Shift-Improve” framework as a new approach for sustainable transport. The first is to avoid people's need for motorized travel by integrating transport and spatial planning, improving regional and urban development policies, and optimizing the management of logistics and travel demand. One example is to have mixed-use buildings, where people can easily meet their daily needs by walking or cycling without having to travel far. The second element is to shift to more environmentally friendly transport modes, such as public transport, walking, cycling, and new mobility services (carpooling and vehicle sharing). The last element is to improve the energy efficiency of transport by reducing its carbon intensity through a range of technologies and practices, such as electric mobility and renewable energy.

This study recommends developing the two best alternatives, i.e., the Rawa Buntu and Sudimara stations, as a pilot project for the revitalization of the transit environment in South Tangerang, recognizing the limitations of the regional budget. The annual budget for the Transportation Agency in South Tangerang was raised to IDR5.4 billion (US\$297,000) in 2024 from IDR5.15 billion the previous year (South Tangerang City 2024). Of this amount, the operating expense increased by IDR1 billion from IDR102 billion to IDR103 billion, while the capital expense declined by IDR917 million from IDR18 billion to IDR17 billion, indicating the government's preference for routine operational and maintenance rather than infrastructure development. Learning from Jakarta, the revitalization of 51 pedestrian nodes cost about IDR327 billion (Hermawan 2019). If the South Tangerang government uses the exact nominal amount as Jakarta did for the pedestrian revitalization, based on South Tangerang's regional income in 2024, it would only cost around 7% of the total regional income (IDR4.5 trillion). However, the recommended revitalization of the train stations will require more, as it includes developing pedestrian infrastructure and related features, as well as improving the local feeder service and quality. This project could shift people's behavior toward active transport by providing walkable, accessible facilities. A study by Mulyadi et al. (2022, 7) found that in 2016, after the revitalization of pedestrian areas in Sudirman-Thamrin, Jakarta, the walkability index increased to 38.98 percent compared to the previous research by Ridhani and Christanto (2015, quoted in Mulyadi et. al 2022, 7) that in 2015, the walkability index at Sudirman road and Thamrin road was relatively lower between 64 and 71, respectively. Besides, due to the revitalization of the sidewalk, the number of passengers on TransJakarta BRT corridor 1 passing through Sudirman-Thamrin road has increased by 15.41 percent from 2017 to 2018 (DKI Jakarta Government 2021, quoted in Mulyadi et al. 2022, 11).

While this research has identified the best train stations to be revitalized to encourage active transport, further study is required to develop specific design proposals to promote a gradual shift from private vehicle use to public transport, as well as appropriate facilities that facilitate walking and cycling.

Fortunately, there is growing public awareness of health and wellness in Indonesia, particularly among younger generations, leading to a trend of increasing physical exercise. According to a survey of Trends in Favorite Sports Among Young People in 2024 shows that young generations choose to exercise once a week (37%) and two to four times a week (23%) (Yusuf 2024). The trend among young generations to start exercising was due to social media; hence, it influences and motivates them to change their lifestyle, such as consuming vegetables and fruits, avoiding fast food, and doing an exercise routine (Asmika et. al 2024, 89).





Furthermore, a Ministry of Health survey indicates that over half of Indonesians are now more likely to engage in physical activities like walking, cycling, or yoga (Indonesia Data 2024). This study recommends a strategic opportunity for the government to support this trend by expanding and upgrading public transport infrastructure to integrate active transport.

Conclusion

The primary goal of integrating active transport with public transport is to encourage people to walk and cycle rather than use private vehicles. The research found that Rawa Buntu and Sudimara stations are the priority areas for this purpose. Rawa Buntu station scores the highest, with an AHP composite weight of 0.249, driven by criteria 3 (feeder services) and 4 (condition of pedestrian areas). The station has at least four feeder routes that provide a wide service area covering Bogor District, as well as the Cities of South Tangerang, Tangerang, and Bekasi. Additionally, this station has the most suitable pedestrian areas with visible sidewalks and vegetation. Sudimara station ranks second, with an AHP composite weight of 0.161, supported by criteria 1 (500-m walkability) and 2 (population density). The station is located in a subdistrict with the highest population density and is surrounded by housing complexes, making it easily accessible.

The findings of this study can inform government strategy to reduce air pollution and improve people's health by revitalizing the identified priority areas to encourage walking and cycling. This is in line with increased awareness of wellness in Indonesia and is a good opportunity for the government to make public transport systems more comfortable and safer, thereby encouraging their use.

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Empowering Youth Climate Action through Digital Engagement: Integrating Climate Resilience into Community-Based Learning and Local Development Planning

I Putu Arisgunarta^{1,2,*}, Arrozaq Ave^{1,3}, Nasya Augusta^{1,4}, Qory Salsabilla^{1,5}

¹ MyCarbonSteps, Bogor, Indonesia

² Department of Applied Climatology, Faculty of Mathematics and Natural Sciences, Graduate School, IPB University, Bogor, Indonesia

³ Coordinating Ministry for Economic Affairs of the Republic of Indonesia, Indonesia

⁴ Department of Digital Business, Faculty of Economics and Business Education, Universitas Pendidikan Indonesia, Bandung, Indonesia

⁵ Department of Sociology, Faculty of Social Sciences and Law, Universitas Negeri Jakarta, Jakarta, Indonesia

* Corresponding Author: Putuarisgunarta@apps.ipb.ac.id

Abstract

Integrating climate adaptation and resilience into development planning requires more than infrastructure; it demands social transformation driven by awareness, participation, and innovation. This study explores how youth-led digital engagement can serve as an enabling pathway for such an integration through the Carbon Vlogger Workshop and Challenge 2025, a national initiative under the MyCarbonSteps community. The project sought to strengthen climate literacy, promote low-carbon lifestyles, and translate knowledge into local action among Indonesian youth aged 17–25. The initiative combined an online workshop with a digital storytelling competition, enabling participants to produce short educational vlogs about sustainable practices. Thirty participants from 10 provinces joined the program, representing diverse educational and regional backgrounds. Using pre- and post-tests, content analysis, and feedback-based qualitative coding, the study evaluated both cognitive and behavioral outcomes. The attention, interest, desire, action (AIDA) model was applied to assess engagement effectiveness. Findings reveal an average increase of 14.7 percent in participants' knowledge of their carbon footprint and a significant rise in motivation to take concrete environmental action. The challenge produced 13 educational vlogs, viewed by over 20,000 social media users, demonstrating the power of peer-to-peer communication to expand climate awareness. The campaign achieved over 30,000 impressions at a digital advertising cost of only IDR50,000 (US\$,2.80), demonstrating relative cost efficiency in digital advertising expenditure.

Keywords: climate adaptation; youth empowerment; digital engagement; community resilience; low carbon development

Introduction

Background and Context

Climate change represents one of the most pressing global challenges, with far-reaching impacts across environmental, social, and economic sectors (Gherheş et al. 2025). The acceleration of greenhouse gas emissions, primarily driven by human activities, has necessitated urgent mitigation and adaptation strategies at all levels of governance. While infrastructure-based approaches have dominated climate action frameworks, there is growing recognition that sustainable climate resilience requires fundamental social transformation anchored in awareness, participation, and innovation (O'Brien et al. 2018; George et al. 2021).

Indonesia, as an archipelagic nation highly vulnerable to climate impacts, faces particular challenges in building adaptive capacity across its diverse communities. The nation's youth population presents both a challenge and an opportunity in this context. According to Statistics Indonesia (BPS 2023), Indonesian youth demonstrate





exceptionally high digital connectivity, with 94 percent using the internet and 96 percent owning smartphones. This digital fluency positions young people as potential catalysts for climate action through innovative communication channels (Schäfer and Schlichting 2014; Luthfia 2025).

However, despite this technological advantage, significant gaps persist in climate literacy among Indonesian youth. Recent research indicates that 49.7 percent of Indonesian adolescents have low climate literacy, with disparities across regions, school types, and parental educational backgrounds (Martha et al. 2025). Furthermore, studies have documented a persistent awareness-action gap, where knowledge about climate change does not automatically translate into behavioral change or concrete action (Moser 2016; Lubej et al. 2025). This disconnect highlights the need for innovative approaches that not only educate but also motivate and enable youth to take meaningful climate action (Risaldi and Ramadani 2025).

This research addresses these gaps by investigating how digital engagement strategies can be designed to simultaneously enhance climate literacy, foster sustainable behaviors, and create scalable models for community-based climate action (George et al. 2021; Fazel 2024). This research explores how youth-led digital engagement can serve as an enabling pathway for integrating climate resilience into community-based learning through the Carbon Vlogger Workshop and Challenge 2025, a national initiative under the MyCarbonSteps community. The project sought to strengthen climate literacy, promote low-carbon lifestyles, and translate knowledge into local action among Indonesian youth aged 17–25 (MyCarbonSteps 2025).

Theoretical framework: The AIDA model

This project employs the attention, interest, desire, action (AIDA) model as its theoretical foundation for understanding and catalyzing behavioral change through digital engagement (Fazel 2024). Originally developed in marketing contexts, the AIDA model provides a structured framework for understanding how communication can move audiences from initial awareness to concrete action. The model has been successfully applied in green marketing and climate communication, particularly in digital contexts where staged engagement is critical (Fazel 2024).

In the context of climate education and youth engagement, the model operates as follows: attention is captured through digital media platforms that youth use daily, leveraging familiar communication channels to introduce climate topics (Schäfer and Schlichting 2014). Interest is cultivated by presenting climate information in engaging, relatable formats that connect with participants' lived experiences and concerns, utilizing visual and emotional appeals that resonate with young audiences (O'Neill et al. 2013). Desire is generated through prize rewards in the carbon vlogger competition and by helping participants understand their capacity to contribute to climate solutions, including opportunities such as green careers that align personal interests with environmental goals (George et al. 2021). Finally, action is facilitated through the vlog creation challenge, which transforms passive learning into active participation and peer education (Gherheș et al. 2025). By combining the AIDA model's staged engagement framework with digital sustainability principles, this study positions youth not merely as recipients of climate education but as active agents capable of leading transformative climate action through digital platforms (O'Brien et al. 2018; Luthfia 2025).

Methodology

Program design and implementation

The Carbon Vlogger Workshop and Challenge 2025 was designed as a hybrid initiative combining educational workshops with a creative digital competition. The program consisted of two interconnected components: an online educational workshop and a video creation challenge.





Workshop component

The online workshop provided comprehensive training in carbon footprint concepts, climate change science, green job opportunities, and digital content creation. Participants learned to use personal carbon footprint calculation applications and engaged in interactive question-and-answer sessions with facilitators. The workshop was designed to be accessible, participatory, and relevant to participants' daily lives, emphasizing practical applications of climate knowledge.

Challenge component

Following the workshop, participants were invited to create educational vlogs under the theme "Karbon di setiap langkah-mu" (carbon in your every step). The challenge offered a total prize of IDR1,400,000 (US\$79), providing both recognition and financial incentive for quality submissions. This competition format transformed participants from passive learners into active educators, amplifying the reach of climate messaging through peer networks.

Participant recruitment and demographics

Participants were recruited through social media campaigns, particularly Instagram, which proved highly effective for reaching the target demographics. The recruitment strategy employed a modest digital advertising budget of IDR50,000 to amplify reach. A total of 30 participants from 10 provinces across Indonesia, namely Aceh, Banten, DKI Jakarta, West Java, Central Java, DI Yogyakarta, East Java, South Kalimantan, South Sulawesi, and West Nusa Tenggara, completed the full program, representing diverse educational backgrounds and geographic regions. Participants' ages ranged from 17 to 25, and the pool was predominantly female (65.7 percent).

Data collection methods

The study employed a mixed-methods approach combining quantitative pre- and post-tests, content analysis of participant vlogs, qualitative feedback coding, and social media engagement metrics. This triangulated methodology addresses the limitations of single-method approaches common in climate communication research (Lubej et al. 2025).

Quantitative analysis

Quantitative analysis focused on comparing pre-test and post-test scores to measure knowledge gains. Knowledge improvement in this study was measured using score differences between post-test and pre-test results for each participant:

$$\text{Knowledge Gain} = \text{Post-test Score} - \text{Pre-test Score}$$

Positive values indicate an increase in knowledge, while zero or negative values indicate no improvement or potential knowledge saturation.

To account for variations in baseline knowledge, a normalized learning gain was also calculated:

$$g = \frac{\text{Post-test} - \text{Pre-test}}{\text{Pre-test}}$$

The N-gain score was calculated using the following formula (Hake et. al. 1998; Coletta and Steinert 2020). An N-gain value of 0 indicates no improvement, while a value of 1 indicates the maximum possible learning gain.

$$\text{N-gain} = \frac{\text{Post-test Score} - \text{Pre-test Score}}{\text{Maximum Possible Score} - \text{Pre-test Score}}$$



The metrics of g and N-gain allows for fairer comparisons across participants with different initial knowledge levels and helps identify ceiling effects. Descriptive statistics were also calculated to identify patterns in score distributions, gender differences, and the relationship between initial knowledge levels and improvement rates.

Qualitative analysis

Qualitative data from participant feedback were analyzed using thematic coding techniques. Responses were systematically reviewed to identify recurring themes related to environmental awareness, behavioral change intentions, and the effectiveness of the interactive learning approach.

Digital Outreach Analysis

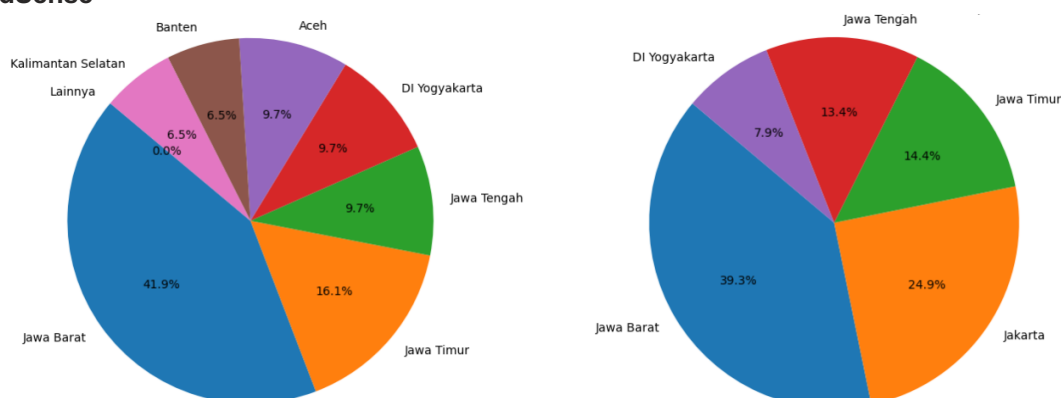
Digital outreach metrics were analyzed to assess cost-effectiveness and reach. The analysis calculated cost-per-impression ratios and evaluated the program's ability to expand climate messaging beyond direct participants through the vlogs created and shared on social media platforms.

Results and Discussion

Participant engagement and reach

The Carbon Vlogger Challenge successfully attracted and engaged youth across Indonesia, demonstrating the viability of digital platforms for climate education and outreach. The social media recruitment campaign achieved remarkable cost efficiency, generating over 30,000 impressions, 133 profile visits, and 25 new followers with an advertising expenditure of only IDR50,000. Compared to conventional climate awareness campaigns, which often require substantial funding for media placement, logistics, and professional content production, this program achieved relatively broad digital reach with minimal direct advertising expenditure. Previous studies have shown that traditional campaigns may involve significantly higher operational costs due to reliance on mass media or in-person outreach (Gherheş et al., 2025). While direct comparisons remain limited due to differences in scale and methodology, the findings suggest that digitally enabled, participatory approaches may offer a cost-efficient alternative for targeted youth engagement. The ad spending and reach translate to a cost of approximately IDR1,000 per 600 views, demonstrating that impactful climate communication can be achieved even under severe budget constraints typical of community-level programs.

Figure 1. The distribution of participants is similar to the location of the Instagram audience when doing AdSense

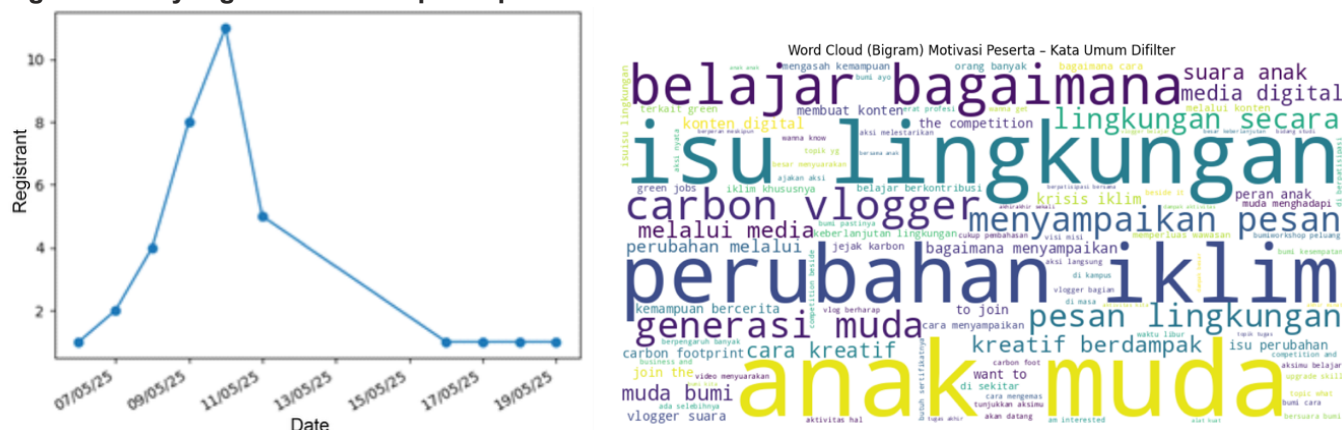


- a. The distribution of the domiciles. b. The distribution of the Instagram audience.

Source: Authors' analysis.

The geographic distribution of participants closely mirrored the program's Instagram account's audience demographics (Figure 1), confirming that Instagram is an effective platform for reaching Indonesian youth on climate topics. Peak registration (Figure 2a) occurred during the period when targeted advertising was employed (May 9-11), providing clear evidence of the value of strategic digital advertising investment. Figure 2b highlights the dominant themes related to climate change, environmental issues, youth involvement, creativity, and the use of digital media to communicate environmental messages.

Figure 2. Daily registrations and participants' word cloud



a. Daily registrations across the enrollment period.
filtering common terms.

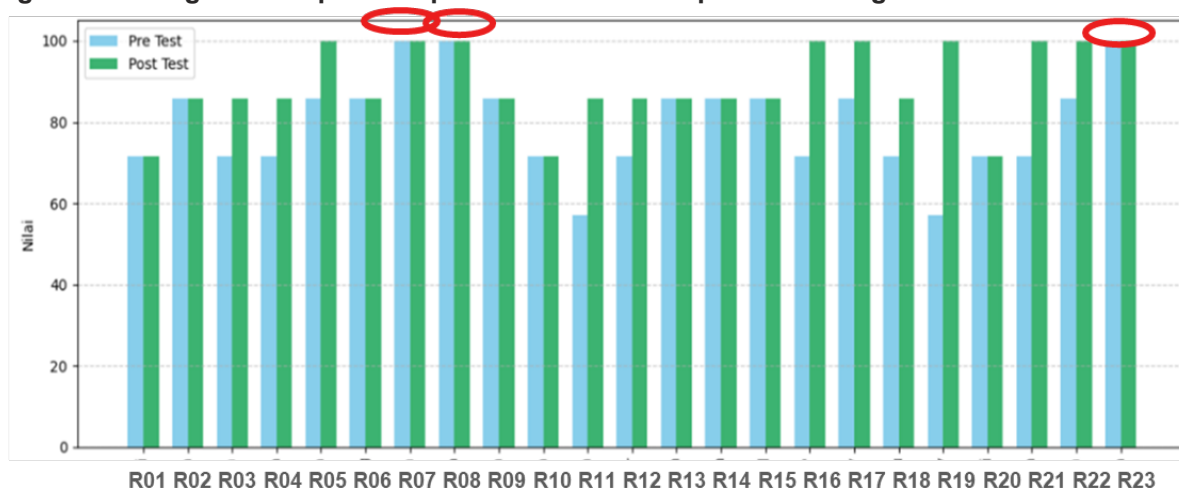
b. Bigram word cloud of participants motivations after

Source: Authors' analysis.

Knowledge acquisition outcomes

Analysis of pre- and post-test results revealed significant improvements in participants' knowledge on carbon footprint. Overall, 47.83 percent of participants demonstrated score increases, while 52.17 percent maintained their scores. The average knowledge increase across all participants was 14.7 percent, with medium effectiveness, as indicated by a 0.38 N-gain score, suggesting substantial learning gains from the workshop intervention (Hake 1998; Coletta and Steinert 2020).

Figure 3. Ceiling effect in pre- and post-test carbon footprint knowledge scores

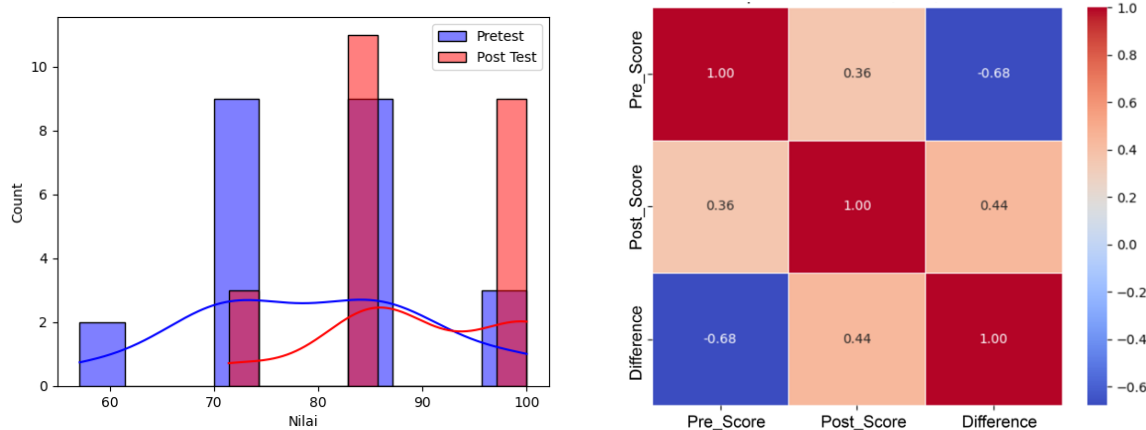


Note: Red circles indicate the ceiling effect.

Source: Authors' analysis.

A ceiling effect was observed in the assessment, with some participants achieving very high scores on both pre- and post-tests (Figure 3). This pattern suggests that these individuals already had a strong understanding of their carbon footprint prior to the workshop, limiting measurable improvement despite potentially benefiting from the program through reinforcement and deeper conceptual understanding. Correlation analysis (Figure 4a) revealed a negative relationship ($R = -0.68$) between pre-test scores and score improvement, indicating that the intervention had a greater measurable impact on participants with lower initial knowledge levels. This finding suggests that the program effectively addressed knowledge gaps among those most in need of climate literacy education.

Figure 4. Distribution of pre- and post-test scores and Pearson correlation heatmap



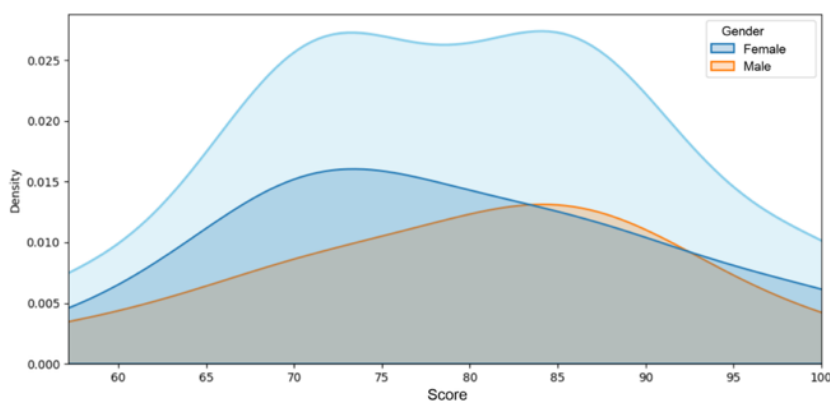
a. Score distribution pre- and post-intervention and post-test scores and learning gains

b. Pearson correlation heatmap illustrating between pre-

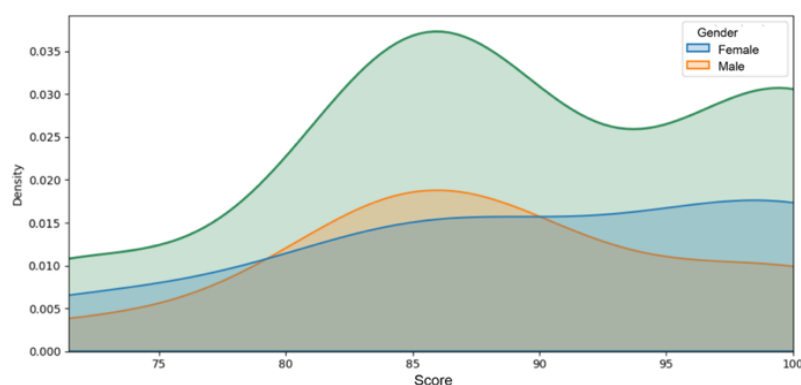
Source: Authors' analysis

Gender-disaggregated score analysis (Figure 5) revealed that female participants achieved higher average scores than male participants, though both groups demonstrated gains in knowledge. This pattern is consistent with prior research suggesting that female participants often demonstrate higher environmental concern and engagement, which may contribute to stronger learning outcomes in climate education contexts (Moser 2016; Üstgörül et al. 2024). This finding warrants further investigation to understand whether gender differences in climate literacy are attributable to prior education, differential engagement with the workshop content, or other factors.

Figure 5. Higher average knowledge scores among female participants



a. Pre-test scores



b. Post-test scores

Source: Authors' analysis.

Awareness and action intentions

The qualitative analysis of participant feedback, based on thematic coding, revealed a transformative theme of youth environmental awareness through creative interactive learning (Table 1). Participant feedback revealed strong self-reported intentions to adopt low-carbon behaviors and continue climate advocacy beyond the program. Participants frequently cited increased awareness of their personal carbon footprints, confidence in their ability to make a difference, and motivation to influence peers as key outcomes. These motivational shifts align with the AIDA model's progression from awareness to action intention (Fazel 2024) and suggest that combining education with creative expression can effectively bridge the climate awareness-action gap (Moser 2016; Lubej et al. 2025).

Table 1. Thematic coding of participant feedback on the carbon vlogger workshop

Core category	Main category (selective coding)	Subcategory (axial coding)	Open coding (participant feedback)
Transforming youth awareness and engagement through interactive environmental education	1. Increased awareness and education	- Increased insight and knowledge	"Terbuka wawasan saya" (It opened my mind) "Materi sangat bermanfaat" (The material was very useful)
		- Understanding of green jobs	"Menambah pengetahuan tentang green jobs" (I gained more knowledge about green jobs) "Topik green jobs menarik" (The topic of green jobs is interesting)
		- New insights into sustainability issues	"Makin sadar bahaya emisi" (I'm more aware of the dangers of emissions) "Jadi lebih peduli terhadap karbon" (I've become more concerned about carbon) "Lebih paham tentang keberlanjutan" (I have a better understanding of sustainability)
	2. Participant appreciation and satisfaction	- Enthusiasm, passion, and joy	"BAGUSS!!! SERUUU" (Awesome!!! Exciting!) "Super insightful!" "Sangat bermanfaat" (Very useful!)
		- Proud to be part of the activity	"Bangga jadi bagian forum" (Proud to be part of the forum) "An honour to be part of Gen Z(Ero)"

Core category	Main category (selective coding)	Subcategory (axial coding)	Open coding (participant feedback)
		- Appreciation of the material and speakers	"Penyampaian menarik" (The delivery was engaging) "Terima kasih infonya" (Thanks for the information) "Materinya keren banget" (The material was excellent)
	3. Environmental awareness and engagement	- Awareness of the importance of behavioral change	"Jadi makin sadar bahaya emisi" (I've become more aware of the dangers of emissions) "Pentingnya gaya hidup minimalis" (The importance of minimalist living)
		- Motivated to take action	"Akan mulai dari sekarang" (I'm going to start now) "Ingin meminimalisir jejak karbon" (I want to minimize my carbon footprint) "Siap bertindak" (Ready to take action)
		- Inspired to get involved in the environmental movement	"Ingin terlibat lebih lanjut" (I want to get more involved) "Gerakan ini harus meluas" (This movement needs to spread) "Masyarakat harus tahu" (People need to be aware)
	4. Technical evaluation & future expectation	- Technical assessment (platform, time)	"Zoom menyenangkan" (The Zoom was fun) "On time mulainya!" (It started on time!) "Sudah sangat baik dan perlu dipertahankan" (It's already very good and should be maintained)
		- Criticism and input	"Kurang interaktif" (Lacks interaction) "Pertanyaan saya belum dijawab" (My question wasn't answered yet) "Butuh sesi diskusi lebih banyak" (We need more discussion sessions)
		- Hope for the program's sustainability	"Semoga kegiatan ini berlanjut" (I hope this activity continues) "Libatkan lebih banyak pemuda" (Get more youth involved) "Harap terus diselenggarakan" (I hope it continues to be held)

Source: Authors' analysis

Digital outreach and peer-to-peer education

The vlog creation challenge resulted in the production of 13 educational videos that collectively reached more than 20,000 viewers across social media platforms. This demonstrates the effectiveness of peer-to-peer communication in expanding climate awareness beyond direct program participants, a dynamic widely recognized in media representation and climate communication research (Schäfer and Schlichting 2014). Studies on youth climate activism in Indonesia further confirm that digital platforms enable young activists to amplify environmental messages through social networks, often achieving broader reach than conventional institutional campaigns



(Luthfia 2025; Risaldi and Ramadani 2025). By positioning participants as climate educators within their own peer networks, the program disseminates climate messages more widely and digitally.

This peer-to-peer model is consistent with findings from environmental psychology and social influence research, which show that messages delivered by peers are often more persuasive (O'Neill et al. 2013). This study highlights that emotional narratives, visual media, and social media platforms significantly enhance youth engagement with climate issues—mechanisms that were central to the vlogging challenge (O'Neill et al. 2013). This outcome further illustrates how youth can function as active agents of digital sustainability rather than passive technology users, aligning with research that frames digitally literate youth communities as key actors in addressing climate challenges through scalable, socially embedded communication pathways (O'Brien et al. 2018; George et al. 2021).

Cost effectiveness and scalability

While the program demonstrated low direct advertising costs (IDR 50,000), this estimate does not account for indirect production costs such as participants' access to smartphones, internet data, and video editing tools, which were not covered by the program. Therefore, cost efficiency should be interpreted within the limited scope of campaign expenditure rather than total resource investment. Additionally, the effectiveness of digital engagement approaches may be influenced by unequal access to internet infrastructure, particularly in rural or underserved areas of Indonesia. As such, digital strategies should be viewed as complementary to, rather than replacements for, offline climate education initiatives. Previous studies have shown that traditional campaigns may involve significantly higher operational costs due to reliance on mass media or in-person outreach (Gherheş et al. 2025). While direct comparisons remain limited due to differences in scale and methodology, the findings suggest that digitally enabled, participatory approaches may offer a cost-efficient alternative for targeted youth engagement

The program's design demonstrates potential replicability across different contexts. The core components of online workshops, creative challenges, and social media dissemination can be adapted to various geographic settings, cultural contexts, and climate-related topics, reflecting the flexible nature of digital sustainability pathways (George et al. 2021). Research on climate awareness campaigns confirms that digital approaches offer adaptability advantages, allowing messages to be culturally localized while maintaining core educational objectives (Gherheş et al. 2025; Schäfer and Schlichting 2014).

AIDA model application and effectiveness

The theoretical application of the AIDA model proved effective in structuring the program's design and understanding its impact (Hidayati 2017; Hung et al. 2025). Each stage of the model was intentionally addressed through specific program elements, demonstrating the model's versatility in sustainability communication contexts (Fazel 2024).

Attention

Attention was successfully captured through targeted social media campaigns on platforms frequented by Indonesian youth, particularly Instagram. The platform's visual nature and the use of peer-relevant messaging ensured initial engagement with climate topics that might otherwise be perceived as distant or abstract (Schäfer and Schlichting 2014). This approach aligns with Hung et al. (2025), who found that attention-grabbing elements significantly enhance audience engagement with sustainability messages.

Interest

Interest was cultivated through workshop content that connected carbon footprint concepts to participants' daily lives and personal experiences. By demonstrating how routine activities contribute to climate change and exploring practical mitigation strategies, the program made climate science relevant and actionable rather than overwhelming or discouraging (Üstgörl et al. 2024). Another study found that interest is significantly influenced by both emotional





engagement and environmental consciousness. When audiences perceive personal relevance in sustainability messages, their interest deepens, consistent with the workshop's strategy of linking carbon footprints to daily activities (Hung et al. 2025).

Desire

Desire was generated through multiple mechanisms. The reward system provided a tangible incentive for participation, while discussions of green careers connected environmental action to personal economic opportunity (George et al. 2021). Additionally, framing carbon reduction as a pathway to healthier living appealed to participants' self-interest alongside their environmental values. This approach reflects Hung et al.'s (2025) findings that desire is significantly influenced by intention, which in turn is shaped by emotional engagement and environmental consciousness. Fazel (2024) demonstrated that digital sustainability marketing is the most effective when environmental benefits are connected to personal advantages.

Action

Action was facilitated through the vlog creation challenge, which provided a clear, achievable pathway for participants to move from passive learning to active climate advocacy. The creative nature of the challenge allowed participants to express their climate commitment in personally meaningful ways while contributing to broader awareness-raising efforts (O'Brien et al. 2018). Hung et al. (2025) validated that desire significantly influences sustainable behavioral action when individuals are provided with concrete, accessible channels for participation.

Integration into local development planning

The findings of this study provide initial insights into how youth-centered digital engagement initiatives may inform climate-related communication strategies within local development planning contexts. In Indonesia, climate adaptation efforts are guided by national frameworks, such as the National Action Plan for Climate Change Adaptation (Rencana Aksi Nasional Adaptasi Perubahan Iklim; RAN-API), which emphasizes the importance of increasing public awareness and adaptive capacity. At the subnational level, these priorities are often operationalized through Regional Medium-Term Development Plans (Rencana Pembangunan Jangka Menengah Daerah; RPJMD) and community empowerment programs.

Within this context, the Carbon Vlogger Workshop and Challenge illustrates a participatory approach that may complement existing planning efforts, particularly in engaging youth populations, who are often underrepresented in formal planning processes (Luthfia 2025; Risaldi and Ramadani 2025). The use of digital platforms and creative content production offers a potential avenue for disseminating climate-related information in ways that are accessible and relevant to younger audiences.

The program's low direct advertising cost (IDR 50,000) suggests that digital platforms can serve as an accessible entry point for youth climate engagement within constrained community budgets. However, it is important to note that this figure reflects only campaign expenditure and does not capture indirect costs borne by participants, such as internet access, device ownership, and time spent on video production. A fuller cost assessment would need to account for these resources, which were not provided by the program.

Üstgörl et al. (2024), in their validation of the Carbon Footprint Awareness Scale among Gen Z participants, found a positive association between carbon footprint awareness and sustainable behavioral intentions, underscoring the importance of environmental literacy as a foundation for climate action. Research on peer-to-peer learning in sustainability contexts suggests that socially embedded dissemination, i.e., where participants share climate content within their own networks, may support broader diffusion of environmental messages beyond the immediate program cohort (O'Neill et al. 2013; Schäfer and Schlichting 2014). However, the extent and duration of this influence in the present study would require longitudinal follow-up to confirm empirically.



Further, the program's success in translating awareness into action intentions suggests that such initiatives can help address the implementation gap that often plagues climate planning. It is important to note, however, that this study only measured self-reported behavioral change over time. Whether these intentions translate into sustained low-carbon practices remains an open empirical question that future longitudinal research should address. Future research is also needed to explore how similar initiatives can be formally incorporated into planning instruments such as RPJMD and local climate action plans, and to assess their long-term contributions to behavioral change and community resilience.

Limitations and considerations

This study has several limitations that should be considered when interpreting the findings. First, the small sample size ($n=30$) and self-selected participant pool mean that results should be treated as exploratory and not generalized to the broader Indonesian youth population. Second, the ceiling effect observed in the knowledge assessments indicates that the pre- and post-test instruments were insufficiently sensitive for participants with high baseline knowledge, suggesting a need for more nuanced evaluation tools capable of detecting deeper conceptual understanding and application.

Third, the study relied on self-reported behavioral intentions measured immediately after the program; no longitudinal follow-up was conducted to determine whether these intentions translated into sustained behavioral change. This limits the strength of any claims about long-term impact, including those relating to peer-to-peer influence and the program's contribution to climate adaptation. Fourth, the program's fully digital format may have excluded youth without reliable internet access or adequate digital literacy, a concern that remains significant despite Indonesia's high national rates of smartphone ownership, particularly in rural and economically disadvantaged communities.

Conclusion

This study explored how youth-led digital engagement can support climate literacy and low-carbon behavior intentions among Indonesian youth through the Carbon Vlogger Workshop and Challenge 2025. The initiative combined interactive online workshops with a digital storytelling competition, enabling participants aged 17–25 to connect carbon footprint concepts to their everyday lives. The combination of interactive workshops and digital storytelling strengthened participants' climate literacy while fostering a sense of personal relevance and agency in addressing climate change.

Taken together, these findings suggest that youth-centered digital engagement initiatives, when carefully designed and properly evaluated, may serve as a low-cost complement to existing climate education and local development planning efforts. Future research should focus on larger and more diverse samples, longitudinal assessment of behavioral change, and the conditions under which such initiatives can be meaningfully integrated into formal planning instruments such as RPJMD or local climate action plans.



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From People's Voice to Advocacy: A Case Study of the 2025 Flash Flood Disaster in Denpasar, Indonesia

Ida Bagus Oka Agastya^{1,*}, Putu Diyan Diwyastra¹, Anak Agung Gde Brahmantya Murti², I Gusti Ngurah Krisna Dana³, Jessica Andrea¹

¹ Indonesian Geologists Association Bali Chapter, Denpasar, Bali, Indonesia

² Public Administration Study Program, Faculty of Social and Political Sciences, Warmadewa University, Denpasar, Bali, Indonesia

³ Government Science Study Program, Faculty of Social and Political Sciences, Warmadewa University, Denpasar, Bali, Indonesia

* Corresponding author: iokaagastya@gmail.com

Abstract

On 10 September 2025, Denpasar and Badung in Bali, Indonesia, experienced one of the most devastating flash floods in the island's history, resulting in 18 fatalities, affecting more than 6,000 households, and disrupting vital infrastructure. Beyond the physical destruction, the disaster exposed a fundamental issue: official government data on the event was delayed and incomplete, raising important questions about how flood dynamics can be captured more accurately and inclusively. This study examines whether real-time, citizen-generated information can complement—or even challenge—official risk maps, and how such knowledge can reshape flood governance in urban Bali. Data for this research were collected from social media posts containing photos, videos, and textual reports, which were subsequently verified, categorized, and spatially mapped using GIS. The analysis reveals both alignments and discrepancies with national flood risk assessments. While most affected areas fall within areas classified as high risk, anomalies were identified in Canggu and Kerobokan following rapid land-use changes, indicating weakening ecological functions in the Ayung and Badung watersheds. The data also highlight systemic vulnerabilities that allowed extreme rainfall to escalate into a major disaster: watershed degradation, the collapse of urban drainage systems, and the absence of functional evacuation routes in dense areas such as Badung Market. This study demonstrates that crowdsourcing not only produces more detailed and timely disaster information but also serves as a participatory instrument that amplifies community voices in shaping risk knowledge. Integrating this approach into official disaster management systems can strengthen adaptive capacity, enhance governance accountability, and ensure a more just and context-appropriate flood response.

Keywords: flood; crowdsourcing; Denpasar; disaster mitigation

Introduction

On 10 September 2025, Denpasar City and Badung District in Bali, Indonesia, were struck by flash floods that were later recorded as one of the most severe hydrometeorological disasters on the island over the past decade. Extreme rainfall that began on the evening of 9 September triggered the overflow of several rivers, particularly the Badung River, which flows through the heart of Denpasar. Within hours, floodwaters rose rapidly, inundating traditional markets, densely populated neighborhoods, and major road corridors. Official data reported at least 18 fatalities, more than 6,000 affected households, and economic losses estimated in the tens of billions of rupiah (Kerta 2025).

The Badung and Kumbasari Markets became powerful symbols of the disaster's impact. Both markets—centers of Denpasar's traditional economy—were submerged under up to two meters of water. Thousands of vendors lost their merchandise, commercial activity came to a halt, and material losses reached billions. The flooding also cut off vital transport access to Kuta and Sanur as the Dewa Ruci Underpass became inundated, while health services at Mangusada Regional Hospital were disrupted as parts of the facility were flooded. The disaster quickly escalated





into a multidimensional crisis, causing not only physical destruction but also deep social and economic disruption (Winata 2025).

This flooding phenomenon cannot be separated from Bali's structural conditions. The Denpasar–Badung area is the region's fastest-growing urban center. Over the past two decades, land conversion has occurred on a massive scale: rice fields and green open spaces have been transformed into residential areas, business districts, and tourism villas (BPS Bali Province 2025). The traditional *subak* system, which is responsible for water distribution and natural infiltration, has become increasingly marginalized, and existing urban drainage systems have failed to keep pace with rapid development. At the same time, the Ayung and Badung River basins have lost significant riparian space, drastically reducing their waterholding and absorption capacity.

In a global context, this trend aligns with the Intergovernmental Panel on Climate Change's (IPCC) findings (2022), showing that tropical coastal cities are becoming increasingly vulnerable to flooding due to the combined effects of climate change and uncontrolled urbanization. In Asia, floods have become the most frequent disasters, with substantial impacts on urban economies (Chan et al. 2018). Indonesia itself records floods as the most recurrent disaster type almost every year (BNPB 2023). Denpasar–Badung exemplifies how flood risk is no longer a theoretical but has become a lived reality.

Significant challenges persist in disaster data management. Official data from government agencies typically emerges only after the event has subsided. Information is often partial, focusing on casualties or financial losses, with limited spatial detail. Yet communities on the ground hold rich, firsthand knowledge: flood locations, inundation depth, damage, and event chronology. Unfortunately, these citizen accounts rarely enter official datasets.

This is where crowdsourcing becomes essential. The concept, introduced by Howe (2006), describes the use of collective public contributions to generate shared knowledge. In disaster contexts, crowdsourcing has been used to map the Haiti earthquake (Meier 2012), monitor epidemics (Boulos et al. 2011), and track flooding in various cities. Its strength lies in its being participatory, fast, and relatively low-cost. With smartphones and social media, every resident can act as a "sensor" capturing real-time events.

In the case of the 2025 Denpasar floods, crowdsourcing addressed gaps in official data. Hundreds of photos, videos, and community posts shared through Instagram, WhatsApp, and local media became valuable sources of information. They not only helped reveal flood patterns but also captured firsthand narratives from affected residents. Therefore, this study aims to demonstrate how a crowdsourcing-based approach can be used to analyze urban flooding while simultaneously serving as a tool for public advocacy.

Methodology

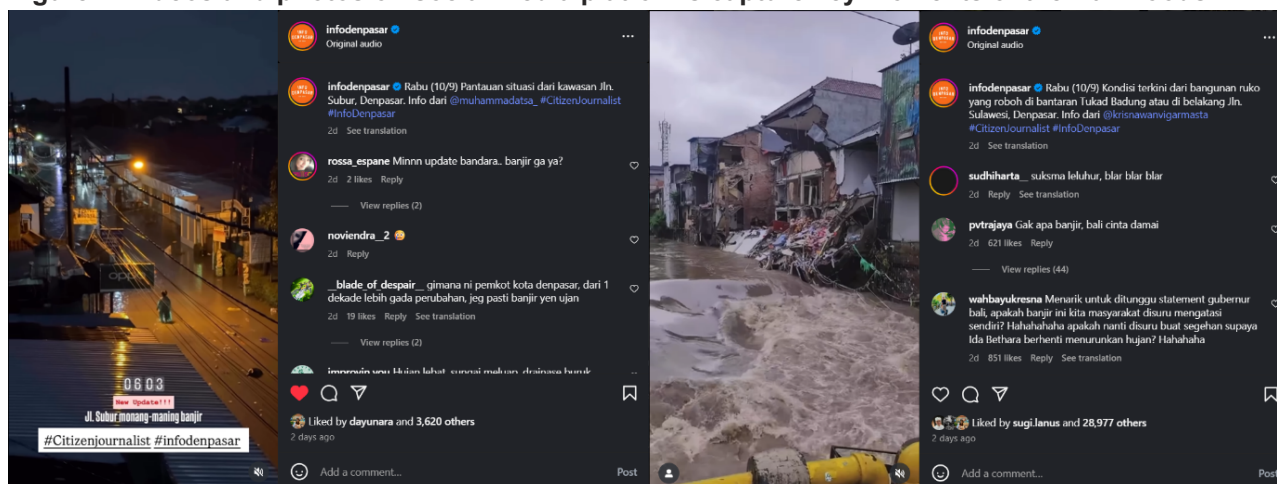
This study employs a descriptive qualitative approach, drawing on crowdsourced data as its primary source of information. A qualitative approach was selected because the aim of the research is not merely to quantify the frequency of events, but to develop an in-depth understanding of the flood phenomenon through the interpretation of spatial data, social information, and citizens' narratives. The descriptive nature of this study indicates that the analysis focuses on systematically explaining flood patterns, their causes, and their socioecological consequences, without making unwarranted quantitative generalizations.

Conceptually, crowdsourcing is defined as the process of gathering information from a large group of people, typically through digital platforms, to solve a particular problem (Howe 2006). In the context of disasters, crowdsourcing is closely related to the concept of volunteered geographic information (Goodchild 2007), referring to geographic data voluntarily contributed by the public, often in the form of photos, videos, or location-based texts. This approach enables communities to become active actors in disaster documentation, rather than merely passive recipients of impact.



The research data were collected from public social media platforms, particularly Instagram. The data collection period spanned 9–15 September 2025, covering the pre-, during-, and post-flood phases of the major Denpasar–Badung disaster. A total of 80 videos, 78 screenshots, and hundreds of photographs were gathered (see examples in Figure 1). Information sources comprised 38 accounts, including local information pages (@infodenpasar on September 10, 2025), official institutional accounts (@satlantas_polrestadenpasar on September 9, 2025), (@poldabali on September 10, 2025), and individual users that directly affected by the disaster during September 10–15, 2025.

Figure 1. Videos and photos on social media platforms capture key moments of the Bali floods

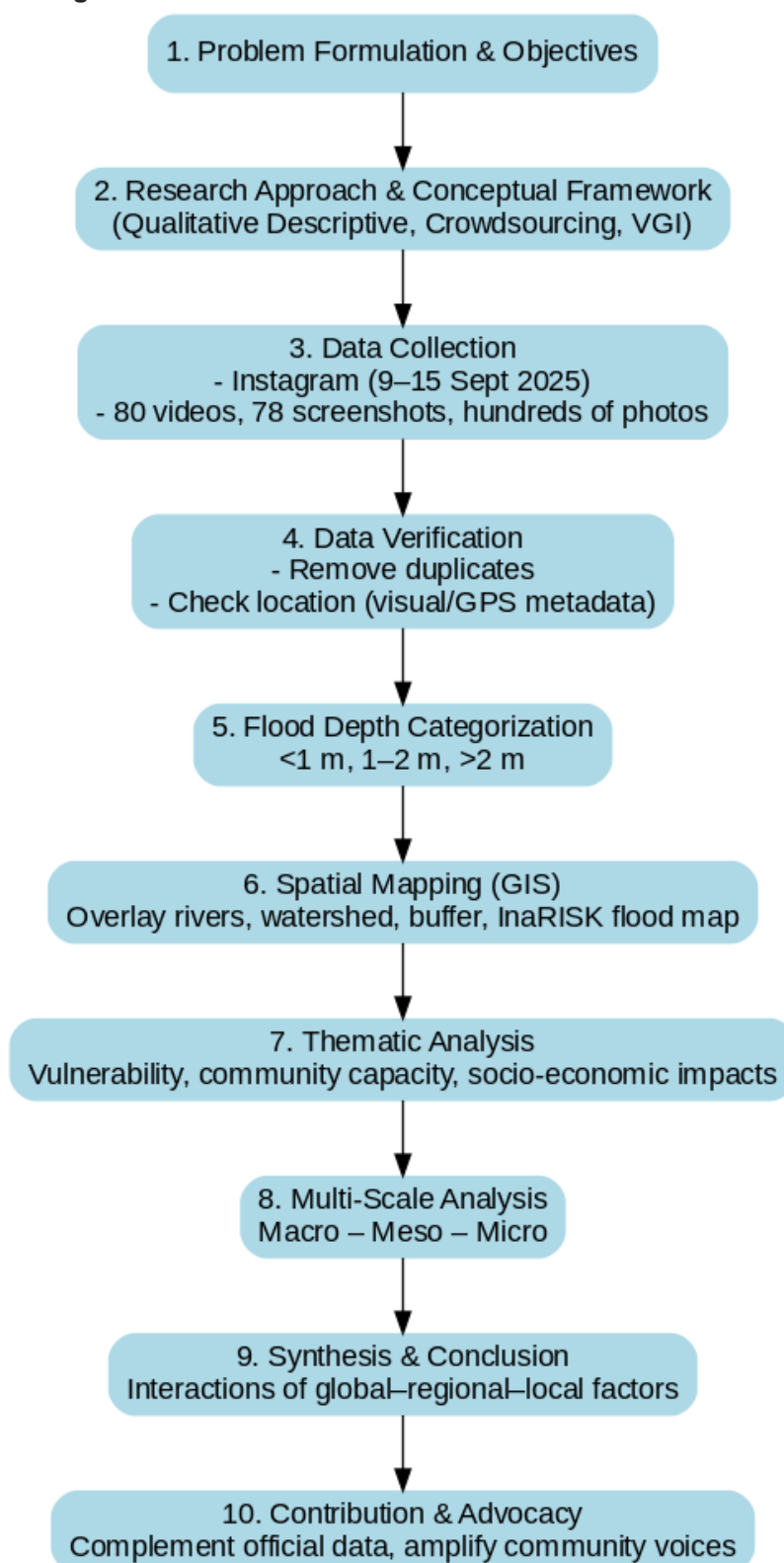


Source: @infodenpasar, September 12, 2025.

Analysis was carried out in several stages (Figure 2). First was data verification, which involved removing duplicate reports and checking the authenticity of location information using visual indicators such as signage, buildings, and GPS metadata. The second phase was flood-depth categorization, conducted by estimating water depth based on human body scale and physical objects such as vehicles and buildings. The data were divided into three groups: <1 m depth, 1–2 m, and >2 m. The third step was spatial mapping using GIS tools, in which flood points were plotted and overlaid with river networks, watershed boundaries, 10–100 m buffer zones, and InaRISK, which comprises the national flood-risk maps from the National Disaster Mitigation Agency (Badan Nasional Penanggulangan Bencana; BNPB) (Figure 3). Fourth was thematic analysis, which coded text, captions, and comments to identify themes related to vulnerability, community capacity, and socioeconomic impacts.

The analytical framework does not stop at spatial mapping; it is complemented by a macro–meso–micro approach. At the macro level, the analysis focuses on global factors such as the climate crisis and environmental justice. At the meso level, the study examines spatial planning, land-use change, watershed degradation, and elements of Balinese cultural cosmology. At the micro level, the research explores local upstream and downstream conditions, community behavior, licensing politics, and emergency response capacity. Through this multiscale approach, the 2025 Denpasar–Badung flood is understood not as a singular event but as the outcome of complex interactions between global, regional, and local factors.

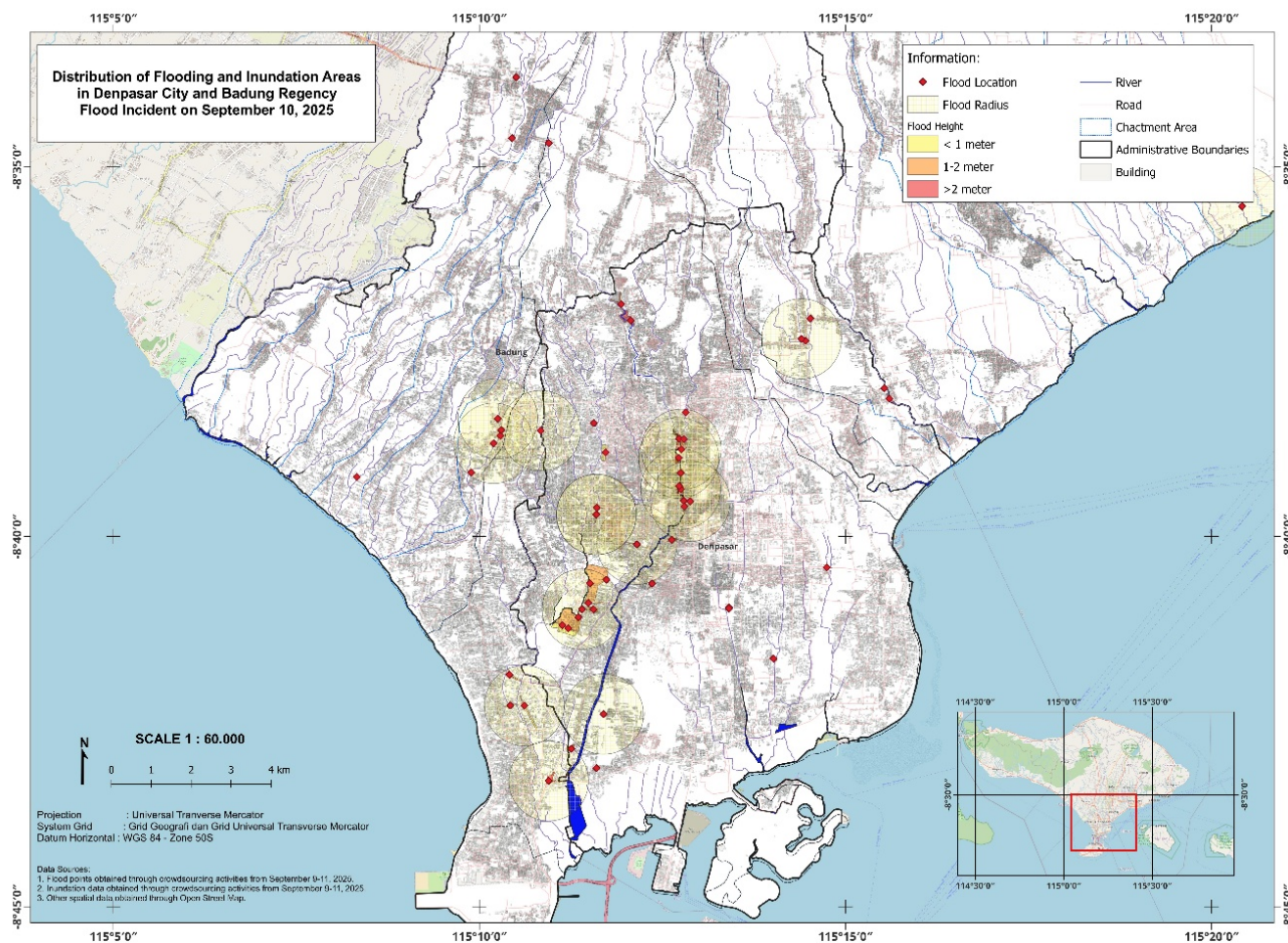
Figure 2. Research flow diagram



Source: Authors.

Under this framework, crowdsourced data functions not only as event documentation but also as a foundation for spatial, social, and policy analysis that highlights community voices. Moreover, this approach offers a tangible contribution to disaster advocacy, as it can compensate for the limitations of official government data, which is often delayed, while simultaneously revealing the lived realities and vulnerabilities experienced by affected residents.

Figure 3. Map of the distribution of flood and inundation points in Denpasar City and Badung District, Bali



Source: Authors' analysis.

Results and discussion

Analysis of the 10 September 2025 floods shows that the most severely affected areas were in central–southern Denpasar and northern Badung, extending to the Denpasar border. Flood depths exceeded 2 m at critical points such as Badung Market and densely populated riverbank settlements, while transitional zones experienced average depths of 1–2 m. These conditions demonstrate that the flood was not merely a shallow inundation but a major overflow event that paralyzed residential areas, markets, and public facilities.



Table 1. Bali flood impact data (2025)

Metric	Data (Denpasar-specific)	Data (all of Bali)	Source
Casualties	12 people	18 people (final figure)	BNPB 2025
Evacuees	±295 people (3 shelters)	6,309 affected households	MetroTV 2025; BNPB 2025
Flood locations	81 locations	>120 locations (7 districts/municipalities)	BPBD Bali Province 2025; BNPB 2025
Maximum flood depth	2–3 meters (residential areas & markets)	N/A (no province-level aggregate)	Fithriansyah 2025
Damaged key infrastructure	Badung & Kumbasari Markets (474 stalls/shops), inner-city roads & bridges	520 damaged public facilities, 3 collapsed bridges, 23 damaged road segments, 82 failed retaining walls, 194 damaged houses	Tirto.id 2025; BNPB 2025

Sources: MetroTV 2025; BPBD Bali Province 2025; Fithriansyah 2025; Tirto.id 2025

Hydrological factors further exacerbated the impacts. The main rivers in Denpasar and Badung follow meandering patterns that are highly susceptible to sedimentation and erosion, resulting in reduced flow capacity (Sudiarsa and Sutapa 2021). Flooding also expanded in the estuarine areas due to the combination of river overflow and tidal influences (backwater effect). This situation aligns with the BNPB's InaRISK map, which classifies Denpasar and southern Badung as high-risk zones. Crowdsourced data adds a new dimension by revealing flood points located far from the river channels, particularly in urban areas with limited drainage capacity.

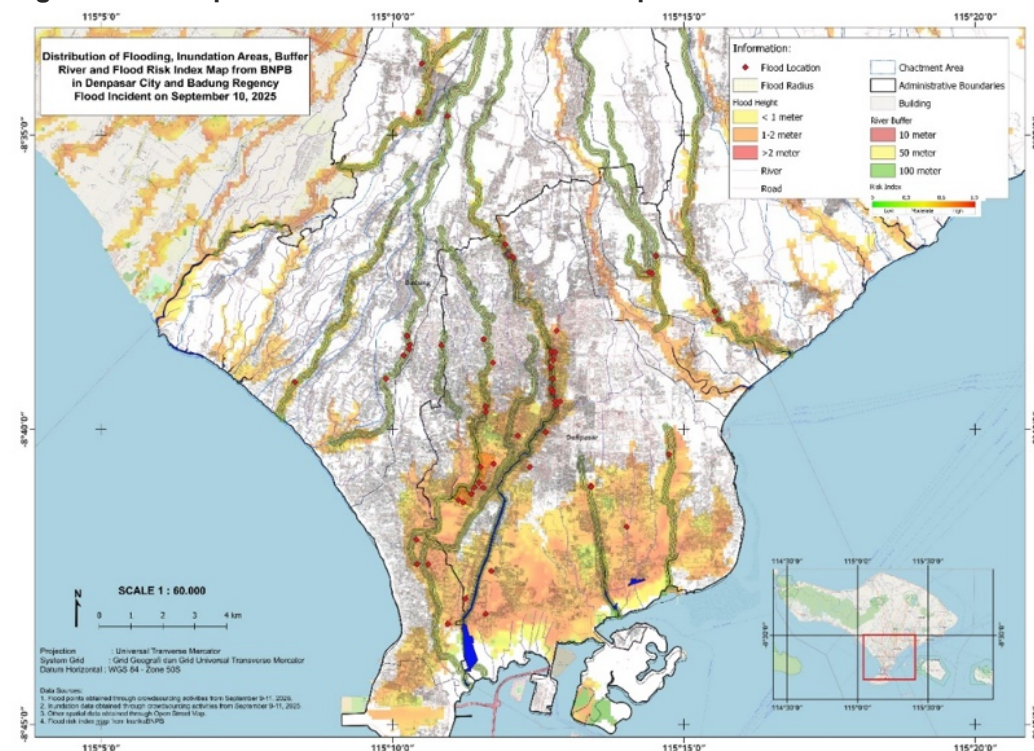
A comparison between the crowdsourced map and InaRISK in Figure 4 shows consistent patterns, indicating that most floods indeed occurred within high-risk zones. Nevertheless, anomalies were identified in Canggu and Kerobokan (Figure 5), where flooding appeared in areas classified as low risk. This may stem from rapid spatial changes, particularly the conversion of rice fields into villas and residential areas, that cause national-scale risk maps to lag behind on-the-ground realities. These findings reinforce the urgency of integrating local data into risk map updates.

Case studies at Badung Market, Pura Demak, and Soputan reveal a similar pattern: flood plains that once functioned as natural retention spaces have transformed into dense residential and commercial zones. As a result, any increase in river discharge now directly spills into buildings. Blocked urban drainage systems, clogged with solid waste, worsen the situation, allowing floodwaters to spread hundreds of meters from the riverbanks.

The flood map analysis for the Badung Market area in Figure 6 shows that the distribution of flood impacts is closely tied to the main river channel. Blue areas, representing inundated zones, follow the river course, while red areas, derived from crowdsourced reports, cluster along the riverbanks within a 10–50 m buffer. This indicates that river overflow was the dominant factor causing flooding in the area.

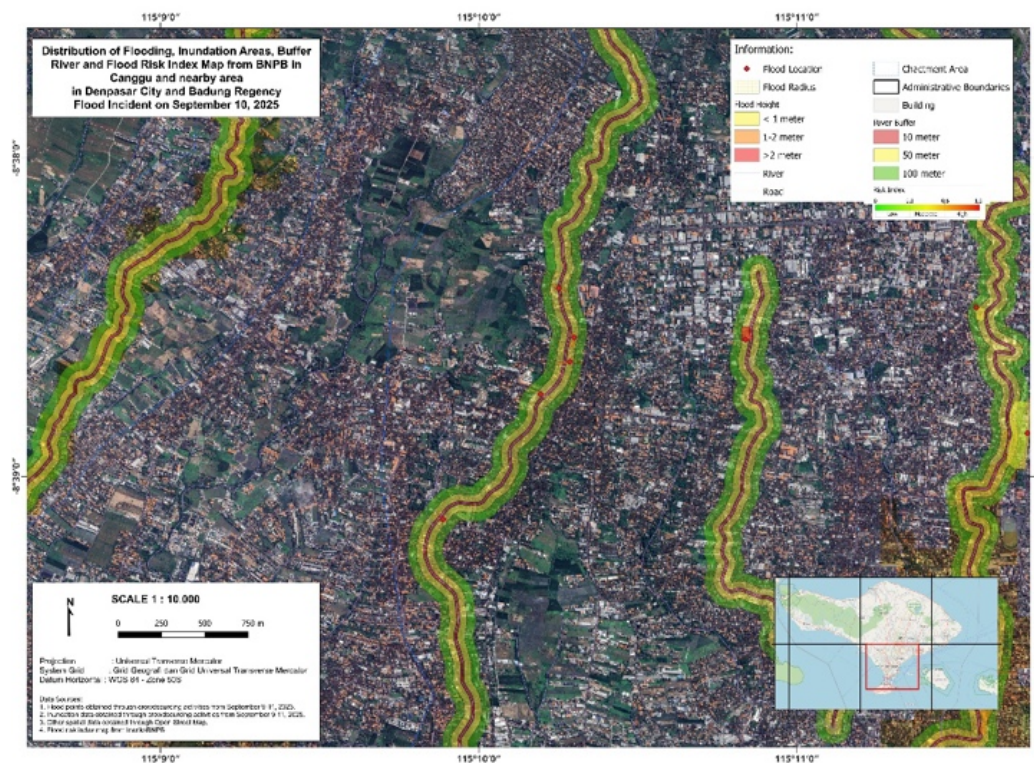


Figure 4. Overlap between floods and inundation points and BNPB's InaRISK flood index



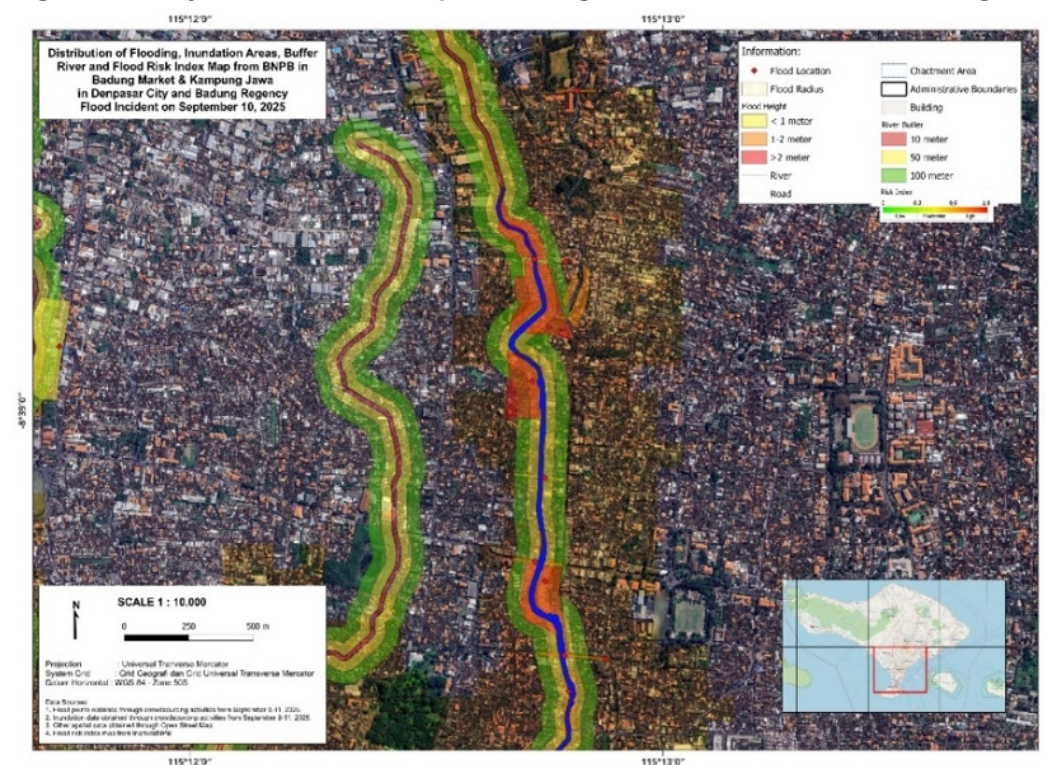
Source: Authors' analysis.

Figure 5. Flood analysis in Canggu shows that flood points and inundation areas were concentrated in densely populated settlements directly adjacent to the river



Source: Authors' analysis.

Figure 6. Analysis of the flood map in Badung Market shows that the flooding follows the river course



Source: Authors' analysis.

Overall, the 2025 Denpasar–Badung flood was the result of interactions between extreme rainfall, complex river morphology, the loss of natural floodplains, and failures in urban drainage systems. While national risk maps can identify long-standing vulnerabilities, crowdsourcing reveals new dynamics, including flood points in areas previously considered safe. This highlights the need for flood management in Bali to adopt a combined approach: restoring river spaces, improving urban drainage, regulating land-use conversion, and integrating real-time community data as the foundation for early warning systems and more adaptive spatial planning policies.

Global dimension: Climate crisis and environmental justice

The global climate crisis forms an essential structural backdrop that cannot be ignored when explaining the escalation of flood disasters. According to the IPCC (2022), the Earth's average surface temperature has increased by 1.1°C during the 2011–2020 period compared to pre-industrial levels (1850–1900). This atmospheric warming increases the amount of water vapor in the air, resulting in far more intense rainfall when condensation occurs. Bali, as a tropical region with a highly dynamic atmospheric system, is among the most affected. On 10 September 2025, recorded rainfall exceeded 200 mm in a single day—well above the normal thresholds and indicative of an extreme weather event.

However, the climate crisis is not merely a natural phenomenon; it reflects global political and economic inequality. Developed countries remain the largest contributors to carbon emissions, yet the most severe impacts are borne by developing nations, including Indonesia. The concept of climate injustice (Roberts and Parks 2007) captures this disparity: Bali contributes minimal emissions from the Nyepi ceremony (IESR 2020) but must endure consequences such as flooding, drought, and coastal erosion. In the Denpasar–Badung case, the 2025 flood is a tangible manifestation of this injustice, with extensive damage occurring in the most vulnerable areas, not in the centers of carbon production.



Human activities at the national scale further aggravate the situation. Indonesia's deforestation rate remained above 175,000 hectares (ha) per year in 2024 (KLHK 2025). The loss of forest cover reduces the ecosystem's capacity to absorb carbon and weakens its hydrological function. Rapid urbanization has sealed the ground with concrete and asphalt, inhibiting infiltration and increasing surface runoff. Bali faces a profound paradox: promoted globally as an island paradise, yet losing ecological carrying capacity as tourism-driven development continues to consume critical environmental spaces (Cole 2012). Thus, the 2025 floods cannot be understood solely as a meteorological event but also as a product of unequal global relations and unsustainable local development choices.

Meso dimension: Spatial planning, land conversion, and cosmological crisis

The 2025 Denpasar–Badung flood is closely tied to spatial planning changes and development practices that disregard environmental limits. Bali's protected forests shrank from 33.7% of its total territory in 1995 to 23.09% in 2020 (Wardana 2020), alongside the loss of 6,522 hectares of rice fields from 2015 to 2020 (BPS Bali Province 2025). The disappearance of these absorption zones means that any extreme rainfall rapidly transforms into large-scale inundation. Land conversion is heavily driven by tourism, with villas, hotels, and housing developments expanding into riparian buffer zones that should function as flood protection areas (Cole 2012).

Beyond spatial issues, the flood also reflects a cosmological crisis. The local philosophy of Tri Hita Karana, which emphasizes harmony between humans, nature, and spirituality, has increasingly been undermined by pragmatic development. Rivers once considered sacred now serve as waste channels, while traditional spatial and socio-cultural guidelines—such as Tri Mandala (the sacred-to-profane spatial hierarchy) and desa-kala-patra (the principle of contextual flexibility based on space, time, and condition)—are frequently ignored (Indrianto 2005; Vickers 2003). Hydrologically, the Ayung and Badung watersheds have lost their ecological function as floodplains have been replaced by residential, market, and tourism facilities. Clogged urban drainage systems and the decline of the subak irrigation network further reduce infiltration capacity. This combination reveals that flooding is not only a consequence of extreme rainfall but also of disrupted ecological and cosmological balance.

Micro dimension: Upstream to downstream dynamics, social behavior, and local politics

At the local level, flood vulnerability forms along the entire continuum from upstream to downstream. Upstream deforestation accelerates runoff into rivers. In midstream areas, rapid urbanization has narrowed riverbanks, with housing and shops built directly along the Badung and Mati Rivers. Downstream, former rice fields that once functioned as absorption zones have been converted into residential districts, such as Pemogan and Taman Pancing, increasing runoff and tidal flood risks.

Social behavior also worsens the problem. Waste disposal into rivers clogs drainage systems; at the Badung River estuary alone, an estimated 15 tons of waste accumulate every month (Kompas 2024). Traditional villages (*desa adat*), once stewards of spatial order, now face dilemmas between cultural values and economic pressures. Local politics also play a role: development permits in riparian zones are often lenient, and the villa development moratorium on productive land (Mongabay 2025) came too late to curb widespread conversion.

Mitigation capacity on the ground remains low. Early warning systems are ineffective, evacuation signage is minimal, and emergency ladders or water-level sensors are absent. During the 2025 floods, warnings did not reach communities, logistical distribution of disaster support was slow, evacuations stalled, and public services, such as those at Mangusada and Wangaya hospitals, were disrupted.

Amid weak governance, crowdsourcing emerged as an alternative solution. Community reports mapped more than 120 flood points, with depths reaching up to 3 m, and documented real-time damage to public facilities. These findings complement official risk maps, which failed to capture flood anomalies in Canggu and Kerobokan areas.





In line with the concept of volunteered geographic information (Goodchild 2007), crowdsourcing positions residents not merely as victims, but as producers of information and agents of policy advocacy.

Conclusion

This study concludes that the major floods that struck Denpasar and Badung areas on 10 September 2025 were a systemic disaster triggered by a combination of extreme rainfall, the degradation of watershed hydrological functions, failures in the urban drainage system, and weak spatial planning that amplified community vulnerability. Analysis of crowdsourced data shows that the floods not only spread across dozens of locations but also reached depths of more than 2 m in several densely populated areas, causing significant economic losses and fatalities that could have been prevented. The crowdsourced data proved capable of capturing detailed on-the-ground conditions, including inundation distribution, evacuation obstacles, and socioeconomic impacts, with a level of accuracy rarely found in official data sources. Further, crowdsourcing demonstrates its potential not only as a documentation method but also as a tool for citizen-driven advocacy. Moving forward, this approach must be systematically strengthened so that community experience can be directly integrated into disaster planning and response, ensuring that resulting policies are genuinely rooted in real conditions on the ground.

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Local Wisdom and Innovation of Indigenous Malind Women: A Path to Socioecological and Economic Resilience

Muhammad Novan Prasetya^{1*}, Tini Adiatma¹, Tutik Yuliatun¹, Ilham Majid¹, and Guntur Arafa¹

¹ Musamus University, Merauke, Indonesia

* Corresponding author: muhnovanprasetya@unmus.ac.id

Abstract

This study explores how Indigenous Malind women draw upon local wisdom to develop community-based innovations that strengthen socio-ecological and economic resilience amid climate change and livelihood uncertainty. Using a qualitative, participatory, and indigenous-centered approach grounded in asset-based community development (ABCD), the research draws from participatory observation, focus group discussions, narrative interviews, and participatory mapping. The findings reveal that indigenous knowledge functions as a dynamic and adaptive system, guiding sustainable resource use and shaping innovation processes rooted in cultural values. Malind women's engagement in producing coconut-based products, such as oil, soap, and body care products, demonstrates how traditional practices are reinterpreted into value-added livelihood strategies through collective learning and experimentation. These innovations strengthen household economies, enhance women's agency and leadership, and reinforce social cohesion within the community. Importantly, the study highlights that resilience extends beyond economic outcomes to include cultural continuity, ecological sustainability, and collective well-being. The research identifies iterative feedback loops between local wisdom, innovation, and resilience, illustrating that indigenous innovation is relational and cyclical rather than linear. By centering indigenous women as knowledge holders and agents of change, this study contributes to broader debates on gender, indigenous knowledge, and climate resilience, offering insights into more inclusive, culturally grounded development and adaptation strategies.

Keywords: indigenous knowledge systems; Malind women; local wisdom; community-based innovation; socioecological resilience; climate change adaptation

Introduction

Across the Global South, indigenous communities stand at the frontline of overlapping ecological, economic, and cultural crises. Climate change, biodiversity loss, and extractive development have increasingly disrupted traditional livelihoods, particularly in coastal and forest-dependent societies (Bebbington et al. 2018). Yet, within these vulnerable contexts, rather than being passive victims of environmental change, Indigenous peoples actively generate knowledge and adaptive innovations that sustain their socio-ecological systems. They are active knowledge holders and innovators who continuously adapt to socioecological transformations through local wisdom, collective practices, and culturally embedded forms of innovation. Among these knowledge holders, indigenous women play a central but often under-recognized role in sustaining community resilience.

In Merauke, South Papua, Indonesia, the Indigenous Malind community inhabits a complex socioecological landscape, shaped by coastal ecosystems, coconut groves, mangrove areas, and customary territories, all deeply intertwined with cultural identity and subsistence practices. For generations, Malind women have been custodians of ecological knowledge related to food systems, natural resource management, and household economies. This knowledge is not only technical but relational, connecting land, sea, community, and spirituality. However, contemporary development paradigms tend to marginalize such indigenous knowledge systems, privileging external technologies and market-oriented interventions that often overlook local sociocultural contexts.





The impacts of climate change have further intensified existing vulnerabilities in coastal indigenous communities, such as in Payum Village, Merauke. Changes in weather patterns, declining fish stocks, and increased environmental uncertainty have affected the livelihoods of fishing households, which traditionally rely on marine resources as their primary source of income. These ecological pressures intersect with gendered economic structures, in which women's contributions are often confined to informal, unpaid domains. As a result, indigenous women's adaptive capacities and innovative practices remain insufficiently documented and rarely integrated into climate resilience and development strategies.

At the same time, Payum Village possesses abundant local resources that hold significant potential for socioeconomic transformation when approached through an indigenous- and community-centered lens. One such resource is coconut, a plant that occupies an important place in Malind culture, ecology, and daily life. Beyond its material value, coconut represents accumulated ecological knowledge, intergenerational practices, and cultural meanings related to sustainability and self-sufficiency. Traditionally utilized for household consumption, coconuts have increasingly become a site of innovation, where indigenous women reinterpret ancestral knowledge to respond to contemporary economic and environmental challenges.

This study argues that the innovations emerging from Indigenous Malind women's engagement with coconut-based products should not be understood merely as small-scale economic activities. Rather, they represent a form of socioecological innovation rooted in local wisdom, collective agency, and adaptive responses to climate change. Through processes of learning, experimentation, and collaboration, Malind women transform traditional practices into new livelihood strategies that strengthen household economies while maintaining ecological integrity. These innovations illustrate how indigenous knowledge systems can evolve dynamically without losing their cultural foundations.

Despite growing global recognition of indigenous knowledge in sustainability discourse, empirical studies that center indigenous women's lived experiences, leadership, and innovation remain limited, particularly in eastern Indonesia. Much of the existing literature treats community empowerment as a technical intervention focused on skills training or income generation, without sufficiently addressing the deeper socioecological relationships and power dynamics that shape indigenous women's agency. Consequently, there is a critical need for research that foregrounds indigenous women as agents of resilience and knowledge production rather than as beneficiaries of development programs.

This paper seeks to address this gap by examining how local wisdom and innovation among Indigenous Malind women contribute to socioecological and economic resilience in Payum Village, building on perspectives of indigenous knowledge and resilience (Folke 2016; Berkes 2018). Building on an asset-based community development (ABCD) approach, this study emphasizes community strengths and locally driven development processes, as outlined in *Building communities from the inside out* and further developed in community-based development literature. The study explores how indigenous women identify, mobilize, and transform local resources, particularly coconuts, into value-added products that support livelihood diversification. More importantly, it analyzes how these practices reinforce social cohesion, enhance women's roles in community decision-making, and foster adaptive capacities in the face of climate-related uncertainties.

The concept of resilience employed in this study extends beyond economic stability to encompass social relationships, cultural continuity, and ecological sustainability. Socioecological resilience is understood as the ability of a community to absorb disturbances, adapt to change, and transform in ways that sustain both human well-being and ecosystem health. These are articulated in resilience scholarship, such as *Resilience thinking: Sustaining ecosystems and people in a changing world* and further developed in the socioecological systems literature (Folke et al. 2010; Berkes and Ross 2013). From this perspective, the innovations led by Malind women are embedded within broader social and ecological systems, reflecting a holistic understanding of resilience that contrasts with narrowly defined development metrics.





By situating indigenous women's innovations within their cultural and ecological contexts, this paper contributes to interdisciplinary debates on indigenous knowledge, gender, and climate resilience. It highlights how local wisdom can serve as a foundation for community-driven innovation that is both economically viable and environmentally sustainable. Further, the study offers insights for policymakers, practitioners, and scholars seeking to design inclusive development and climate adaptation strategies that recognize and strengthen indigenous women's leadership.

Ultimately, this research positions Indigenous Malind women not only as beneficiaries of empowerment initiatives but as key actors in shaping pathways toward socioecological and economic resilience. Their experiences demonstrate that sustainable futures in indigenous territories are most effectively built when local knowledge, cultural values, and women's agency are placed at the center of development and environmental governance.

Theoretical components

Indigenous knowledge systems

Indigenous knowledge systems (IKS) form the epistemic foundation of this framework. IKS refers to locally grounded, cumulative bodies of knowledge developed through long-term interactions between indigenous communities and their environments, as elaborated in works such as Sacred ecology (Berkés 2018) and studies on indigenous knowledge systems (Agrawal 1995). Among the Malind people, such knowledge encompasses resource use, seasonal cycles, food processing, and cultural norms governing relationships between humans and nature. This study treats local wisdom not as a static tradition, but as a dynamic, adaptive system that continuously evolves in response to socioecological changes.

Feminist political ecology

Feminist political ecology provides a critical lens to understand how environmental knowledge, access to resources, and decision-making power are gendered, as articulated in foundational works such as Feminist political ecology: Global issues and local experiences (Rocheleau et al. 1996) and further developed in gender and environment studies (Agarwal 2010). Indigenous Malind women occupy a unique position as caretakers of household economies, processors of natural resources, and transmitters of ecological knowledge. However, their roles are often undervalued within dominant development narratives. By applying this perspective, the framework highlights how women's agency and leadership are central to both environmental stewardship and economic adaptation.

Community-based innovation

Community-based innovation emphasizes processes that emerge from collective action, shared learning, and local resource mobilization, as discussed in the literature on grassroots and community innovation (Seyfang and Smith 2007) and community-based enterprise development (Peredo and Chrisman 2006). In Payum Village, innovation is not externally imposed but arises from indigenous women's reinterpretation of traditional practices, such as coconut processing, into value-added livelihood strategies. These innovations are socially embedded, culturally meaningful, and oriented toward long-term sustainability rather than short-term profit maximization.

Socioecological resilience

Socioecological resilience refers to the capacity of communities to absorb disturbances, adapt to change, and transform while maintaining essential functions, identities, and ecological relationships, as articulated in resilience frameworks (Walker et al. 2004; Folke et al. 2010). In this framework, resilience is understood as multidimensional, encompassing economic security, social cohesion, gender equity, cultural continuity, and ecosystem health.





(Berkes and Ross 2013). Indigenous women's innovations contribute to resilience by diversifying livelihoods, strengthening collective institutions, and reinforcing reciprocal relationships between people and nature.

Integrative logic of the framework

The framework illustrates a causal and relational pathway in which climate and ecological pressures interact with indigenous sociocultural contexts, activating local wisdom and women's agency. Through collective learning and experimentation, this agency generates community-based innovations that enhance socioecological and economic resilience. Importantly, the process is iterative rather than linear, allowing feedback between innovation outcomes and the continual evolution of local knowledge systems.

By integrating these theoretical perspectives, the framework offers a holistic lens to analyze how Indigenous Malind women navigate climate change and development pressures through culturally grounded innovation. It challenges technocratic approaches to resilience by foregrounding indigenous epistemologies, gendered agency, and community-driven pathways toward sustainability.

Methodology

Research design and approach

This study adopts a qualitative, participatory, and indigenous-centered research design to understand how local wisdom and innovation among Indigenous Malind women contribute to socioecological and economic resilience. The methodology is intentionally aligned with the conceptual framework, which positions indigenous women as agents of knowledge production and innovation rather than passive subjects of development interventions.

The research is grounded in a participatory, community-based approach, drawing inspiration from asset-based community development (ABCD) while extending it through indigenous research principles. These principles are as articulated in Building Communities from the Inside Out and further developed in asset-based and participatory development literature. The research is also extended using indigenous research methodologies that emphasize relationality and community engagement (Smith 1999; Chilisa 2012). Rather than focusing on deficits or vulnerabilities, this approach emphasizes existing capacities, cultural knowledge, and collective practices embedded within the Malind community. Knowledge generation is treated as a relational and iterative process, co-produced through engagement with community members.

Study site and community context

The research was conducted in Payum Village in Merauke District, South Papua Province. Payum is a coastal Indigenous Malind village whose socioecological system is closely linked to marine resources, coconut groves, and customary land. Livelihoods are primarily based on small-scale fishing and subsistence activities, making the community particularly sensitive to climate variability and environmental change.

Indigenous Malind women play a central role in household economies, food processing, and the transmission of ecological knowledge. Coconut, as a locally abundant resource, holds cultural, ecological, and economic significance within the community and serves as a key entry point for examining indigenous innovation and adaptive livelihood strategies.





Participants and ethical considerations

Participants in this study were Indigenous Malind women actively engaged in community-based economic activities, particularly in coconut processing and collective learning initiatives. Participants were selected through purposive and relational sampling, based on community recommendations and existing social networks, to ensure cultural appropriateness and trust.

Ethical considerations were guided by principles of respect, reciprocity, and indigenous data sovereignty. Prior to data collection, informed consent was obtained through culturally appropriate dialogue rather than through solely formal documentation. Participants were informed about the purpose of the study, the use of their data, and their right to withdraw at any time. The research process emphasized mutual learning and aimed to produce outcomes beneficial to the community.

Data collection methods

To capture the complexity of Indigenous women's innovation and resilience practices, multiple qualitative methods were employed, as described below. Participants consisted of Indigenous Malind women actively engaged in community-based economic activities, particularly coconut processing and collective learning initiatives. Participants ranged in age from 17 to 55 years. Participants were selected through purposive and relational sampling based on community recommendations and existing social networks to ensure cultural appropriateness and trust.

Participatory observation

The researcher conducted sustained observation of community activities related to coconut processing, group discussions, and collective decision-making. This method enabled the documentation of everyday practices, interactions, and embodied knowledge that are often overlooked in conventional research approaches.

Focus group discussions

Three focus group discussions (FGDs) were conducted, involving 18 Indigenous Malind women who were actively engaged in coconut-based livelihood activities and community initiatives. All participants were women, reflecting the study's focus on indigenous women's experiences, agency, and knowledge systems.

The FGDs explored the participants' shared experiences, aspirations, and challenges related to livelihood diversification and environmental change. They facilitated collective reflection and allowed participants to articulate their understanding of innovation, resilience, and local wisdom in their own terms.

Narrative and informal interviews

Fifteen Indigenous Malind women were interviewed between April and August 2025 during community engagement and fieldwork in Payum Village. Semi-structured and narrative-based interviews were used to capture personal life histories, learning trajectories, and reflections on women's roles within the community. This method prioritizes storytelling as a legitimate form of knowledge, consistent with indigenous epistemologies.

Participatory mapping of Innovation practices

A total of 20 Indigenous Malind women took part in the participatory mapping process, conducted across two sessions. Participants collaboratively identified and mapped stages of coconut-based innovation, from traditional knowledge and resource use to product development and collective enterprise formation. This process highlighted the link between ecological knowledge, cultural values, and economic practices.



Findings

The findings are organized thematically to reflect the lived experiences, collective practices, and innovative strategies of Indigenous Malind women in Payum Village. Rather than presenting outcomes as technical outputs, this section highlights how local wisdom, women's agency, and community-based innovation intersect to build socioecological and economic resilience.

Local wisdom as a living socioecological knowledge system

Indigenous Malind women in Payum Village possess a deep, embodied understanding of their surrounding ecosystems, particularly coastal areas and coconut groves. This knowledge is transmitted intergenerationally through daily practices, such as food preparation, resource processing, and household management. Coconut is not merely an economic commodity but part of a broader ecological relationship linking land, sea, and community well-being.

Participants described how traditional knowledge guides decisions about harvesting cycles, resource use, and waste minimization. For example, coconut shells, husks, and residual oil are reused for household needs or communal activities, reflecting principles of ecological balance and sustainability. This insight demonstrates that local wisdom functions as a living knowledge system, continuously adapted to changing environmental conditions, rather than a static cultural artifact.

Figure 1. Intergenerational learning and community engagement in coastal livelihood practices in Payum Village



Source: Field documentation by the researchers, Kampung Payum Village, Merauke, South Papua (2025).

Indigenous women's agency and collective learning

Women's agency emerged strongly through collective learning spaces, such as group-based coconut processing workshops, hands-on product-making sessions (e.g., producing coconut oil, soap, and body care products), regular group discussions on production techniques, quality control, and marketing strategies, and shared decision-making processes. Indigenous Malind women actively negotiated roles within groups, distributed responsibilities, and supported one another in acquiring new skills. Learning occurred not only through formal instruction but also through observation, experimentation, and peer-to-peer knowledge exchange.

Many participants emphasized increased self-confidence and a sense of recognition as a result of collective engagement. Women who were previously confined to domestic roles began to articulate aspirations related to economic contribution, leadership, and community participation. This shift reflects a transformation from individual survival strategies to collective agency, in which women view themselves as capable actors in shaping household and community futures.

Figure 2. Community-based production and knowledge sharing among Indigenous Malind women



Source: Field documentation by the researchers, Kampung Payum Village, Merauke, South Papua (2025).



Figure 3. Hands-on coconut processing and collective learning activities in Payum Village



Source: Field documentation by the researchers, Kampung Payum Village, Merauke, South Papua (2025).

Innovation pathways rooted in tradition

Innovation among Indigenous Malind women followed pathways that are deeply rooted in traditional practices while responding to contemporary challenges. Coconut processing techniques evolved from household-scale use to more organized, value-added production through collective experimentation. Women combined inherited knowledge with new ideas related to product formulation, hygiene, and packaging, without abandoning cultural norms.

These innovation pathways were incremental and adaptive rather than disruptive. Participants emphasized learning by doing, gradual improvement, and mutual support as key principles guiding innovation. The resulting coconut-based products, such as soap, body butter, and oil, represent not only economic outputs but also cultural expressions of indigenous ingenuity. Innovation, therefore, functioned as a social process, embedded in relationships and shared values.

In this process, the Indigenous Women's group has received sustained support from an external civil society organization (CSO), Perkumpulan Sophia Nusantara, since 2024. This support has been facilitative rather than directive, focusing on strengthening existing local capacities. Key activities include





- participatory training on coconut-based product development (soap, body butter, oil, and other derivatives);
- mentoring in production techniques, hygiene standards, and simple quality control;
- assistance in developing packaging and branding rooted in local identity;
- facilitation of collective learning spaces and group organization; and
- support in exploring local market access and small-scale entrepreneurship strategies.

Furthermore, this collective initiative has evolved into a community-based micro enterprise called Payum Iwag, which in the Malind Indigenous language means “women of Payum Village.” The establishment of Payum Iwag reflects not only an economic transformation but also a strengthening of collective identity, where women position themselves as active agents of change within their community.

Importantly, the role of Perkumpulan Sophia Nusantara has been to accompany and co-learn with the community, ensuring that innovation processes remain grounded in indigenous knowledge systems and cultural values. No significant direct intervention from local government was identified during the study period, highlighting the importance of community–CSO collaboration in enabling locally driven innovation.

Community-based innovation and social cohesion

The emergence of collective production groups strengthened social cohesion within the community. In Payum Village, these groups take the form of small, community-based women’s production units organized under Payum Iwag as the broader initiative. They primarily focus on producing coconut-based value-added products, including coconut oil, soap, body butter, and other simple natural body care products derived from locally available resources.

These groups were initiated collectively by Indigenous Malind women, emerging from shared concerns over declining fishing income and the need for alternative livelihoods. The process was further supported since 2024 by Perkumpulan Sophia Nusantara, which facilitated the group formation through participatory discussions, training, and ongoing mentoring. The organizational structure, division of roles, and decision-making processes are determined internally by the women themselves.

In terms of structure, there is currently one active production group consisting of approximately 18 Indigenous Malind women members. Membership is flexible and based on kinship ties, proximity, and willingness to participate, reflecting local social structures. Within each group, team members distribute roles, including preparing raw materials, processing, packaging, and coordinating sales.

Women described how working together fostered trust, reciprocity, and mutual accountability. Group-based innovation reduced individual risk and enabled shared problem-solving when facing challenges related to production, resource availability, or market access. These community-based arrangements also created new spaces for dialogue and leadership. Decisions regarding production schedules, quality standards, and distribution were made collectively, reinforcing democratic practices at the community level. Such arrangements reflect the principles of community-based enterprise, where economic activities are inseparable from social relationships and collective well-being.

Socioecological and economic resilience outcomes

The innovations led by Indigenous Malind women contributed to multiple dimensions of resilience. Economically, coconut-based products provided alternative income sources that complemented fishing livelihoods, reducing





vulnerability to climate-induced fluctuations in marine resources. Socially, increased participation of women in economic activities enhanced their standing within households and community institutions.

Ecologically, the continued reliance on locally available and renewable resources reinforced sustainable resource management practices. Participants expressed a heightened awareness of environmental stewardship, recognizing that long-term economic benefits depend on maintaining ecological balance. These outcomes illustrate that resilience in Payum Village is not solely measured by income generation but by the capacity to sustain livelihoods, cultural identity, and ecosystem health simultaneously.

Feedback loops between innovation and local wisdom

Findings also reveal an iterative relationship between innovation and local wisdom. As women engaged in new forms of production, such as transforming traditionally extracted coconut oil into value-added products including natural soap, body butter, lip balm, and better-quality coconut oil using more refined processing and hygiene standards, they reinterpreted and reaffirmed traditional knowledge, strengthening cultural continuity. In addition, women introduced basic innovations in packaging, product consistency, and small-scale branding under the collective identity of Payum Iwag, which expanded the use of coconut beyond household consumption into market-oriented products.

Successful innovations reinforced community pride and motivation, which in turn encouraged further experimentation and learning. This feedback loop highlights that indigenous innovation is not a linear process with fixed endpoints. Instead, it is cyclical and relational, shaped by ongoing interactions between people, culture, and the environment. Through this process, Indigenous Malind women actively construct pathways toward socioecological and economic resilience grounded in their own values and knowledge systems.

Discussion

This study demonstrates that local wisdom and innovation among Indigenous Malind women constitute a critical foundation for building socioecological and economic resilience in coastal Papua. By situating women's coconut-based innovations within indigenous knowledge systems, feminist political ecology, community-based innovation, and socioecological resilience, the findings move beyond a narrow understanding of empowerment as skills acquisition or income generation (Berkes. 2018). Instead, they reveal resilience as a culturally embedded, gendered, and relational process (Folke. 2016).

Indigenous knowledge and innovation as dynamic processes

The findings affirm that indigenous knowledge among Malind women is not a static tradition but a dynamic system that evolves through interaction with environmental change and socioeconomic pressures (Whyte 2017; Berkes 2018). Women's reinterpretation of coconut-based practices illustrates how indigenous knowledge adapts without losing its cultural grounding. This challenges dominant development narratives that frame indigenous knowledge as outdated or incompatible with innovation (Agrawal 1995). Instead, the study supports perspectives that view indigenous knowledge as a living epistemology capable of generating context-specific solutions to climate and livelihood challenges (Cochran et al. 2013).

Innovation in Payum Village emerged through incremental, collective experimentation rather than disruptive technological change. This aligns with the scholarship on community-based innovation, which emphasizes learning-by-doing, social embeddedness, and shared values (Peredo and Chrisman 2006; Seyfang and Smith 2007). By integrating inherited practices with new techniques related to product quality and organization, Indigenous Malind women demonstrate how innovation can strengthen, rather than erode, cultural identity (Smith 1999).



Gendered agency and feminist political ecology

From a feminist political ecology perspective, the findings highlight how environmental knowledge and economic adaptation are deeply gendered (Rocheleau et al. 1996). Indigenous Malind women occupy a strategic position at the intersection of household economies, natural resource management, and cultural transmission (Agarwal 2010). Their increased participation in collective production and decision-making reflects a shift in gendered power relations, albeit within existing social structures.

Figure 4. Payum Iwag products: coconut soap, lip balm, body butter, and others



Source: Field documentation by the researchers, Kampung Payum Village, Merauke, South Papua (2025).

Rather than portraying empowerment as an individual achievement, this study underscores collective agency as central to women's resilience (Kabeer 1999). Group-based innovation creates spaces for leadership, negotiation, and mutual accountability, enabling women to navigate constraints while expanding their roles (Cornwall 2016). This resonates with feminist critiques of development approaches that prioritize individual entrepreneurship without addressing social relations and structural inequalities (Elson 1995).

Community-based innovation and social cohesion

The emergence of community-based innovation groups illustrates how economic activities can reinforce social cohesion and collective well-being. Consistent with community-based enterprise theory, the findings show that shared ownership, trust, and reciprocity reduce individual risk and enhance adaptive capacity (Peredo and Chrisman 2006; Nikkhah and Redzuan 2010). Economic activities are inseparable from social relations, and success is measured not only by income but by strengthened community bonds and collective confidence (Putnam 2000).

Such arrangements are particularly relevant in indigenous contexts, where communal values and kinship networks shape economic behavior (Escobar 2015). By embedding innovation within community structures, Indigenous Malind women have created livelihood strategies that are resilient to external shocks and aligned with local values (Bebbington et al. 2018).



Socioecological resilience beyond economic metrics

The study expands conventional interpretations of resilience by demonstrating its multidimensional nature. Economic diversification through coconut-based products contributed to household security, but equally important were social and ecological outcomes (Folke et al. 2010). Women's innovations reinforced sustainable resource use, heightened environmental awareness, and strengthened cultural continuity (Berkes and Ross 2013).

These findings support socioecological resilience frameworks that emphasize adaptability, transformation, and the maintenance of identity (Walker et al. 2004). In Payum Village, resilience is not defined by growth or accumulation but by the capacity to sustain relationships between people, culture, and ecosystems amid uncertainty (Whyte 2017).

Feedback loops between knowledge, innovation, and resilience

A key contribution of this study is the identification of feedback loops among local wisdom, innovation, and resilience. As women engaged in innovation, they reaffirm and revitalize traditional knowledge, which, in turn, motivates further collective action (Berkes 2018). This cyclical process challenges linear models of development and adaptation, highlighting the importance of iterative, community-driven pathways (Leach et al. 2010).

Implications for development and climate policy

The findings carry important implications for development and climate adaptation policies in indigenous territories. Interventions that overlook indigenous women's knowledge and agency risk undermining existing resilience mechanisms (Chilisa 2012). Conversely, policies that support community-driven innovation, respect indigenous knowledge systems, and strengthen women's collective institutions can enhance both social equity and environmental sustainability (UN Women 2018).

Rather than scaling standardized solutions, policymakers and practitioners should prioritize enabling conditions for indigenous-led innovation, including secure land tenure, access to local markets, and long-term accompaniment (Ribot and Peluso 2003; Ostrom 2010). Recognizing indigenous women as leaders and knowledge holders is essential for designing inclusive and effective resilience strategies (Whyte 2017).

Conclusion

This study has examined how local wisdom and innovation among Indigenous Malind women in Payum Village contribute to socioecological and economic resilience in the context of climate change and livelihood uncertainty. By centering indigenous women's experiences, knowledge, and collective practices, the research demonstrates that resilience is not merely the outcome of external interventions or technical solutions, but a process rooted in culturally embedded knowledge systems, gendered agency, and community-based innovation. This study has examined how local wisdom and innovation among Indigenous Malind women in Payum Village contribute to socioecological and economic resilience in the context of climate change and livelihood uncertainty. By centering indigenous women's experiences, knowledge, and collective practices, the research demonstrates that resilience is not merely the outcome of external interventions or technical solutions, but a process rooted in culturally embedded knowledge systems, gendered agency, and community-based innovation.

The findings reveal that coconut-based innovations developed by Indigenous Malind women are more than alternative income-generating activities. They represent adaptive strategies that integrate ecological stewardship, cultural continuity, and social cohesion. Through collective learning and experimentation, women reinterpret traditional knowledge to respond to contemporary challenges without abandoning indigenous values and relationships with the environment. This process highlights the dynamic nature of indigenous knowledge and its capacity to generate locally grounded pathways toward sustainability.





Moreover, the study shows that women's collective agency plays a crucial role in strengthening resilience. Participation in community-based innovation enhances women's confidence, leadership, and decision-making roles within households and the wider community. At the same time, these innovations contribute to livelihood diversification, reduce vulnerability to climate-related shocks, and reinforce sustainable resource management practices. Taken together, these outcomes underscore the importance of recognizing indigenous women as central actors in socioecological transformation.

Ultimately, this research affirms that sustainable futures in indigenous territories are most effectively built when development and climate adaptation efforts are grounded in local wisdom, respect indigenous knowledge systems, and support women's collective leadership. The experiences of Indigenous Malind women in Payum Village offer valuable insights for rethinking resilience beyond technocratic and gender-neutral frameworks.

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Local Waste Governance in Small Islands: Lessons from Community-Led Waste Working Groups in Central Maluku, Indonesia

Kristanto Irawan Putra^{1,*}

¹ Program to Protect Biodiversity in the Central Maluku Region through Plastic Waste Management (Program Melindungi Keanekaragaman Hayati Wilayah Maluku Tengah dengan Pengelolaan Sampah Plastik; Plasma-B), Bintari

* Corresponding author: kristantoirawan.putra@gmail.com

Abstract

Saparua and Banda Islands in Central Maluku, Indonesia, exemplify the country's small islands: ecologically rich yet burdened by unmanaged solid waste. Household burning, burying inorganic waste, and coastal dumping accelerate marine plastic leakage, threatening fisheries and coral ecosystems that sustain livelihoods. Preliminary analysis by non-governmental organization Bintari's Program to Protect Biodiversity in the Central Maluku Region through Plastic Waste Management (Program Melindungi Keanekaragaman Hayati Wilayah Maluku Tengah dengan Pengelolaan Sampah Plastik; Plasma-B) shows that in year 2024 over 80 percent of waste is unmanaged, with nearly 40 percent entering the sea. To address this challenge, the program introduced participatory waste governance through village-level waste working groups (*Pokja*, abbreviation of the term in Bahasa Indonesia) in formed through Maluku's traditional village deliberation process. The waste governance aims to embed waste reduction, collection, education, and inter-island logistics in customary systems rooted in inclusion, the Indonesian spirit of *gotong royong* (working together), and shared accountability, aligned with district regulations. Early outcomes across four pilot communities include strengthened local ownership, improved coordination, and emerging recycling pathways to Ambon, despite infrastructure gaps. This paper demonstrates that governance capacity—not infrastructure—is the primary determinant of waste system performance in small island contexts.

Keywords: small islands; waste governance; *Pokja*; marine plastic leakage; Maluku

Introduction

Globally, the transition toward a circular economy has been promoted as a pathway to decouple economic growth from resource depletion and environmental degradation (Ellen MacArthur Foundation 2015; Kirchherr et al. 2017). However, critical scholarship cautions that circular economy frameworks often prioritize material efficiency and market mechanisms while overlooking questions of power, spatial inequality, and governance (Gregson et al. 2015; Demaria and Schindler 2016). These blind spots are particularly evident in geographically isolated and resource-constrained settings, where technical solutions cannot be separated from social relations and institutional arrangements.

Solid waste management systems, as Wilson et al. (2012) demonstrate, are fundamentally shaped by governance capacity rather than technological sophistication. Comparative studies across cities further show that collection coverage, recycling performance, and environmental outcomes depend less on infrastructure and more on institutional coherence, stakeholder coordination, and financial sustainability (Wilson et al. 2012; World Bank 2018). In small island contexts, these structural constraints are even more pronounced due to geographic and economic limitations (Asian Development Bank 2014). Brunner and Velis (2013) further argue that waste management must shift from a quantitative focus on throughput to a qualitative emphasis on system integrity, governance, and material stewardship.





In Indonesia, waste governance has increasingly been framed within the language of circular economy. National policy documents emphasize the economic, social, and environmental benefits of circularity, including job creation, resource efficiency, and pollution reduction (Bappenas 2021). Popular and policy-oriented publications further promote the circular economy as a strategic response to Indonesia's plastic pollution crisis (Bestari 2023; Subekti 2023). Yet, these narratives are largely urban-centric and infrastructure-oriented, implicitly assuming the presence of landfills, processing facilities, and stable logistics networks.

Small islands disrupt these assumptions. In many island communities, including those in Central Maluku, Indonesia, formal disposal sites or waste processing facilities exist only on the main islands. Household practices such as burning, burying, or dumping waste into coastal areas become normalized survival strategies rather than behavioral anomalies. Recyclable material prices decline sharply in small-island contexts. Used cardboard prices range from IDR2,000–2,400 (about 13 U.S. cents) per kilogram (kg) in Surabaya in Java, but fall to only IDR650–900 per kg in Banda Island in Maluku. Similarly, used clean PET bottle prices reach IDR5,000–7,500 per kg in Surabaya, compared to just IDR1,500–4,500 in Banda (Bintari 2025). From a governance perspective, this condition reflects what Graham and Marvin (2001) describe as “splintering infrastructures,” where peripheral regions are systematically excluded from networked service provision. Consequently, environmental burdens, such as marine plastic leakage, are spatially displaced onto communities least equipped to manage them, raising issues of spatial and environmental justice (Soja 2010).

Environmental governance literature provides a useful lens for understanding these dynamics. Lemos and Agrawal (2006) define environmental governance as the set of institutions, actors, and processes that shape environmental decision-making across scales. Importantly, governance is not synonymous with government. It encompasses informal norms, community institutions, and negotiated power relations. Van Assche et al. (2014) further conceptualize governance as evolutionary, shaped by historical trajectories, local knowledge, and adaptive learning rather than linear policy implementation. The dynamics, interactions, and negotiations between formal and informal institutions continuously reshape governance arrangements.

Community-led waste governance initiatives offer an alternative pathway. Empirical studies from the Global South demonstrate that cooperative and community-based waste systems can enhance social inclusion, accountability, and material recovery when embedded within local governance structures (Gutberlet 2015). These findings suggest that waste management systems are not merely technical assemblages but sociopolitical infrastructures that must align with local institutions and cultural practices.

This paper addresses that gap by examining the formation and function of village-level waste working groups (*Pokja*, abbreviation of the term in Bahasa Indonesia) in Central Maluku as governance mechanisms for integrated sustainable waste management (ISWM). Rather than assessing its technical performance or project outcomes, the study investigates how *Pokja* reconfigures power relations, institutional roles, and collective action across social, institutional, and operational dimensions of waste management. Despite growing attention to circular economy and waste infrastructure, this paper demonstrates how locally embedded governance systems enable waste management in small island contexts.

This paper responds to a central question: How can small islands govern waste effectively under conditions of infrastructural scarcity and geographic isolation? Drawing from the Program to Protect Biodiversity in the Central Maluku Region through Plastic Waste Management (Program Melindungi Keanekaragaman Hayati Wilayah Maluku Tengah dengan Pengelolaan Sampah Plastik; Plasma-B) implemented by non-governmental organization (NGO) Bintari, the study examines the emergence of village-level *Pokja* as a governance innovation grounded in local institutions and social capital.





Methodology

Study area

The study focuses on four pilot communities across the Saparua and Banda Islands of Maluku Province: Mahu, Owu, Tanah Rata, and Pulau Rhun. Saparua and Banda Islands are characterized by limited land availability, high coastal dependency, and strong customary governance systems.

Case study approach

The research draws on village-level cases in Central Maluku under the Plasma-B program. The Mahu, Owu, Tanah Rata, and Pulau Rhun villages were selected to represent variations in village size, population density, accessibility, and existing social institutions, while sharing common structural constraints, such as the absence of disposal sites and waste-processing facilities, and limited logistics connectivity.

Each village is treated as a governance laboratory, allowing cross-case comparison of Pokja formation processes and functional roles without positioning the study as a project impact evaluation.

Research design

This study adopts a qualitative, process-oriented case study design to examine how community-led Pokja emerge and function as governance mechanisms for ISWM in small island contexts. The research focuses on institutional formation, social processes, and governance roles of Pokja across multiple village settings. The design is exploratory and explanatory, aiming to understand how and why Pokja enables waste management systems to function in socially and environmentally constrained island environments. The author's positionality as a program facilitator provided deep access to governance processes, while also requiring reflexive awareness to distinguish between facilitation and analysis.

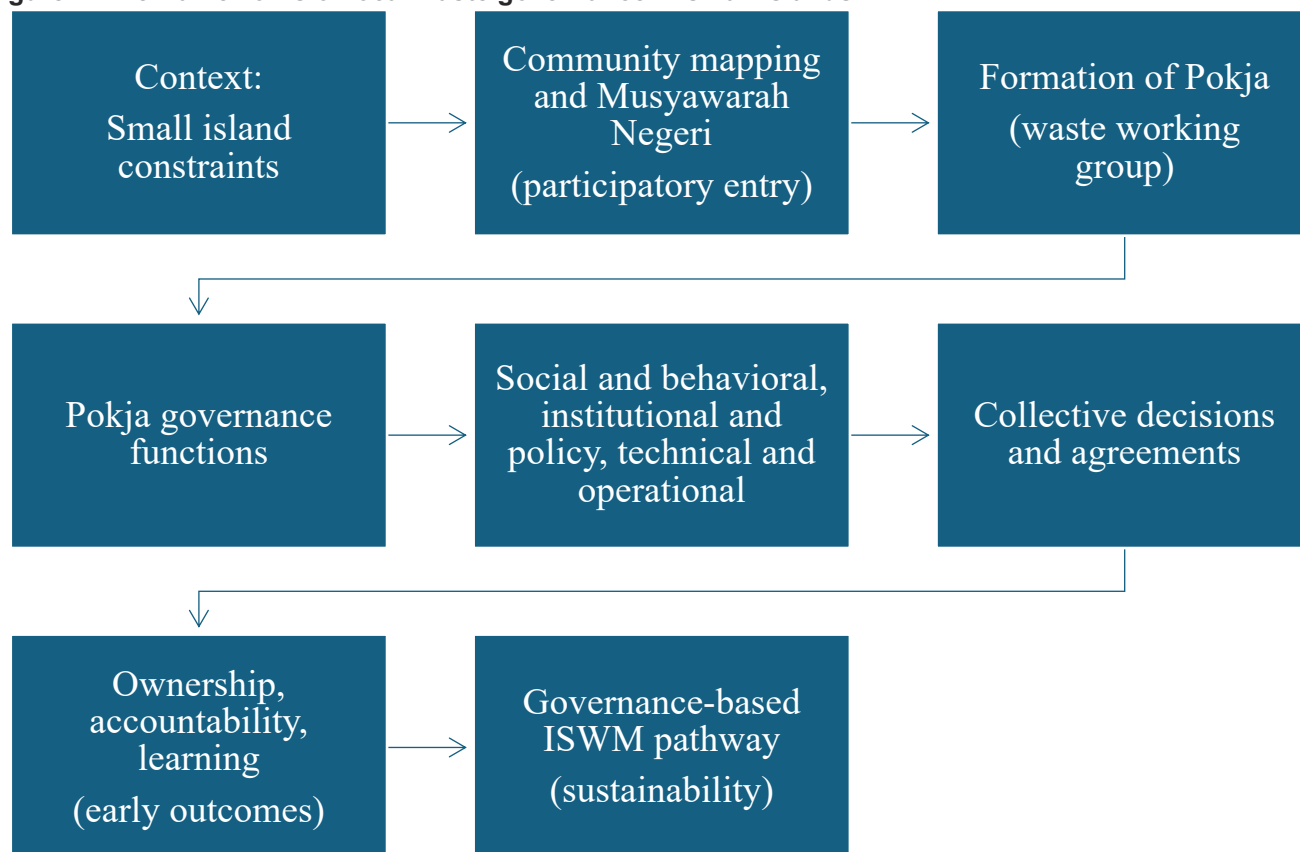
The research design operationalizes Pokja as the unit of analysis, examined across three interrelated ISWM dimensions:

- **Social and behavioral governance.** This dimension explores how *Pokja* influences community norms, awareness, and collective action related to waste management. Analysis focuses on the process of selecting local waste cadres; the role of the cadres as cultural translators of waste practices; and community responses to behavior change initiatives mediated through *Pokja* structures.
- **Institutional and policy governance.** This dimension examines *Pokja*'s role as a deliberative body that shapes local decision-making. Key aspects include *Pokja* formation through Maluku's traditional assembly called *Musyawarah Negeri*; representation of non-elite actors, such as women, youth, and religious institutions; and *Pokja*'s function in recommending village regulations, service models, and financing mechanisms.
- **Technical and operational governance.** Rather than assessing technical performance, this dimension analyzes how *Pokja* governs technical decisions, including agreements on waste collection systems (individual vs, communal), determination of service frequency and processing methods, and the formation and oversight of village-level waste management organizations. By framing technical aspects as governance decisions rather than engineering outputs, the study emphasizes process legitimacy over immediate efficiency.



The author argued that waste management in small island contexts requires a governance-centered approach that recognizes structural constraints such as geographic isolation, limited land availability, high transportation costs, and restricted access to recycling markets (Figure 1). The establishment of locally embedded governance mechanisms begins with participatory community mapping and deliberation, for example, under *Musyawarah Negeri* (village deliberation), where stakeholders collectively identify waste challenges and align on feasible responses.

Figure 1. The frameworks of local waste governance in small islands



Source: Author.

Once established, the local waste governance *Pokja* functions as an intermediary actor responsible for planning, coordination, service oversight, and financial management. Its effectiveness depends on the integration of three key dimensions: social and behavioral factors, including participation and willingness to pay; institutional and policy support, such as village regulations and integration into development planning; and technical and operational systems, including collection, transport, and processing. These elements converge in the formulation of collective agreements that define roles, service standards, and financing arrangements, thereby strengthening legitimacy and reducing free-riding.

Over time, the implementation of these agreements fosters ownership, accountability, and iterative learning among stakeholders. This process ultimately leads to a governance-based ISWM pathway in which institutional capacity, financial sustainability, and community participation reinforce one another. In small island contexts, this framework demonstrates that waste system performance is primarily determined by the strength of governance rather than infrastructure provision alone, offering a scalable approach to reducing marine plastic leakage.



Data collection

Data were collected through a combination of

- participatory observations during village meetings, *Pokja* deliberations, and community discussions;
- three facilitated group discussions (FGDs) with *Pokja* members, cadres, and representatives of youth groups and religious institutions, of which two to three were conducted for initial brainstorming and waste management planning in September and November 2025, and one before the launch of the waste collection service in early 2026;
- review of community agreements, meeting notes, and draft waste management plans developed during the planning phase; and
- the researcher's embedded role within the Plasma-B facilitation process, which enabled real-time documentation of governance dynamics, negotiations, and institutional learning.

Data analysis

Data analysis followed a thematic and process-tracing approach to identify recurring patterns in *Pokja* formation, role differentiation, and decision-making across villages. Analytical emphasis was placed on

- sequencing of governance processes;
- actor roles and power redistribution; and
- linkages between governance decisions and early system outcomes.

Findings were synthesized across cases to generate insights into *Pokja* as a scalable governance mechanism for small island waste management.

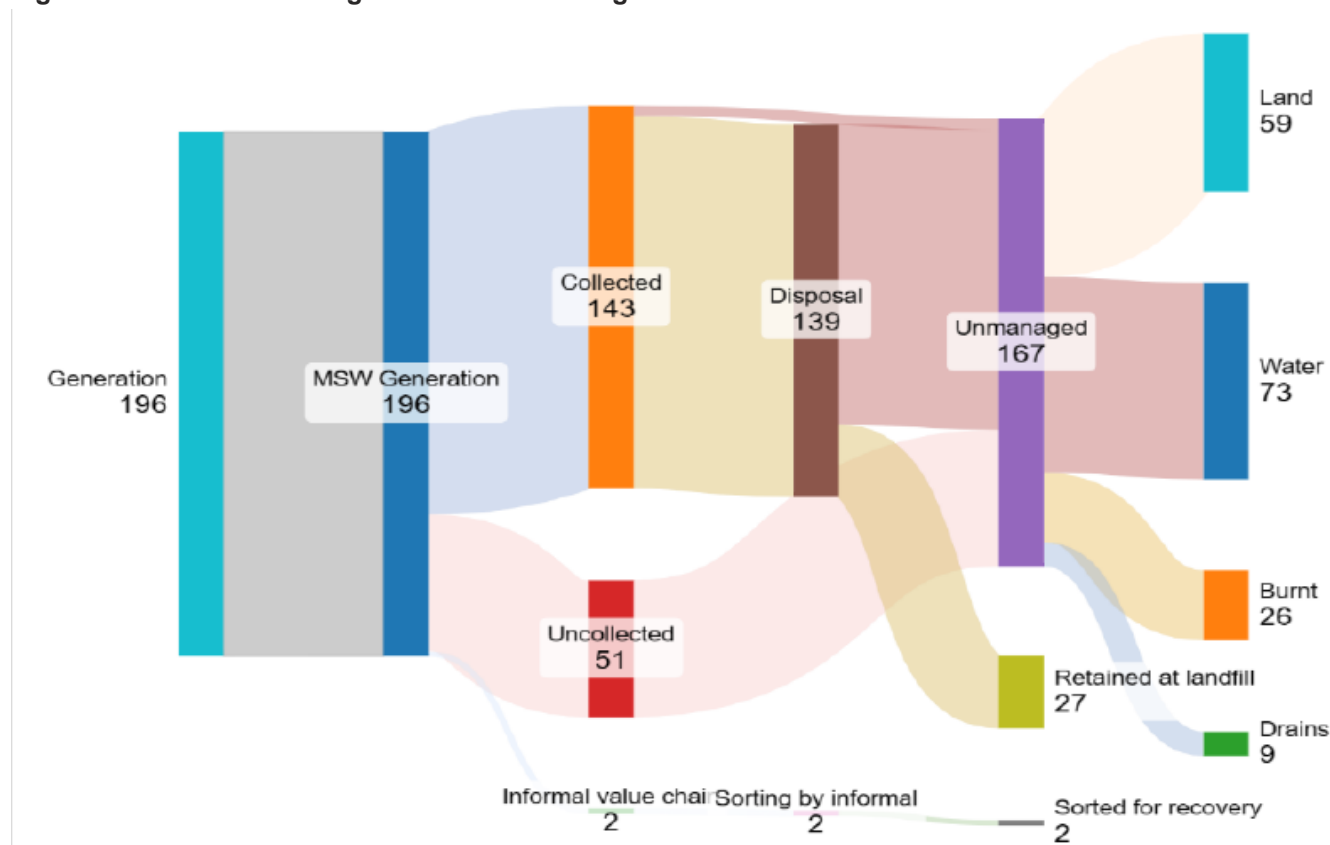
Results and discussion

Unmanaged waste and marine leakage

Baseline analysis in year 2024 indicates that 167 tons out of 196 tons, or more than 80 percent of household waste across the pilot villages, are unmanaged (Figure 2). About 73 tons, or about 37–40 percent, are estimated to leak into the marine environment, either through direct disposal or tidal transport from informal dumpsites.



Figure 2. Estimated waste generation and leakage on Banda Island



Source: Plastic flow analysis on Banda Islands (Coral Triangle Center 2024)

Formation and structure of Pokja

Since the establishment of the *Pokja*(s) in September 2025, each village-level *Pokja* has convened three to four meetings, with more than 60 percent of members consistently participating. In three out of four *Pokja* meetings observed across four villages, deliberations demonstrated democratic processes, participatory argumentation, and inclusive engagement among men, women, and youth. While the level of support from local governments varied across villages, the idealism and cooperative spirit demonstrated by *Pokja* members indicate strong local ownership and warrant sustained institutional support.

Pokja serves as a governance interface that connects households, service providers, customary institutions, and village governments. Unlike conventional waste committees dominated by village elites or project-appointed members, *Pokja* in Central Maluku was formed through *Musyawarah Negeri*, ensuring representation from women's groups, youth, fishers, religious institutions, and customary leaders (Table 1). This inclusive structure strengthened representation from women's groups, youth, fishers, religious institutions, and customary leaders and was associated with higher participation and reduced resistance during early implementation. This structure aims to foster a collective sense of responsibility in waste management, as reflected in early participation patterns.



Table 1. A sample of *Pokja* structure in Tanah Rata Village, Banda Island

<i>Pokja</i> structure	Name	Village elements
Advisor	Fitra La Djaharia	Head of Village
Chairwoman	Eda La Djanu	Women's group
Vice Chairman	Lihan La Hamadi	Neighborhood head
Secretary	Nurlela S.A. Rumatiga	Youth
Treasurer	Aisa Ali	Women's group
Technical Operational Coordinator	Winton La Tani	Lecturer
Members	Aderudin	Youth
Education and Capacity Development Coordinator	Fatma La Aci	Teacher
Members	Nur Jannah	Village Council
Monitoring and Evaluation Coordinator	(Babinsa Negeri Tanah Rata)	Village Supervisory
Members	(Head of RT 02)	Neighborhood head
Coastal Sanitation Coordinator	(Head of RT 01)	Fishers
Members	Samsudin Ode Ugu	Customary leader
Interlogistics/Partnership Coordinator	Mizwar Kahar	Religious institution
Members	Abidin La Hamuna	Entrepreneur

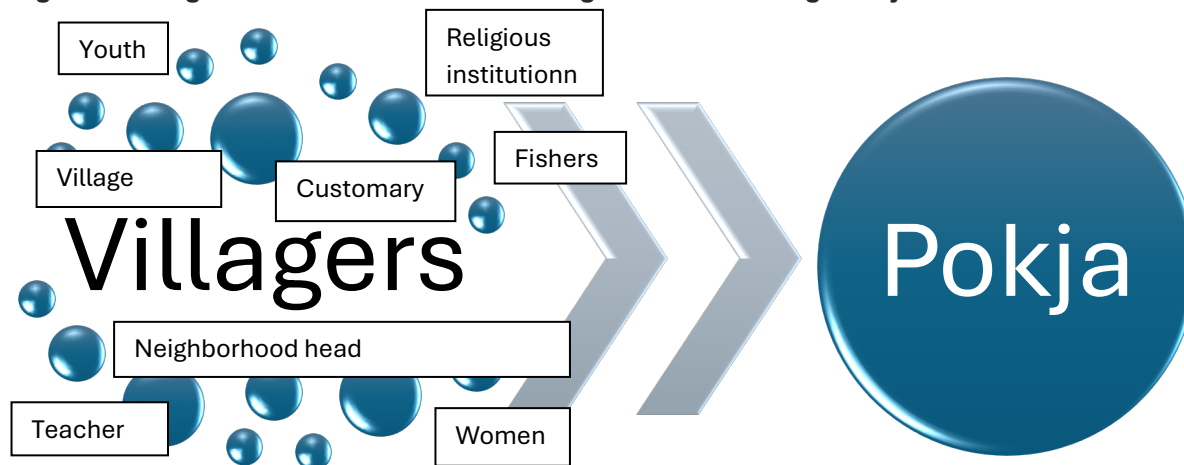
Source: Author based on Bintari (2025).

Pokja's capacity development is facilitated through Plasma-B, which provides a structured yet adaptable approach that combines education, mentoring, and continuous engagement. Rather than relying solely on formal training sessions, the program emphasizes sustained dialogue, leadership, and group facilitation skills. This approach is used because formal schooling does not sufficiently equip individuals with competencies in local governance, coordination, and participatory decision-making. Observations indicate that both structured facilitation and ongoing deliberative processes contributed to gradual improvements in leadership, coordination, and decision-making capacities among *Pokja* members.

Importantly, capacity building also emerges organically from within the *Pokja* itself. Through regular discussions, problem-solving processes, and collective decision-making, *Pokja* members gradually strengthen their leadership, facilitation, and negotiation skills. In this sense, the *Pokja* functions not only as an implementation body but also as a learning institution, where governance capacity is continuously shaped through practice. This dual approach—external facilitation through Plasma-B and internal learning dynamics—enables the *Pokja* to evolve as a local waste governance body with increasing coordination capacity.



Figure 3. Village elements learn about waste governance through *Pokja*



Source: Author.

The governance role of *Pokja* extends beyond coordination. It mediates collective decision-making on service models, financial contributions, and accountability mechanisms, indicating a shift toward locally managed public service arrangements.

Governance functions of Pokja

Behavior change anchored in local cadres and cultural translation

One of the most significant governance outcomes is the emergence of locally selected waste cadres as cultural translators of waste management practices (Figure 4). Rather than acting as technical trainers, the cadres function as trusted social actors who contextualize waste messages within local norms, faith-based values, and daily routines.

Figure 4. Cadres training and discussion of education strategy



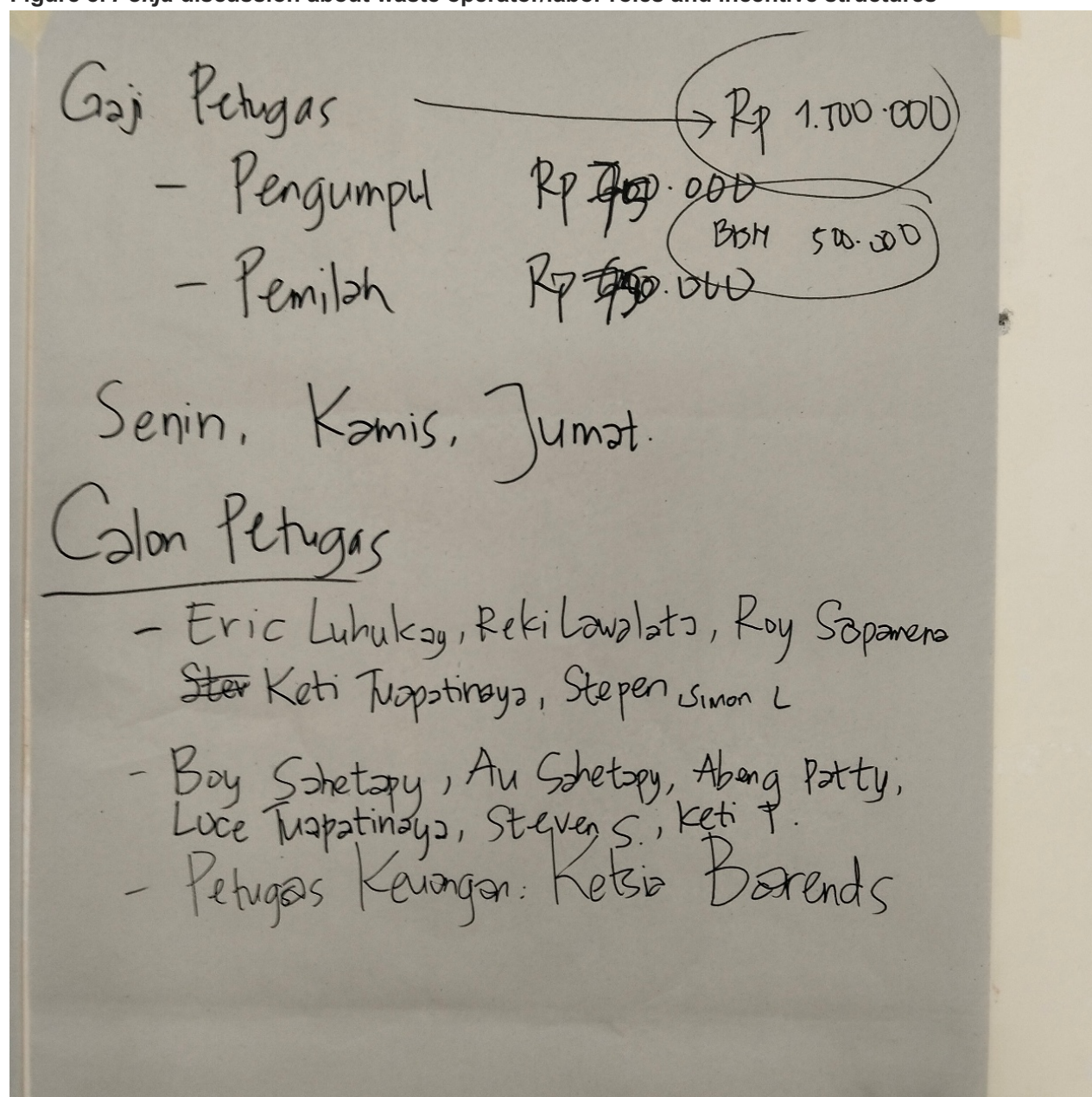
Source: Bintari 2025.

Observations suggest that behavior change processes were mediated through social interactions and negotiation, rather than one-way information delivery. Households, schools, and small businesses demonstrated higher acceptance of waste separation and fee contributions when messages were delivered by cadres embedded within existing social networks.

Governance of labor, incentives, and community financing

Another critical governance result lies in how *Pokja* guided the formation of village-level waste management organizations (Figure 5). *Pokja* facilitated transparent discussions on labor roles, incentive structures, and community-based financing mechanisms, including household contributions.

Figure 5. *Pokja* discussion about waste operator/labor roles and incentive structures



Source: Bintari 2025.

By positioning waste management organizations as community service entities rather than project-funded units, *Pokja* contributed to the emerging acceptance of paying for waste services, which is uncommon in small island villages. While service implementation remains in planning stages in the four villages of Tanah Rata, Pulau Rhun, Mahu, and Ouw, the governance groundwork has been established to support future operational sustainability. The 12-step readiness criteria for starting a collection service have been introduced, and the update is discussed during all *Pokja* meetings.

Collective decisions and early system outcomes

Through *Pokja* discussions, communities collectively defined waste service parameters, including individual versus communal collection systems, collection frequency, and processing methods appropriate to island conditions. These decisions were not imposed but negotiated, thereby allowing communities to align technical choices with labor availability, settlement patterns, and transport constraints (Figure 6). Ferry services between Ambon Island and Saparua Islands operate only four times per week, while no regular ferry service is available for the Banda Islands. Container shipping services operated by the national shipping company PT Pelni on the Ambon-Banda route are limited to twice per month (PT Pelni 2025).

Figure 6. Discussion on the effective collection route for upcoming collection service



Source: Bintari 2025.



Pokja also serves as a deliberative space for discussing village regulations and budget allocations for waste management. Importantly, it dilutes the concentration of decision-making power traditionally held by village heads or political elites. Recommendations on policy and financing emerge from multi-stakeholder discussions, enhancing transparency and social acceptance.

Although formal village regulations are still under development, *Pokja* has already influenced how waste management is framed in village planning conversations, i.e., not as an ad hoc activity but a public service requiring long-term commitment and budgeting.

This study does not present *Pokja* as a finalized model, but as an evolving governance mechanism. Current implementation in four villages remains at the service planning stage. The *Pokja* discusses the 12-step readiness criteria intensively (Table 2). While technical challenges persist at times, *Pokja* advances toward learning-oriented governance, where planning, monitoring, and evaluation are understood as continuous processes rather than donor-driven requirements.

Table 2. The 12-step readiness criteria for starting a collection service

No	Readiness criteria	Remarks
1.	Vehicle	Infrastructure
2.	Waste bins	Infrastructure
3.	Processing facility	Infrastructure
4.	Operator	Governance
5.	Standard operating procedures	Governance
6.	Operator training	Governance
7.	Community education	Governance
8.	Finance	Governance
9.	Treatment method	Infrastructure/governance
10.	The Village Head decree	Governance
11.	Early adopters	Governance
12.	Monitoring template	Governance

Source: Author based on Bintari (2025).

The 12-step readiness criteria developed under Plasma-B were formulated during *Pokjas'* discussions to understand why usual interventions struggled. Four criteria are explicitly infrastructural, namely vehicle, bins, processing facility, and treatment method, and eight others are governance-related, comprising operator designation, standard operating procedures, training, financing, community education, formal decrees, early adopters, and monitoring systems. This governance orientation allows communities to adapt systems over time without waiting for new projects or external directives.

Governance as the primary constraint

This study contributes to the literature by repositioning waste management in small islands as a governance problem rather than a technical or infrastructural challenge. The central finding focuses on the establishment of *Pokja* as a deliberative and coordinating governance body that enables multiple system components to function coherently. Initial findings reveal that infrastructure provision alone would not address systemic failures. Previous attempts to introduce bins or clean-up activities without governance structures resulted in rapid deterioration and community disengagement.

The imbalance of four infrastructural criteria and eight governance-related criteria (Table 2) is not incidental. It highlights that the binding constraint in small-island waste systems is not a lack of physical assets, but rather a lack of institutional readiness. Even treatment methods, often perceived as technical choices, require governance decisions on responsibility, compliance, and cost-sharing.





Initiatives in Tilos in Greece and Zlarin in Croatia and the Moana Taka Partnership in the Pacific Islands succeeded due to strong community engagement (Flouri et al. 2025). Typical interventions that focused primarily on the provision of physical assets failed to produce sustained outcomes. In the absence of governance mechanisms, these assets quickly deteriorated, were misused, or were abandoned altogether, leading to renewed community disengagement.

The establishment of *Pokja* marked a fundamental shift in the intervention logic. Rather than treating waste management as a series of discrete activities, *Pokja* reframed it as a continuous service requiring long-term coordination. This transition involved three critical changes, described below.

From ad hoc cleanups to continuous management.

Clean-up activities, while visible and politically appealing, do not alter waste generation or disposal behavior. In contrast, continuous collection and processing require routines, enforcement, and financing, which are core governance elements.

From individual responsibility to collective governance

Previous narratives emphasized household responsibility without providing institutional support. *Pokja* redistributed responsibility across actors, including operators, village authorities, religious institutions, and community groups, making waste management a shared obligation rather than a moral burden placed on individuals.

From external project ownership to internal accountability

By embedding *Pokja* within existing governance structures, the responsibility shifted inward. Waste management outcomes were no longer attributed to NGOs or donors but to local decision-making processes.

The use of *Musyawarah Negeri* proved to be a decisive enabling factor. Rather than introducing waste management as a technical solution, the deliberative process positioned it as a collectively negotiated social norm. It embedded waste governance within the moral and cultural authority of traditional institutions, increasing its legitimacy beyond what formal regulations alone could achieve.

Religious institutions, women's groups, and youth organizations emerged not merely as implementation partners but as norm carriers. The role of *Pokja* in selecting, mentoring, and legitimizing these cadres underscores the importance of governance as a prerequisite for sustained behavioral change. The success story of Waste Banks Initiatives in Indonesia demonstrates their administrators' willingness and energy to conduct waste socialization and education on various occasions, including social gatherings, religious study groups, and other community events (WWF-Indonesia 2024). The involvement of all village elements transformed waste management from an external environmental agenda into a locally owned responsibility tied to communal values, dignity, and stewardship.

This study extends environmental governance theory by demonstrating how community-led institutions function as hybrid governance mechanisms bridging formal policy and informal social systems in resource-constrained island settings.

Structural constraints beyond local governance

Despite notable progress, several structural challenges remain unresolved.

First, irregular transport schedules continue to disrupt service reliability. In island contexts, the availability of sea transport is exogenous to waste governance but directly determines system viability. Without routine and affordable logistics, even well-governed systems face operational bottlenecks.





Second, while the *Pokja* structures have been formally established and have demonstrated strong deliberative capacity, much of the observed progress remains concentrated at the planning and coordination stage. Decision-making processes, route planning, tariff discussions, and institutional role clarification have advanced faster than full operational execution. This reflects the early implementation phase, in which governance foundations are still being tested before scaling into routine service delivery. Consequently, the long-term effectiveness of *Pokja* in sustaining collection services, financial discipline, and inter-island logistics requires further longitudinal observation.

Third, limited financing mechanisms restrict scalability. Current systems rely heavily on service fees collected from households and project-based funding, which are insufficient for long-term service provision. Fiscal refocusing in 2026 has reduced the availability of the Village Funds (*Dana Desa*) for waste-related services. Further, residual waste management should fall under municipal-level public service obligations. However, municipal governments remain largely absent from routine waste service provision in small-island subdistricts, leaving communities to internalize costs that exceed their fiscal capacity.

Finally, producer responsibility also remains limited in supporting waste management financing. Extended Producer Responsibility (EPR), a policy approach that requires producers to contribute to the collection and management of post-consumer packaging waste, has been increasingly promoted in Indonesia.

However, existing EPR mechanisms are largely designed around urban and mainland contexts. They often assume economies of scale and efficient logistics that are rarely present in geographically isolated small islands. Consequently, local governments and communities continue to bear a disproportionate share of waste management costs.

These findings suggest that improving waste management outcomes in small islands requires policy alignment beyond the village level. Municipal, provincial, and national governments play a critical role in enabling governance-first approaches through regulatory flexibility, targeted subsidies, and island-adapted EPR schemes. Policy frameworks must shift from infrastructure delivery toward sustained investment in local governance capacity. Without such alignments, local governance innovations risk remaining fragile and dependent on external support.

Misaligned policy models in small island contexts

Despite increasing national attention to waste management, many policy instruments and programmatic interventions remain designed on the basis of mainland or urban assumptions. Initiatives such as waste banks (*bank sampah*) and dump sites' reduce, reuse, recycle facilities have been widely promoted as standardized solutions across Indonesia.

However, findings from small island contexts suggest that these models often face implementation challenges due to limited waste volumes, fragmented settlements, high logistical costs, and limited access to downstream recycling markets. As a result, interventions risk underutilization when not aligned with local governance capacity and system conditions. These findings reinforce Lemos and Agrawal's (2006) argument that governance extends beyond formal institutions, highlighting how locally embedded mechanisms can compensate for structural infrastructural deficits.

This insight reflects a broader pattern of policy misalignment, in which solutions developed in densely populated, infrastructure-rich regions are transferred to geographically isolated areas without sufficient adaptation. In small islands, effective waste management requires not only technical appropriateness but also institutional fit, financial viability, and logistical realism.

Therefore, policy approaches should shift from replication of standardized models toward context-sensitive governance frameworks that prioritize system functionality over infrastructure presence. This study suggests that the failure of waste systems in small islands is not primarily a failure of technology, but a failure of contextual





alignment between policy design and local system realities. This misalignment reflects a form of policy transfer failure, where institutional models are replicated without accounting for spatial, economic, and governance asymmetries.

In this sense, improving waste management on small islands is less about scaling technologies than about rethinking how governance systems are designed, adapted, and sustained in geographically constrained contexts.

Conclusion

The experience of community-led *Pokja* in Central Maluku demonstrates that sustainable waste management in small islands begins with strengthening the governance, not infrastructure. *Pokja* provides the institutional backbone necessary to translate awareness into action and participation into accountability.

Grounded in local wisdom and collective deliberation, *Pokja* transforms geographic isolation into collaborative strength. Strengthening island-based waste governance is not merely an environmental intervention; it is a matter of social justice for communities living at the frontline of marine pollution and climate vulnerability.

This study contributes to global debates on waste governance by demonstrating that, in geographically constrained contexts, governance capacity—not infrastructure—is the primary determinant of waste system performance. These findings are relevant not only for Indonesia but for small island developing states facing similar structural constraints.

Acknowledgement

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Black Soldier Fly Larvae Flooding Technique for Reducing Fly Population in Temporary Waste Disposal Sites in Indonesia

Yulia Sukma Supriatna^{1,*} and Arief Sabdo Yuwono¹

¹ Civil and Environmental Engineering, IPB University, Bogor, Indonesia

* Corresponding author: yuliasukma220703@gmail.com

Abstract

Organic waste dominates the composition of solid waste at temporary waste disposal sites (TPS, from its initial in Bahasa Indonesia), often causing odor problems that create favorable conditions for disease-vector fly breeding and potentially trigger fly population outbreaks that disrupt public health and environmental comfort. This study aims to analyze the relationships among organic waste fractions, hedonic scale, and fly population, as well as to evaluate the effectiveness of the black soldier fly (BSF) (*Hermetia illucens*) larvae flooding technique in reducing hedonic scale and the fly population index. An experimental study was conducted at the School of Waste Management and TPS Taman Semangat in Bogor, Indonesia. Fly population index was measured using a fly grill, and odor intensity was assessed using an olfacto-screen to determine the hedonic scale. The results show that fish and shrimp waste, as well as food waste, attracted flies the most due to their strong odors and high nutrient content, followed by chicken feather waste and fruit and vegetable waste. Higher hedonic scale values tend to be associated with increased fly populations, although waste characteristics and nutrient composition also influence this relationship. The BSF larvae flooding technique effectively reduced fly populations by 65–71 percent and decreased odor intensity by 33–44 percent, primarily due to accelerated decomposition and biological competition by the larvae. These findings indicate that the BSF larvae flooding technique is a feasible and effective approach for organic waste management at TPS, supporting a sustainable management cycle while providing added value through larvae for animal feed and frass as organic fertilizer.

Keywords: black soldier fly larvae; disease-vector fly; flooding technique; hedonic scale

Introduction

The amount of solid waste generated in Indonesia reached 33.9 million tons in 2024, with organic waste accounting for 39.28 percent of the total composition (SIPSN 2024). The dominance of organic waste, particularly food waste, poses a major challenge for waste management in large cities, where waste is often only collected and disposed of without further treatment (Wiryono et al. 2020). Organic waste accumulated at temporary waste disposal sites (TPS, from its initial in Bahasa Indonesia) decomposes rapidly and produces strong odors, which attract disease-vector flies (Prajaningtyastiti and Pawenang 2023). This condition increases the risk of environmental pollution and public health problems (Abubakar et al. 2022). Nindia et al. (2019) found a correlation between the waste volume and fly populations, indicating that higher waste volumes are associated with higher fly populations. This situation is driven by poorly organized waste handling, especially decomposable organic waste that emits strong odors, making it an attractive medium for flies to obtain nutrients and serve as breeding sites. These flies can act as vectors for the transmission of germs and pathogens that cause disease (Yunus and Juherah 2020; Putri and Emilia 2022).

Fly control can be carried out using various methods, including the application of natural or synthetic pesticides and the use of fly traps. Each method has its limitations. Natural pesticides tend to be less effective and require frequent reapplication (Irfan 2016), while synthetic pesticides pose environmental contamination risks and potential harm to humans and non-target organisms (Ahyanti et al. 2022). The use of fly traps also requires regular maintenance and sufficient space for proper implementation (Krismahardi et al. 2020). Alternative fly control



methods are more commonly applied in the agricultural sector. One such approach is the utilization of black soldier fly (BSF) larvae through the flooding technique, which also supports integrated organic waste management.

The application of the flooding technique using BSF larvae in TPS shows strong potential to reduce disease-vector fly populations and mitigate odor from organic waste. This technique involves inundating organic waste with a large number of BSF larvae/maggot. Studies by Putri (2023) and Zainudin et al. (2024) demonstrated that increasing the number of BSF larvae significantly reduced populations of disease-vector flies. In addition, Miranda et al. (2019) showed that adding BSF larvae into fresh poultry manure effectively reduced the presence of disease-vector fly larvae. According to Bradley and Sheppard (1984), BSF larvae act as natural competitors to disease-vector flies. This technique also has the potential to reduce unpleasant odors from organic waste (Putri 2023).

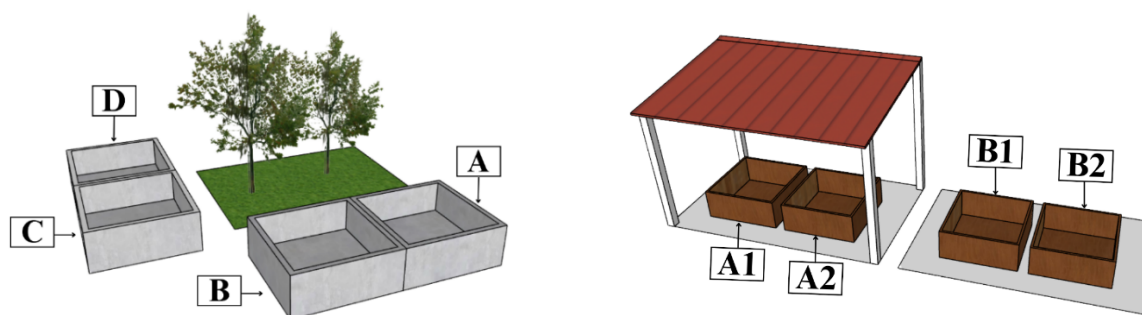
Most studies have focused on controlled laboratory conditions or source-separated substrates, limiting understanding of their effectiveness under real field conditions. This study examines fly-attractive organic waste fractions, the relationship between odor intensity and fly populations, and the effectiveness of the BSF flooding technique in reducing fly populations and hedonic scale values at TPS.

Methodology

Study location and materials

This study was conducted at the School of Waste Management (SWAM) in Bogor, Indonesia, and at Taman Semangat TPS at the IPB University campus in Dramaga, also in Bogor, from March to April 2025. The research activities involved collecting organic waste fractions from several locations to obtain a variety of organic fractions required for the first stage of the study. In the second stage, the BSF larvae flooding technique was implemented at the TPS. The equipment used in this study included test containers, 50-liter (l) buckets, a fly grill, bioponds, and a laptop equipped with Microsoft Excel and Microsoft Word software. The materials used in this study included seven-day-old BSF larvae (7-DOL), various types of organic waste fractions, and mixed waste collected from Taman Semangat TPS. The arrangement of the test containers used in this study is presented in Figure 1.

Figure 1. Arrangement of the test containers during the first and second stages of the experiments



a. First stage at SWAM

b. Second stage at Taman Semangat TPS.

Note: In picture b, treatment A represented TPS conditions protected from rainfall (roofed), while treatment B represented TPS conditions exposed to rainfall (unroofed). Each treatment included a control bin (A1 and B1) and a treatment bin with BSF larvae flooding (A2 and B2).

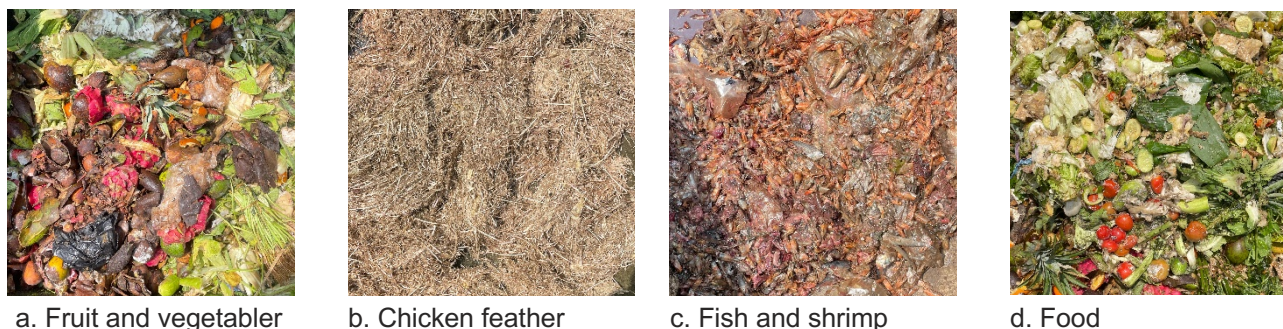
Source: Authors.



Collection of organic waste fractions

This study involved collecting four organic waste fractions: fruit and vegetable waste, chicken feather waste, fish and shrimp waste, and food waste. The samples were obtained from markets, restaurants, and slaughterhouses, collected in 50 l containers. The collected samples were then placed in separate test bins measuring 1 m × 1 m × 0.5 m at SWAM (Figure 1). This stage aimed to identify the organic waste fraction most attractive to flies and to measure its hedonic scale, thereby examining the relationship between odor intensity and fly population index. Each waste fraction is shown in Figure 2.

Figure 2. Organic waste fractions used in this study



Source: Authors.

Application of the BSF larvae flooding technique

In the second stage, BSF eggs (10 g) were reared using coconut pulp as their growth medium. After the larvae reached seven days of life (7-DOL), the flooding technique was applied by introducing a large number of larvae into each experimental bin. The BSF larvae flooding technique was conducted in compost bins measuring 1 m × 1 m × 0.5 m with a wire-mesh base, each filled with 50 l of mixed waste collected from Taman Semangat TPS. The determination of the experimental duration was based on the national standard SNI 19-2425-2002 (SNI 2002), which states that the maximum waste collection period ranges from one to four days. The experiment consisted of two different treatments, representing roofed and unroofed TPS conditions, each comprising a control and a treatment bin.

Fly population index

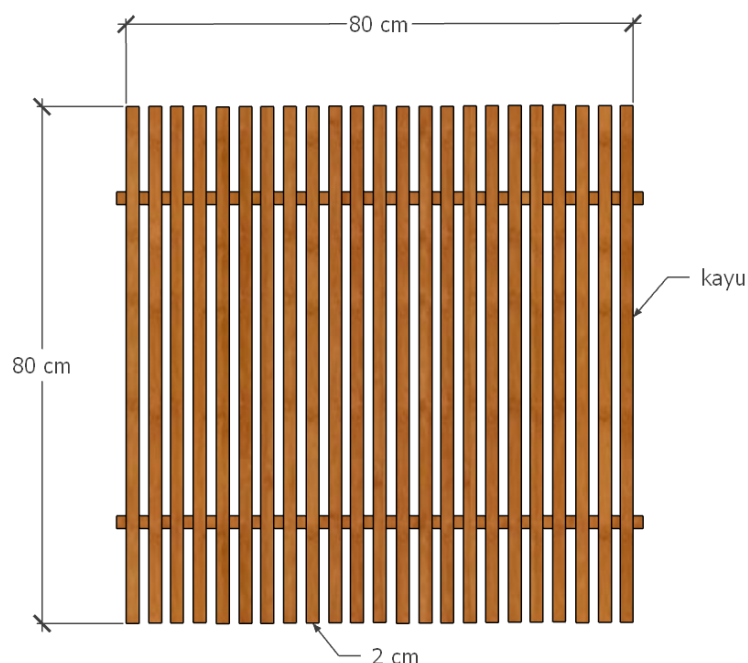
The study measured the fly population index to evaluate fly populations across different organic waste fractions, examine the relationship between the hedonic scale and the fly population index, and assess the effectiveness of the BSF larvae flooding technique in reducing fly populations in TPS. This measurement was conducted in accordance with Indonesia's Minister of Health Regulation No. 50/2017 (Menteri Kesehatan Republik Indonesia 2017). The process involved counting the number of flies landing on a 1 m² area within 30 seconds, repeated ten times. From these ten observations, the five highest values were selected and averaged to obtain the fly population index. According to the regulation, the acceptable standard for the average fly population index is less than 2.

In this study, fly population measurements were carried out during the day between 10:00 and 12:00 local time, as previous studies by Prajnowita et al. (2020) and Masyhuda et al. (2017) reported that fly populations peak during this period. The fly population index was measured using a wooden fly grill measuring 80 cm × 80 cm and 2 cm thick (Figure 3).





Figure 3. Design of the flygrill used in the study



Source: Authors.

Hedonic scale measurement

The hedonic scale was measured for each organic fraction to examine its relationship with the fly population and to assess the effectiveness of the flooding technique in reducing odor, evidenced by an increase in the hedonic scale. The process followed Yuwono (2008). Eight panelists, selected based on screening and consistency tests, evaluated the odor of each organic fraction in the first and second stage of the experiment. The hedonic scale ranged from +4 (very pleasant) to -4 (very unpleasant), with 0 representing a neutral odor. Each measurement was repeated three times. In this study, the hedonic scale was assessed using an olfacto-screen (Figure 4)

Figure 4. Olfacto-screen used in the study



Source: Authors.



Data analysis

Pearson correlation analysis was used to assess the strength and direction of the relationship between the fly population index and the hedonic scale for organic fractions. The correlation coefficient (r) indicates the degree of association between the variables, while the p -value determines statistical significance. The analysis was conducted using Microsoft Excel at a 95 percent confidence level ($\alpha = 0.05$). In addition, a paired t -test was performed to evaluate the significance of differences in the fly population index and hedonic scale before and after the application of the BSF larvae flooding technique.

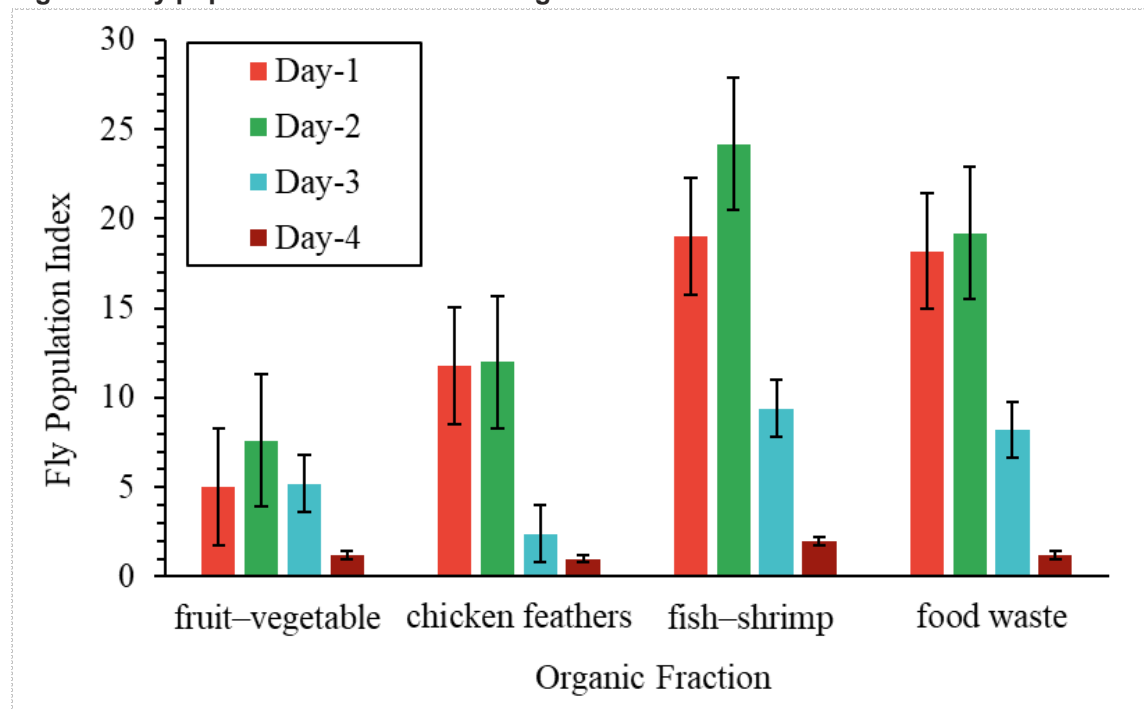
Results and discussion

Organic fractions and disease vector flies

This study evaluated four types of organic waste fractions commonly found at TPS, namely fruit and vegetable waste, fish and shrimp waste, food waste, and chicken feather waste. Fruit and vegetable waste and food waste are generally easily degradable and nutrient-rich, whereas chicken feathers and hard components of fish and shrimp waste, such as shells and fish bones, are more resistant to decomposition due to the presence of recalcitrant compounds, including keratin, chitin, and calcium phosphate (Peng et al. 2019; Thomas et al. 2022).

The observation results indicate that flies were most attracted to the fish and shrimp waste and food waste fractions, particularly on days 1 and 2, when active decomposition began and unpleasant odors emerged due to intensified microbial activity (He et al. 2020). Fractions that are difficult to degrade, such as chicken feather waste, tend to have textures that are harder to digest and are relatively low in readily available nutrients, making them less attractive to flies. This is related to the sponge-type parts of a fly's mouth, which allow them to feed only on liquid substances or materials that can be liquefied before ingestion (Geden et al. 2021). The texture and nutrient content of organic waste fractions significantly influence fly attraction during decomposition. Figure 5 shows the disease vector fly population index for each organic fraction.

Figure 5. Fly population index for each organic fraction



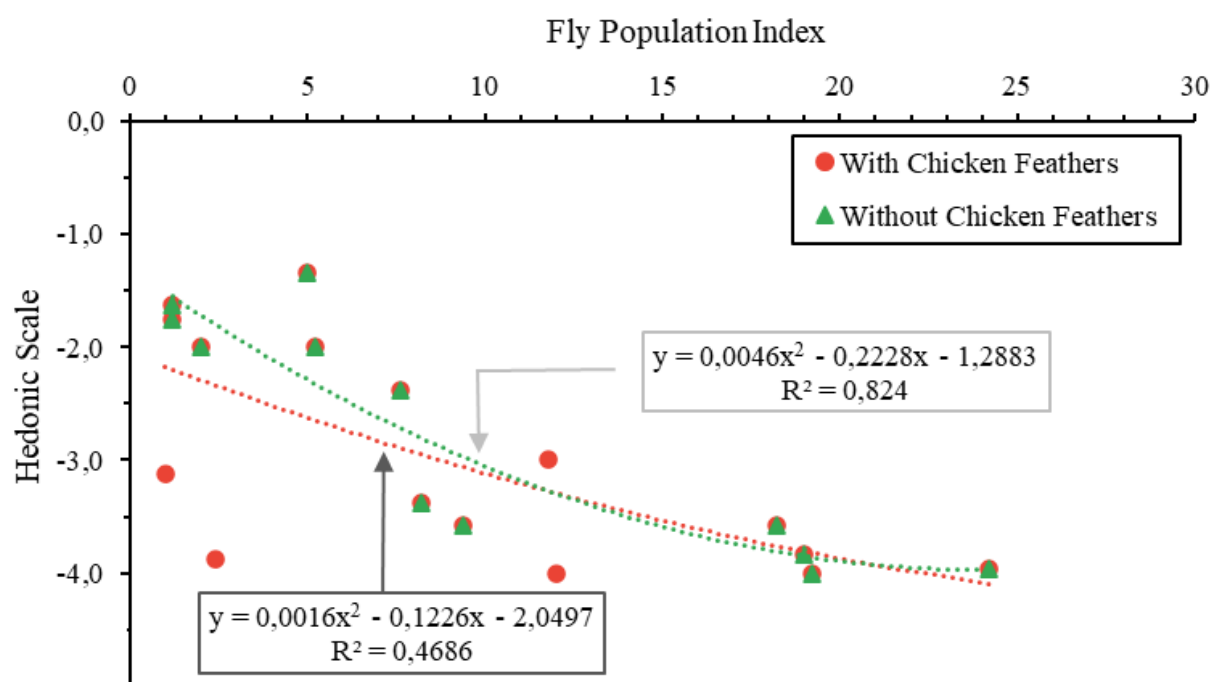
Source: Authors.

Relationship between fly population index and hedonic scale

Odor serves as a biological indicator of organic waste decomposition, as volatile compounds such as ammonia, hydrogen sulfide, and others are generated as microbial activity increases (Wu et al. 2010). These gases not only cause odor nuisance to humans but also attract disease vector flies, which rely on olfactory cues to locate nutrient sources and oviposition sites (Gaudry et al. 2012). The data indicate that the highest odor hedonic scale values occurred on day 2 for all waste types, except for fruit and vegetable waste, which exhibited the highest odor intensity on day 3. Chicken feather, fish and shrimp, and food waste fractions produced average odor levels categorized as unpleasant (−3.0 to −3.5), whereas fruit and vegetable waste was relatively less unpleasant (−1.8). On days 2 and 3, odor intensity reached its maximum, as reflected by higher hedonic scale values, which coincided with an increase in the fly population index. However, a significant decline in odor intensity was observed after day 3, followed by a corresponding decrease in both the hedonic scale and fly population index.

This pattern can be attributed to the feeding activity of fly larvae during the early stages of decomposition, which accelerates the degradation of simple organic compounds. As decomposition progresses, only more recalcitrant components remain, resulting in reduced odor emissions (Supriyatna and Ukit 2016). These findings support the hypothesis that unpleasant odors not only influence human-perceived hedonic responses but also serve as triggers to attract disease vector flies (Figure 6).

Figure 6. Relationship between hedonic scale and fly population index



Source: Authors.

Figure 6 shows that the correlation between the hedonic scale and the fly population index was stronger in treatments without chicken feather waste ($R^2 = 0.824$) than in those with chicken feather waste ($R^2 = 0.4686$). Pearson correlation analysis confirmed a significant negative correlation in the absence of chicken feathers ($r = -0.883$, $p = 0.02$), while the correlation was weaker and not significant when chicken feathers were present ($r = -0.680$, $p = 0.08$). This finding indicates that increasing odor intensity (lower hedonic scale) was significantly associated with higher fly populations when chicken feathers were absent. However, this relationship diminished

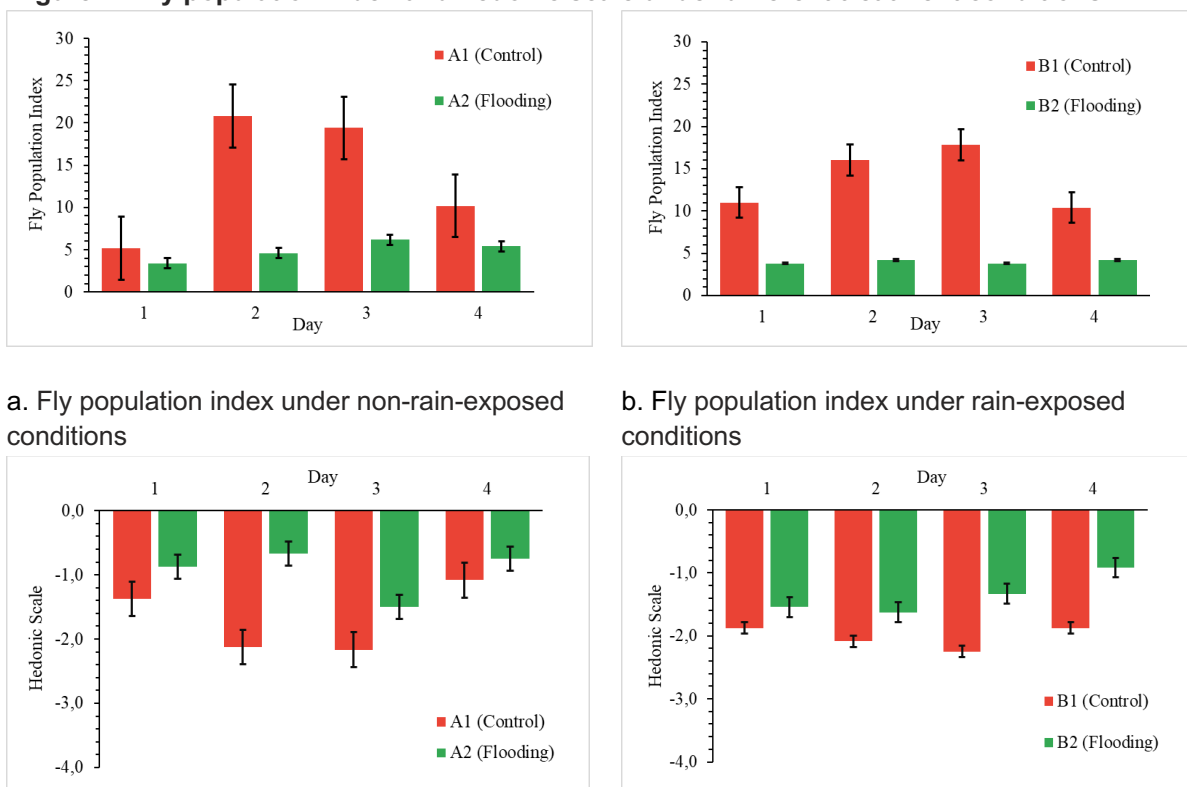
with the addition of chicken feathers. This change may be attributed to the strong odor, yet low nutritional value and poor digestibility of chicken feathers, making them less attractive as food and oviposition substrates.

These findings are consistent with Grimenstein et al. (2025), who reported that disease-vector flies require carbohydrates, proteins, and lipids for reproduction, and with Gaudry et al. (2012), who emphasized odor as a key long-range attractant. Overall, odor influences fly attraction, but substrate characteristics and nutrient content also play a critical role in determining fly population levels.

Effectiveness of the BSF larvae flooding technique

The results demonstrate that the application of the BSF larvae flooding technique effectively reduced both fly population indices and odor intensity in mixed organic waste at TPS (Figure 7). These findings are consistent with previous studies by Putri (2023). Through intensive feeding activity, BSF larvae consume readily degradable organic materials and convert them into biomass and residual by-products. The resulting residues exhibit higher hedonic scale values (i.e., less offensive odors), making them less attractive as feeding and oviposition sites for other flies (Bradley and Sheppard 1984; Siddiqui et al. 2022). Further, BSF larvae treatment has been shown to significantly reduce odor during the conversion of organic waste into value-added products (Amrul et al. 2022; Putri 2023). Overall, the application of this technique is expected to reduce both fly population indices and odor intensity.

Figure 7. Fly population index and hedonic scale under different treatment conditions



c. Hedonic scale under non-rain-exposed conditions

d. Hedonic scale under rain-exposed conditions

Source: Authors.

Study results show that the BSF larvae flooding technique significantly reduced disease-vector fly population indices, with reductions of 65 percent under non-rain-exposed conditions and 71 percent under rain-exposed conditions. Independent t-tests revealed statistically significant differences between flooding and non-flooding treatments ($p = 0.048$ for non-rain-exposed and $p = 0.006$ for rain-exposed conditions), indicating the strong



effectiveness of the flooding technique in suppressing fly populations. Waste media treated with BSF larvae was less attractive to flies, consistent with previous studies reporting substantial reductions in fly populations following BSF application (Putri 2023; Zainudin et al. 2024). This suppression is attributed to competitive mechanisms, including rapid consumption of organic substrates, emission of volatile compounds, and the release of allomones that deter fly feeding and oviposition.

In addition, odor reduction was observed following BSF flooding application, as indicated by higher hedonic scale values (-0.7 to -1.7) compared to untreated controls (-1.1 to -2.3). Statistical analysis confirmed significant differences between treatments ($p = 0.048$ for non-rain-exposed and $p = 0.007$ for rain-exposed conditions). Hedonic scale reductions reached 44 percent under non-rain-exposed conditions and 33 percent under rain-exposed conditions. These findings suggest that BSF larvae accelerate the decomposition of organic waste and reduce odor-causing gaseous emissions (Siddiqui et al. 2022). Overall, the BSF flooding technique effectively reduces both fly populations and odor intensity under varying environmental conditions, highlighting its potential applicability as a biological fly control strategy in TPS.

Conclusion

Based on the findings of this study, fish and shrimp waste, as well as food waste, exhibited the highest fly population indices due to their strong odors and high nutrient content, indicating the need for rapid, prioritized handling in TPS to prevent the proliferation of disease-vector flies. A decreasing hedonic scale was strongly associated with increased fly attraction and population growth, highlighting odor control as a critical component for effective waste management. Nevertheless, fly activity was also influenced by nutrient content and the physical characteristics of organic waste, emphasizing the importance of integrated management approaches.

The application of the BSF larvae flooding technique was shown to be highly effective, reducing fly population indices by 65 percent under non-rain-exposed conditions and 71 percent under rain-exposed conditions, while odor intensity decreased by 44 percent and 33 percent, respectively. These results demonstrate that BSF flooding is a robust and adaptable biological control strategy capable of mitigating fly populations and odor disturbances under varying environmental conditions. Overall, BSF flooding shows strong potential for field-scale implementation as part of a sustainable waste management system.

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Plastics in Motion: Local Circularity Pathways in Shrimp Aquaculture in Banyuwangi, Indonesia

Ni Putu Ayu Eka Sundari^{1,*}, You One Van Tomi Lumbanraja¹, and Citra Septiani¹

¹ World Resources Institute (WRI) Indonesia, Jakarta, Indonesia

* Corresponding author: ayu.eka@wri.org

Abstract

Plastics are integral to modern shrimp aquaculture—from pond liners and feed packaging to pipes and bottles—yet their end-of-life management remains largely undocumented. While aquaculture is frequently cited as a contributor to marine plastic pollution, limited evidence exists on how these materials move through local waste systems. This study explores plastic use and disposal practices in shrimp farming in Banyuwangi, East Java, Indonesia, examining how local circularity emerges within existing systems. Using an exploratory mixed-methods approach that combined field observations, farmer surveys (n=29), and interviews with waste collectors, the study traced plastic flows from farms to community waste networks. Findings reveal that 79 percent of farmers sell plastics to local collectors, 45 percent reuse materials within their operations, and 55 percent share items with neighboring households. However, 62 percent of farmers still burn plastics. Twelve equipment categories were identified, each with distinct end-of-life pathways based on durability and market value. Plastic leakage into water bodies appears minimal, but it depends heavily on informal collection systems. Three key actors sustain this circularity: farmers as decision-makers, collectors who link aquaculture waste to recycling markets, and community members who enable local reuse. Without stronger mechanisms to manage low-value plastics such as pond liners or contaminated packaging, leakage risks could increase as production intensifies. This research reframes aquaculture plastics as materials in motion—resources circulating between farms and communities rather than solely pollutants—highlighting the need to strengthen existing pathways to support a locally grounded circular economy.

Keywords: circular economy; coastal community; plastic leakage; shrimp aquaculture; waste collectors

Introduction

Global fisheries production exceeded 200 million tons in 2022, with 58 percent originating from aquaculture (Mojumder 2024). Indonesia accounts for approximately 10 percent of global production, predominantly through aquaculture operations (BPS 2024). This growth has been accompanied by increasing dependence on plastics as part of the plasticulture trend, with widespread use of plastics in food production systems, including aquaculture (Brander et al. 2025; Hastuti et al. 2025). While plastics enhance production efficiency, inadequate management creates environmental risks, particularly through potential leaks into coastal ecosystems (Cole et al. 2011; Rochman et al. 2013; Ranjan and Boyd 2018; Huntington 2019).

Shrimp represents one of Indonesia's most economically valuable aquaculture commodities. It accounts for 30 percent of the national aquaculture production value (IDR 62.7 trillion, or US\$3.47 billion) despite accounting for only 6 percent of the national production volume. Shrimp also generates \$1.68 billion in export earnings and supports more than 400,000 coastal livelihoods (BPS 2024; KKP 2024, 2025). Banyuwangi District in East Java, Indonesia, exemplifies this significance as a major shrimp production center, hosting diverse farming systems that range from traditional extensive ponds to corporate intensive operations. This diversity enables comparison across different production scales and management regimes, making Banyuwangi an ideal context for examining plastic dynamics in Indonesian aquaculture systems.

Despite aquaculture often being cited as a source of marine plastic pollution, empirical evidence on plastic flows within aquaculture systems remains limited. Most existing studies focus on documenting the presence of plastic in





marine environments rather than understanding how circularity can emerge within local systems (Chairrany et al. 2021; Zuhdi 2022; Lin et al. 2023). This knowledge gap obscures both the actual scale of aquaculture's contribution to marine plastic pollution and the community-based practices that may already prevent leakage.

This study addresses two research questions. First, it documents how the shrimp farmers manage plastic materials after use. Second, analyzing the local practices helps retain plastic within the system and prevent leakage. The research examines how shrimp farmers manage plastic materials after use and which local practices help retain plastics within economic circulation while preventing environmental leakage. By conceptualizing aquaculture plastics as materials in motion, the study shifts from viewing them solely as pollutants to recognizing their role as socioeconomic resources within coastal communities.

Methodology

Research approach

This study employed an exploratory-descriptive, mixed-methods approach to understand the flows of plastic material in shrimp aquaculture systems. The research design combined quantitative surveys with qualitative interviews and field observations to capture both the scale and contextual nuances of plastic management practices. This methodological approach was selected to provide comprehensive insights into a specific phenomenon, recognizing that local waste management practices are highly context-dependent and may not conform to generalizable statistical patterns.

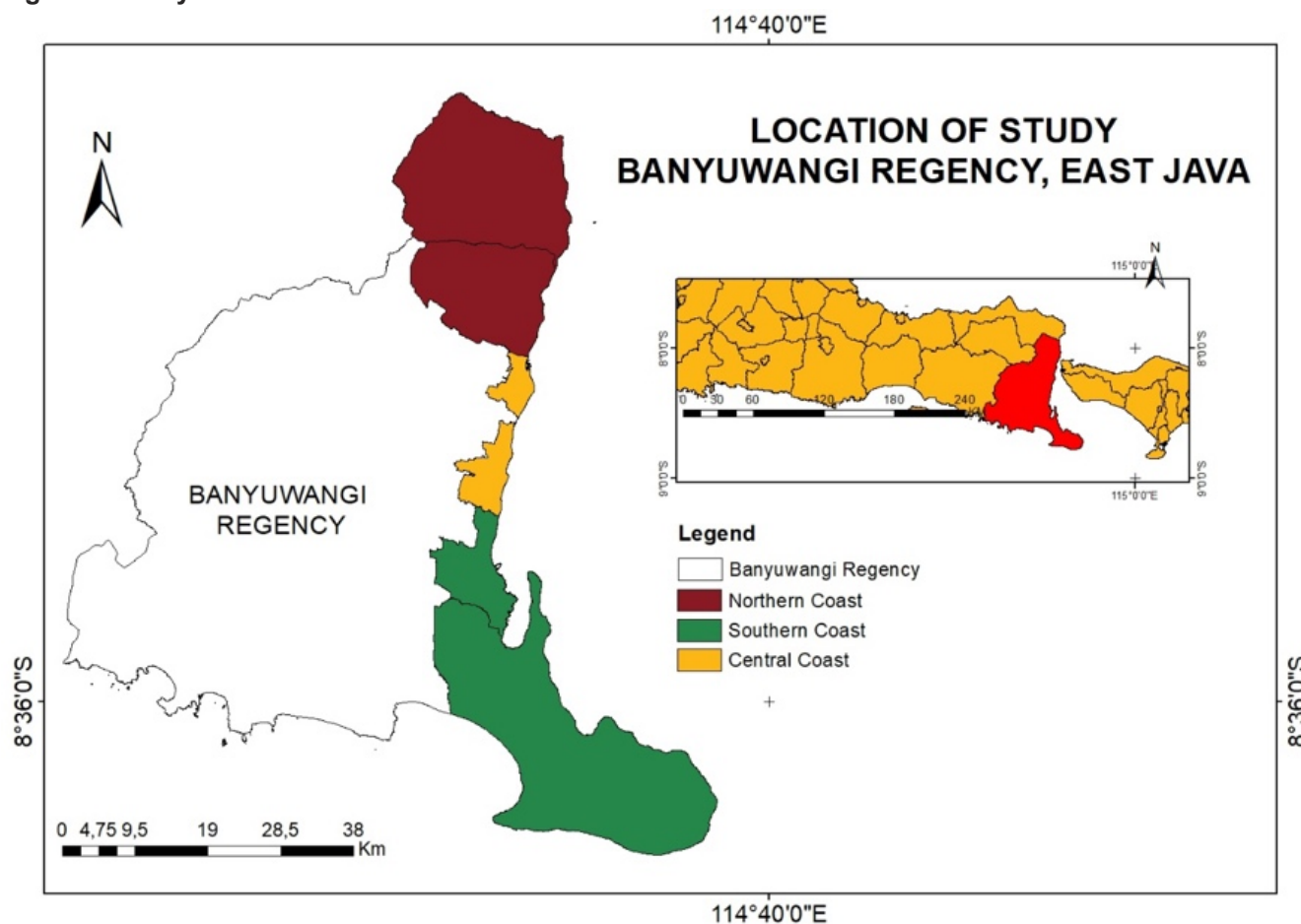
Study location

Banyuwangi District was selected based on three criteria: high shrimp production volume as a major national production center; diverse farming systems, ranging from individual traditional operations to intensive corporate facilities; and presence of established waste management infrastructure to provide context for understanding how aquaculture waste interacts with broader municipal systems. The study encompassed six subdistricts along the coast from north to south: Wongsorejo, Kalipuro, Banyuwangi, Blimbingsari, Muncar, and Tegaldimo (Figure 1). Together, they account for substantial aquaculture activities and represent different operational scales and farmer profiles.

The north coast (Wongsorejo and Kalipuro) is dominated by large-scale corporate shrimp ponds operating intensive production systems. The central coast (Banyuwangi and Blimbingsari) exhibits mixed farming patterns, including semi-intensive and intensive systems managed by individuals, corporations, and traditional farmers. The south coast (Muncar and Tegaldimo) is characterized predominantly by traditional ponds managed by small-scale, household-based farmers with minimal technology adoption and relatively low stocking densities. This geographic and operational diversity enables comparison across the full spectrum of Indonesian shrimp aquaculture systems.



Figure 4. Study location



Source: Authors.

Banyuwangi District provides suitable conditions for examining the potential for plastic waste circularity due to its relatively advanced, multi-actor waste governance system, combined with persistent service gaps in coastal aquaculture areas. Since 2022, the local government has implemented the Banyuwangi Hijau (Green Banyuwangi) program, which promotes sustainable waste management through strengthening local waste management units, expanding community-based and commercial waste management facilities (TPS3R, from its initial in Bahasa Indonesia), encouraging household waste sorting, and developing innovative financing mechanisms beyond local government budgets (DLH Banyuwangi 2025). These efforts were institutionalized through the Waste Master Plan under District Head Regulation No. 1 of 2024 and have resulted in the establishment of 26 TPS3R facilities across subdistricts and villages with support from development partners.

At the same time, Banyuwangi hosts a dynamic ecosystem of non-governmental organizations, such as Systemiq, CLOCC, Rijig Pradana Wetan, Sungai Watch, and 4Ocean, and private actors, alongside a strong informal recycling sector centered in Rogojampi District, forming an interconnected plastic recovery network. However, formal waste services remain concentrated in urban areas and have not adequately reached coastal zones where shrimp aquaculture is concentrated. As such, aquaculture plastic waste is managed almost entirely through informal collector networks. This coexistence of progressive waste policies, active circularity initiatives, and structural service gaps makes Banyuwangi an ideal case study for analyzing plastic management pathways and leakage risks in aquaculture systems.



Data collection

Primary data were collected through three methods. First, structured surveys were administered to 29 shrimp farmers across four categories: traditional (14), semi-intensive (12), and corporate-intensive (3). Farmer categories were determined by stocking density, measured as post-larvae (PL) per square meter (m^2): traditional (<50 PL/ m^2), semi-intensive (50–100 PL/ m^2), and corporate-intensive (>100 PL/ m^2).

Second, in-depth interviews were conducted with seven local waste collectors (*pengepul*) who serve as intermediaries between farming operations and recycling markets. These interviews explored collection practices, pricing mechanisms, material flows to downstream markets, and collector perceptions of aquaculture waste management challenges. Third, direct field observations documented the types of plastic equipment, storage practices, and disposal behaviors.

The study acknowledges potential social desirability bias in self-reported practices such as burning or disposal to waterways, as these behaviors may be perceived as environmentally inappropriate. The triangulation of survey data with field observations and collector interviews helps mitigate this limitation by providing multiple perspectives on actual practices. Secondary data were obtained from local government agencies, including the Banyuwangi Environmental Agency (Dinas Lingkungan Hidup; DLH), as well as from relevant academic and technical literature on aquaculture waste management.

Data analysis

Survey data were analyzed using quantitative descriptive statistics to profile plastic equipment used at all stages of shrimp aquaculture across farmer categories. Qualitative data from interviews and observations underwent thematic analysis to understand patterns of use and end-of-life management. The analysis integrated quantitative and qualitative findings to trace flows from initial equipment use through various end-of-life pathways, mapping how different plastic types circulate through or exit local economic and social systems. This mixed-methods synthesis enabled the identification of both the scale of different practices (quantitative) and the underlying mechanisms and meanings that shape them (qualitative).

Results and discussion

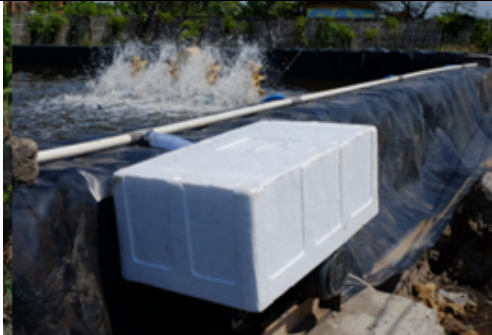
Profile of plastic equipment in shrimp aquaculture

The study identified 12 categories of plastic equipment commonly used in shrimp farming: pond liners, water wheel, protein skimmers, automatic feeders, pipes, hoses, buckets, bottles, nets, styrofoam, seed packaging, and feed packaging (Table 1). Each equipment type serves specific technical functions within the production system, from maintaining water quality and dissolved oxygen levels to facilitating feeding operations and biosecurity measures. The polymer composition varies by function: high-density polyethylene (HDPE) predominates in durable equipment such as pond liners, aerators, and buckets, while polyethylene (PE) and polypropylene (PP) are common in packaging materials and consumables.



Table 2. Plastic equipment categories in shrimp aquaculture

No	Name and description	Picture
1	Pond liners Polymer content: HDPE Function: to maintain the pond water quality	
2	Water wheel Polymer content: HDPE Function: to increase dissolved oxygen levels and create water currents, both of which are major factors in the success of shrimp cultivation with high stocking densities (Desmita 2024; Fiyanti and Suciya 2017)	
3	Protein skimmer Polymer content: HDPE Function: to purify water by removing dissolved solid waste (leftover feed, shrimp waste, and other organic waste) before it becomes ammonia, which inhibits shrimp growth (Krisandini 2024; Vanessa 2024)	
4	Automatic feeder Polymer content: HDPE Function: for scheduled and automatic feeding	
5	Pipe Polymer content: PVC Function: to channel clean water sources (sea/river/drilled well) and channel waste from ponds to disposal sites.	
6	Hose Polymer content: HDPE Functions: for sterilization and sediment cleaning (siphoning) to reduce pathogens carried over to the next cycle (WOAH 2009; Thi Kim Chi et al. 2017); and a form of implementing stricter biosecurity and modern sanitation (Zulfikar 2023)	

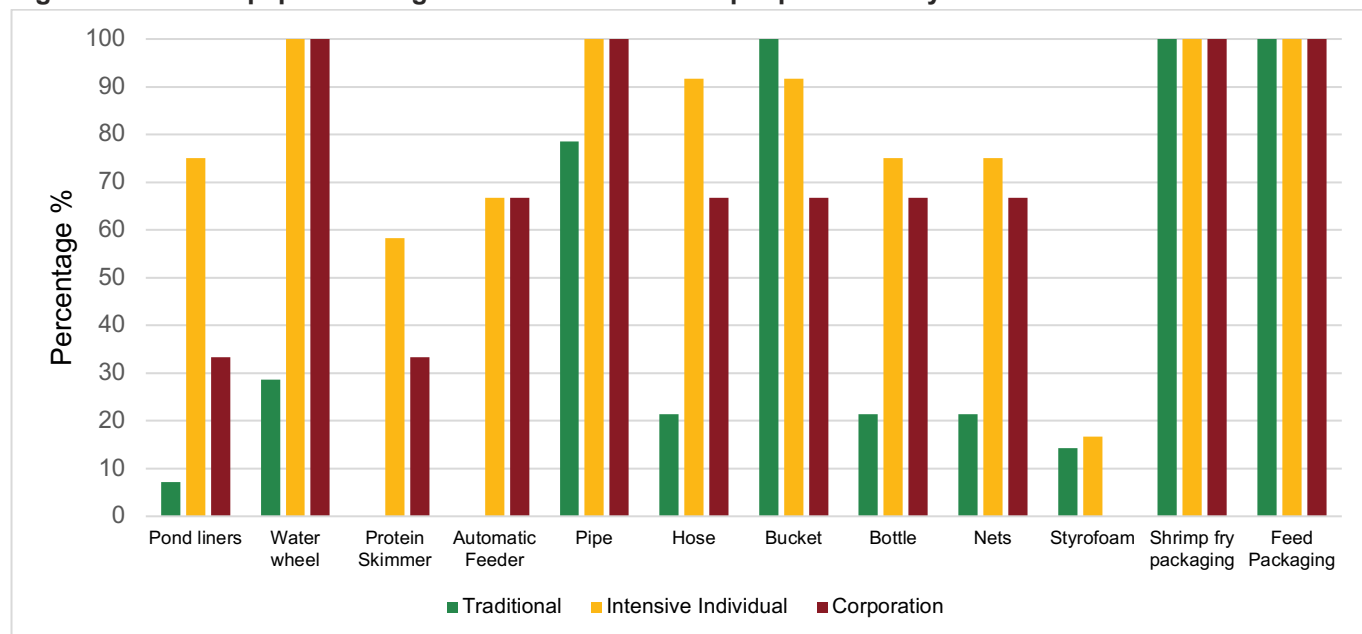
No	Name and description	Picture
7	Bucket Polymer content: HDPE Function: for daily treatment, including manual feeding	
8	Bottle Polymer content: PET Function: as a container for shrimp probiotics. They are not reused and are collected directly for sale.	
9	Nets Polymer content: PE Function: for shrimp sampling (in the form of <i>ancho</i>), total and partial harvest, and pond biosecurity fencing (Cahyani et al. 2023; Desmita 2024).	
10	Styrofoam Polymer content: PS Function: equipment storage or a temporary container during harvest. It is rarely used in ponds because it is easily damaged and can pollute the environment (Lee et al. 2023; Seo and Park 2024).	
11	Shrimp fry packaging Polymer content: PE Function: bags for shrimp seeds/fry. Some farmers reuse them at harvest time.	

No	Name and description	Picture
12	Feed packaging Polymer content: PE Function: to package feed. After the feed is used, the bags are usually collected to be sold.	

Source: Authors' analysis.

The patterns of equipment usage vary significantly across farming intensity levels, reflecting the different technical requirements and resource capacities (Figure 2). Traditional farmers typically use 4–7 types of equipment, relying primarily on basic items such as pipes, buckets, nets, and packaging of shrimp fry and feed. Semi-intensive and individual-intensive farmers use 8–12 types of equipment, while corporate farms use 7–11 types despite operating at substantially larger scales. This counterintuitive pattern reflects corporate operations' greater financial capacity to invest in non-plastic alternatives, particularly concrete pond construction that eliminates reliance on plastic pond liners, which are among the most problematic waste categories due to their large volume, limited recyclability, and extended replacement cycles.

Figure 5. Plastic equipment usage across different shrimp aquaculture systems



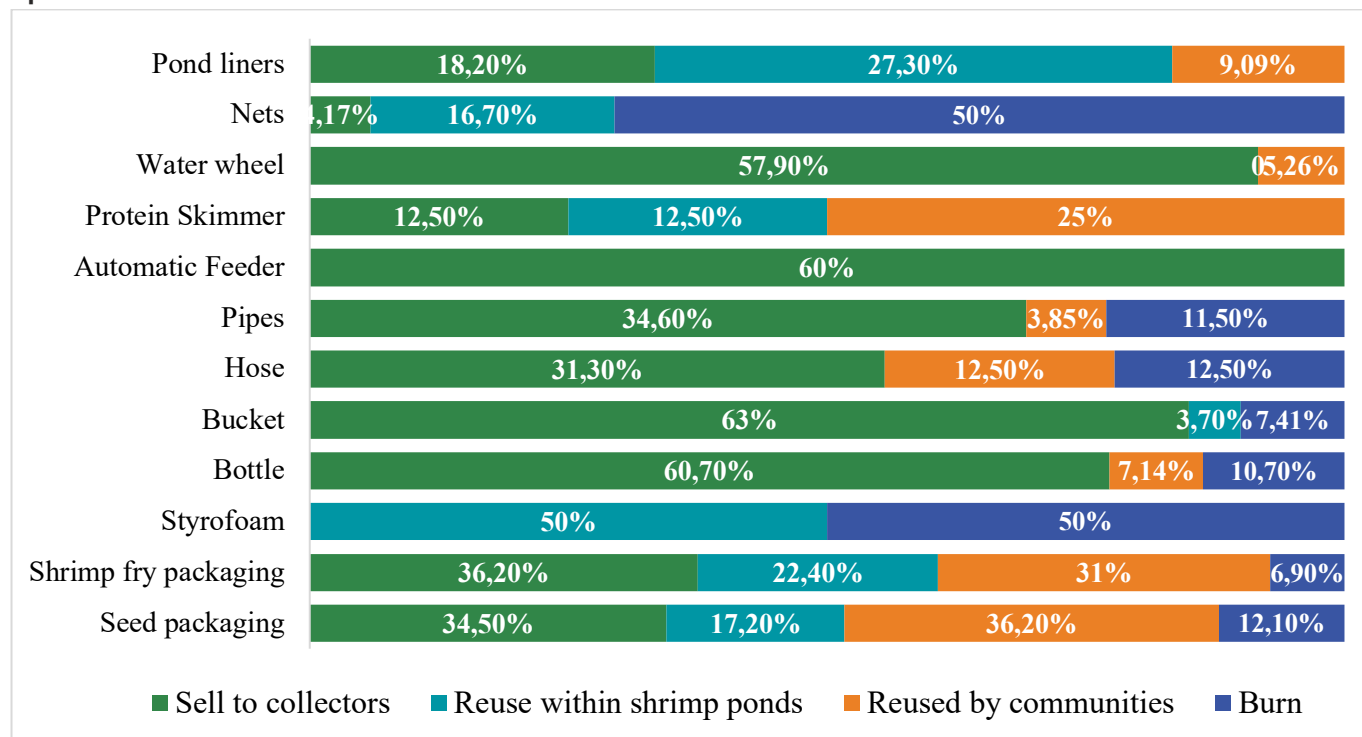
Source: Authors' analysis.

Analysis of equipment characteristics enabled categorization into high and low-value plastics based on durability, lifespan, and market demand within recycling networks. High-value plastics include durable items with extended functional lives and established resale markets: aerators (water wheels), protein skimmers, automatic feeders, pipes, hoses, and buckets. These items typically operate over multiple production cycles, maintain structural integrity through cleaning and maintenance, and are purchased by waste collectors for their material quality and recyclability. Low-value plastics comprise short-lived items that rapidly degrade, potentially become contaminated, or lack viable recycling pathways: feed packaging, seed packaging, styrofoam containers, and nets. These materials present management challenges due to contamination with organic residues, structural degradation from exposure to sun and saltwater, and limited market demand even when collected.

End-of-life pathways and circularity practices

Survey results revealed multiple circularity pathways operating simultaneously within the local system, with most farmers employing different management strategies for different equipment types based on condition, market value, and available alternatives (Figure 3). The primary pathways identified were sale to waste collectors, on-farm reuse for alternative purposes, sharing with community members for household applications, open burning, and, in limited cases, disposal to waste streams or stockpiling. The prevalence of each pathway varied significantly by equipment type and farmer category.

Figure 6. Management pathways through which plastic equipment exits active use in shrimp aquaculture operations

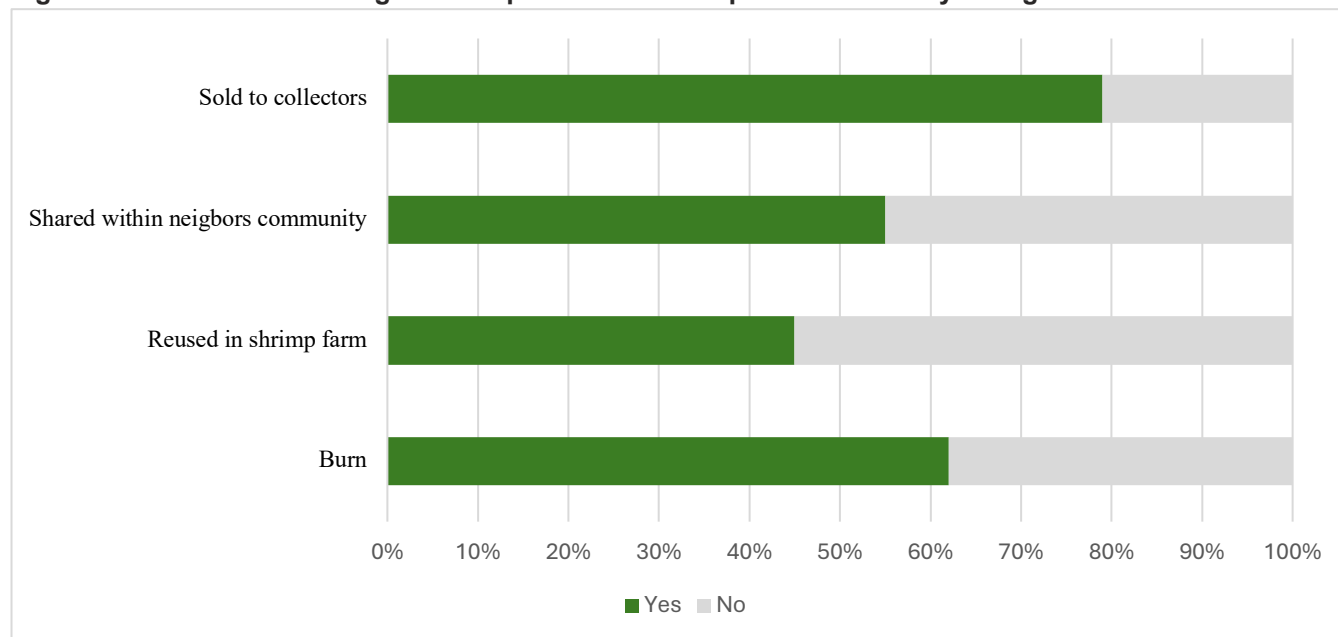


Source: Authors' analysis.

The diagram in Figure 3 demonstrates that materials rarely follow a single linear trajectory from use to disposal. Instead, farmers make pathway decisions based on equipment condition, market opportunities, social networks, and perceived value. High-value equipment typically enters collection and recycling pathways, while low-value materials face more diverse and problematic end-of-life routes, including burning and stockpiling.

The majority of surveyed farmers (79 percent) reported selling used plastic equipment—primarily high-value items such as automatic feeders, buckets, bottles, and intact pipes—to local waste collectors (Figure 4). These materials enter regional recycling value chains through collector networks that aggregate plastics from multiple sources and transport them to processing facilities in urban centers. Collection typically occurs through regular collector routes or farmer-initiated contact once sufficient material has accumulated to support economically viable transactions. Prices vary by material type and market conditions, but generally provide modest supplementary income rather than substantial revenue. Farmers reported that this income, while limited, creates meaningful economic incentives to segregate and store recyclable materials rather than dispose them by burning or other non-recovery pathways.

Figure 7. Plastic waste management experience of shrimp farmers in Banyuwangi



Source: Authors' analysis.

The data presented in Figure 4 reveal that selling to collectors is the most common practice for high-value materials, while burning remains prevalent for low-value plastics with no alternative management options. The graph also shows variation across farming-intensity levels, with more intensive operations demonstrating greater engagement with collection systems due to higher plastic volumes use and greater awareness of material values.

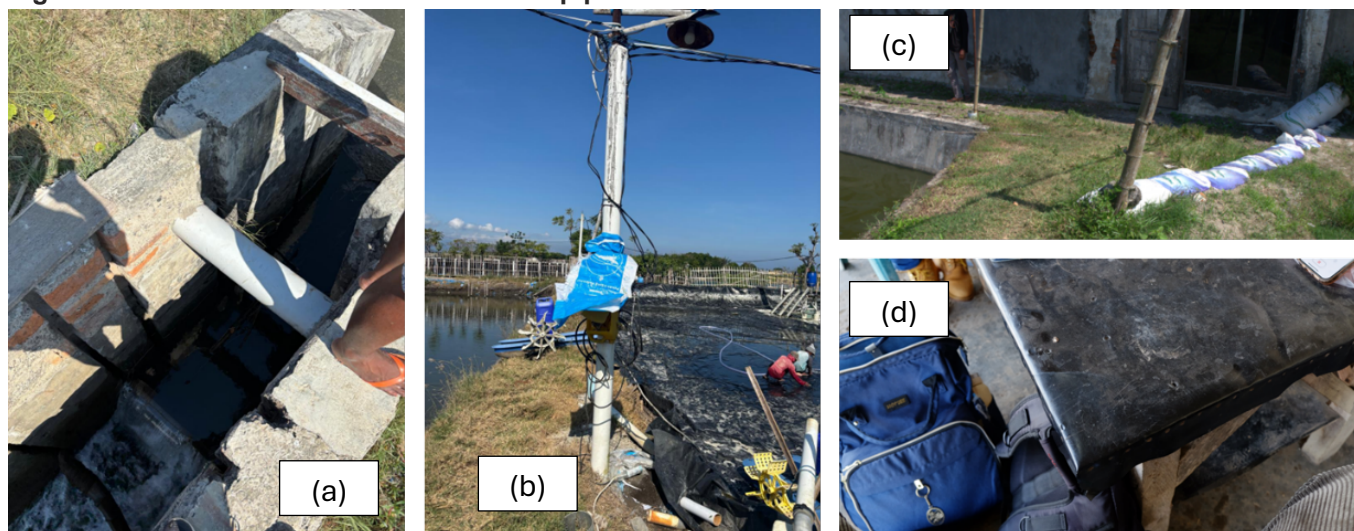
Figure 8. Plastic equipment sold to collectors



Source: Authors' documentation.

Nearly half of respondents (45 percent) practice on-farm reuse and creatively repurpose equipment for functions beyond their original design intent (Figure 5). Common reuse practices include converting feed sacks into pond embankment reinforcement to prevent erosion, using seed packaging bags as covers for electrical equipment or as water gate stoppers, employing degraded pond liner sections as work surface mats, and repurposing containers for storing tools or supplies. These practices demonstrate shrimp farmers' practical knowledge of material properties and functional needs, extending the equipment lifecycles while reducing new material purchases and disposal volumes. Reuse typically occurred when equipment retained sufficient structural integrity for alternative applications, even though it no longer met requirements of primary aquaculture functions.

Figure 9. Plastic reuse within internal shrimp ponds



Notes: (a) Seed packaging used as a water gate stopper; (b) Feed packaging used as a cover for pond electrical equipment; (c) Feed packaging used as a pond embankment; (d) Pond lining used as a table mat.

Source: Authors' observation and documentation.

Community-level sharing was also prevalent, with 55 percent of the farmers surveyed reporting that they distributed used plastics to neighboring households. Recipients repurpose these materials as mats, agricultural drying surfaces, waste containers, and various household applications (Figure 7). This practice demonstrates how aquaculture plastics circulate beyond farm boundaries, generating value for the wider communities.

Figure 10. Plastic is reused by communities near the shrimp pond



Note: (a) Birdcage cover; (b) Mat; (c) Trash can; (d) Fruit cover.

Source: Authors' observation and documentation.

However, 62 percent of surveyed farmers still burned plastics with no reuse or recycling pathways. This practice primarily affects low-value plastics, such as contaminated packaging, degraded pond liners, and styrofoam (Figure 8). Burning occurred sporadically during farm cleaning periods rather than as a routine practice, typically when storage space became limited or when preparing ponds. Although the informal nature of burning raises air quality and health concerns, direct disposal into water bodies appeared to be minimal based on both survey responses and field observations.

Figure 11. Plastic burning near a shrimp pond

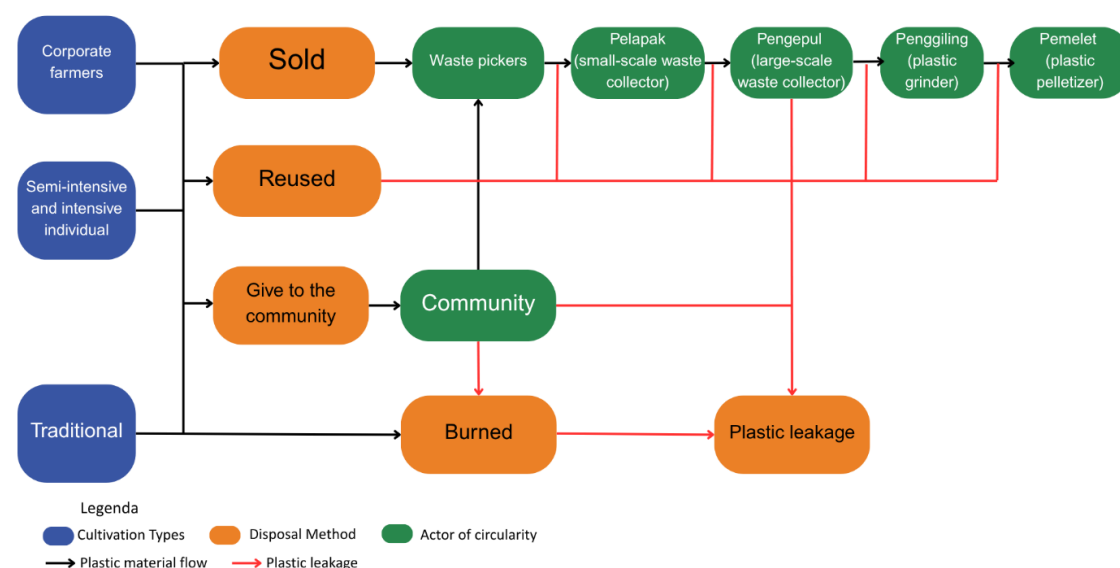


Source: Authors' documentation.

Key actors in plastic circularity

Three actor groups emerged as central to maintaining circularity (Figure 9). First, farmers serve as primary decision-makers, determining which materials enter reuse, recycling, or disposal pathways. Their knowledge of material properties, market values, and alternative uses directly influences leakage rates. Farmers operating at higher levels of intensification demonstrated greater awareness of plastic values and more systematic separation practices.

Figure 12. Plastic flow, leakage, and actors of circularity



Source: Authors' analysis.



Second, waste collectors function as crucial intermediaries linking aquaculture operations to recycling value chains. These informal sector workers provide essential services by purchasing used plastics directly from farms, offering both waste removal and modest income generation. Their presence creates economic incentives for farmers to segregate and store recyclable materials rather than burn or improperly dispose of them.

Third, community members, particularly neighboring farmers and households, enable local reuse by accepting and repurposing shared materials. This informal exchange system extends plastic lifecycles while distributing economic benefits throughout coastal communities. The social relationships underlying these exchanges suggest that interventions should strengthen rather than replace existing networks.

Leakage risks and management gaps

While current leakage to natural water bodies appears limited, several vulnerabilities threaten this stability. Low-value plastics, particularly pond liners, contaminated packaging, and styrofoam, lack viable circularity pathways and often get burned or stockpiled. As aquaculture production intensifies and scales up, the volume of these problematic materials will increase proportionally.

The reliance on informal collection systems presents both strengths and vulnerabilities. While these networks currently function effectively, they remain economically fragile and geographically limited. Collectors prioritize high-value plastics with established markets, leaving low-value materials without management options. Additionally, the lack of formal infrastructure for aquaculture waste means collection coverage depends on individual collectors' routes and relationships rather than on systematic service provision.

Farmers reported limited awareness of proper disposal methods for problematic plastics and expressed willingness to adopt better practices if viable alternatives existed. This suggests that leakage prevention depends not on changing farmer behavior but on creating accessible infrastructure and markets for currently non-recyclable materials.

Conclusion

This study demonstrates that aquaculture plastics in Banyuwangi function as materials in motion, circulating through overlapping economic and social networks rather than following linear waste trajectories from use to disposal. Multiple circularity pathways already operate, including selling to collectors (79 percent), on-farm reuse (45 percent), and community sharing (55 percent). These practices reveal considerable local knowledge, economic rationality, and social coordination in managing plastic materials, contradicting assumptions that aquaculture inevitably leads to uncontrolled pollution. However, the persistent burning of low-value plastics, reported by 62 percent of farmer respondents, indicates a clear management gap that requires intervention.

Three strategic opportunities emerge from these findings. First, farmers could benefit from simple sorting and storage systems that differentiate reusable, recyclable, and problematic plastics. This would reduce burning while maximizing recovery values. Second, local governments could support small-scale collection hubs near farming concentrations, enhancing collector efficiency and expanding service coverage. Third, connecting existing informal networks to formal recycling infrastructure would create markets for currently non-recyclable materials while improving waste collectors' livelihoods.

Effective interventions must recognize and strengthen existing community practices rather than imposing external solutions. The three key actors—farmers, collectors, and community members—already demonstrate circular economy principles through daily practices. Policymakers and development practitioners should focus on removing barriers these actors face: lack of collection infrastructure, absence of markets for low-value plastics, and limited awareness of material properties and alternatives. By supporting the actors who keep materials in motion, interventions can enhance both environmental outcomes and coastal livelihoods.



Future research should examine the scalability of successful local practices and develop economically viable solutions for problematic low-value plastics. As Indonesian aquaculture continues to expand, understanding and supporting grassroots circularity mechanisms will be essential to preventing marine plastic pollution while sustaining productive coastal communities.

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Driving Household Behavior Change for Food Waste Reduction in Bandung, Indonesia

Hosiana Simamora^{1,*}, Romauli Panggabean¹, Bergita Gusti Lipu¹, Peter Xandya Rudyan¹, Sri Noor Cholidah¹, Sarah Gracia Keinamada¹, and Talitha Fauzia Chairunnisa¹

¹ World Resources Institute (WRI) Indonesia, Jakarta, Indonesia

* Corresponding author: hosiana.simamora@wri.org

Abstract

Bandung City, one of Indonesia's largest urban centers, faces a serious food waste challenge, prompting the government to declare a waste emergency. Households have been identified as major contributors to this challenge, and while initiatives such as waste-free zones, composting, and maggot houses have been introduced, their effectiveness remains limited without consistent household-level behavior change. This study examines whether locally adapted behavioral interventions can reduce household food waste by addressing motivation, opportunity, and ability within everyday practices. The study implemented three context-based behavioral interventions in Nyengseret subdistrict in the city, comprising economic incentives through staple-food rewards, social recognition through neighborhood unit performance rankings, and behavioral nudges using posters and stickers. Conducted over eight weeks, the intervention involved 263 households in a community unit that already had communal waste management support. A mixed-methods approach was used, combining direct food waste measurement, household surveys, in-depth interviews, and a post-intervention focus group discussion. Results show that 136 households (51.8 percent) consistently practiced food waste sorting, contributing to a reduction of over 32 percent in household food waste. The findings indicate that willingness is the key mechanism linking intention to perceived ability, highlighting that information alone is insufficient to drive behavior change. Overall, this study demonstrates that a locally tailored behavioral intervention can effectively complement technical food waste management infrastructure by aligning motivation with enabling conditions and everyday capabilities.

Keywords: behavior change; food waste management; food waste reduction; household incentives; nudges; willingness

Introduction

Data from the United Nations Environment Programme (UNEP) show that Indonesia is the largest contributor to food waste in Southeast Asia and the fourth-largest in the world (UNEP 2024). This challenge is due to Indonesia's large population and consumption patterns, with 58 percent of food waste generated at the consumption level. Several factors influence household food waste, including routine food-related behavior, frequency of grocery shopping, eating-out behavior, cultural background of the local community, knowledge, and religious beliefs (Aulia and Martha 2025). To reduce food waste, the top priority is to reduce waste generation at the source, meaning it should be prevented in the first place. Behavior change is positioned as the top-priority intervention for addressing food waste (Bappenas 2021). However, most national-level implementation focuses mainly on technical solutions, such as infrastructure development and awareness-raising campaigns. The gap goes beyond knowledge, as supporting behavioral change requires motivation, opportunity, and the ability to drive it (Hou et al. 2025; Heidig et al. 2025).

As one of Indonesia's largest and most densely populated cities, Bandung faces an escalating food waste challenge. With 2.59 million residents, the city generates approximately 1,490 tons of waste per day, of which 44.5 percent is food waste, mainly from households and the hospitality sector (Kementerian Lingkungan Hidup 2024). This has placed severe pressure on landfill capacity, resulting in repeated waste emergency declarations and public appeals to reduce disposal at final disposal sites (Diskominfo Kota Bandung 2024). In response, the





municipal government has introduced multiple initiatives, including waste-free zones (Kawasan Bebas Sampah), waste-sorting campaigns, maggot-based bioconversion, household composting, machine-based waste processing, and digital platforms to encourage public participation (Diskominfo Kota Bandung 2025; Dinas Lingkungan Hidup Kota Bandung 2025). However, these efforts remain largely technical and normative, with limited consideration of local socioeconomic contexts, constraining their ability to drive sustained behavior change at the source.

Formative research in Bandung frames food waste as a “super wicked problem”, marked by fragmented governance, siloed actors, and interdependent responsibilities (Chairunissa et al. 2025). The findings show that food waste reduction is influenced not only by awareness but by locally embedded drivers such as perceived benefits, social norms, religious values, collective practices, and access to solutions. This highlights the need for context-sensitive behavioral interventions that complement existing technical measures.

Despite increasing policy attention, urban food waste governance continues to rely on one-size-fits-all technical approaches with limited behavioral evaluation. Empirical evidence on how locally grounded behavior change can reinforce structural interventions in dense urban contexts remains scarce. Addressing this gap is essential to strengthening food waste governance in Bandung and other rapidly urbanizing cities.

This study presents empirical evidence on the effectiveness of simple, context-based behavioral interventions in reducing household food waste in urban environments. Grounded in the premise that locally tailored behavioral approaches can reinforce existing technical waste-management systems, the study examines how these interventions shape household practices, participation levels, and behavioral consistency over time. The findings highlight the importance of social and institutional factors, including community dynamics, trust among residents, and the functioning of communal systems such as shared collection and processing mechanisms, in enabling or constraining household-level behavior change. Overall, the study demonstrates that low-cost, context-sensitive behavioral interventions can deliver measurable reductions in food waste while enhancing the performance and sustainability of urban food-waste management infrastructure, offering practical insights for policymakers seeking scalable, people-centered solutions.

Methodology

Study design

To understand whether a context-based behavior change intervention could help households reduce food waste, the study employed a mixed-methods approach to track progress before and after an eight-week period that ran from May to July 2025. The whole pilot, from planning to the final review, took place between February and August of the same year.

Before starting, the authors observed Nyengseret Subdistrict, which was selected due to its supportive local governance, existing food waste management facilities, and prior commitment to waste-related programs. These conditions were essential to ensure that sorted waste could be properly processed once the intervention was implemented. Despite these enabling factors, household participation remained low, highlighting a gap between the availability of infrastructure and actual behavior.

From seven community units (RW, from its initials in Bahasa Indonesia) in Nyengseret Subdistrict and based on preliminary observations and informal consultations with community leaders, RW 07 was selected as a pilot location due to strong community leadership. This area consists of 263 households across seven neighborhood units (RT, from its initials in Bahasa Indonesia). Local norms, daily routines, how food waste was already being managed, and motivations and challenges households faced were observed.





Quantitative and qualitative data collection

To collect quantitative data, the authors measured actual food waste from eight selected households over eight consecutive days, both before and after intervention, following the national standard “Metode Baku Perhitungan Sisa Pangan pada Ritel” (Standar Nasional Indonesia 1995; Bachtiar et al. 2024). This approach allowed the authors to observe what households were throwing out and how much.

Seventy households were surveyed at baseline (April–May), midline (June), and endline (July–August) to track changes in their knowledge, willingness, and perceived ability. Respondents were selected using stratified and snowball sampling to ensure proportional representation across the RT.

To gain a deeper understanding, the study collected qualitative data through in-depth interviews with five households at the baseline, midline, and endline data collection. This approach was taken to trace how their behavior changed over time and identify the key factors that helped or hindered them. After the pilot ended, a focus group discussion (FGD) was held to hear households’ collective reflections, the benefits they noticed, and the challenges they faced.

Intervention design

The intervention was built around a simple idea: for people to change their behavior, they need the right motivation, opportunity, and ability (Hou et al. 2025; Heidig et al. 2025). Initial observations showed that while people knew food waste was an issue, they lacked the routines and feedback needed to act on it consistently. The authors then established a reliable system with a regular collection schedule for sorted food waste, designated collectors, and transparent weighing to build trust and consistency.

Building on this foundation, three behavioral interventions were rolled out:

- **Economic incentives.** To help build a routine, a simple coupon-based reward mechanism was used. At the end of the intervention, households that consistently sorted food waste could trade in their stickers for staple food packages as a small reward. This incentive was a temporary trigger to get things started and motivate them.
- **Social recognition.** Each week, food waste data for each RT were tallied, and performance rankings in community chat groups were shared, fostering a sense of social comparison and friendly competition.
- **Behavioral nudges.** Simple posters and stickers put up in visible community spots. The messages were framed in different ways, focusing on saving money, social, and religious values that are relatable to their characteristics.

Data analysis

Changes in food waste generation were analyzed by comparing pre- and post-intervention measurements. To assess the effect of behavioral nudges, e.g., posters and stickers, a Spearman correlation analysis was conducted to examine the relationships between poster exposure and behavioral variables and demographic factors.

Multivariate regression analysis was used to identify key predictors of perceived ability. Analyzed independent variables included knowledge, perceived knowledge, willingness, and sociodemographic factors. This analysis aimed to test whether knowledge alone was sufficient or whether motivation played a stronger role in shaping behavioral capacity. Moderation regression was conducted to examine the interaction between willingness and sociodemographic variables, including gender, disability, and elderly status, to test whether the effect of willingness on perceived ability varied across these groups.





Qualitative data from interviews and FGD were analyzed using a process tracing approach to identify behavioral change pathways. Findings were synthesized into four stages of behavior change, i.e., contextual triggers, information exposure, practical adaptation, and social reinforcement.

Results and discussion

Food waste generation

At the start of the measurement, the study found that most of the food wasted was edible food. This was not just a waste of money, with good food going into the bin, but it also generated greenhouse gases (GHG). Even with some awareness and community facilities already in place, the amount of this type of waste remained high, indicating that infrastructure alone was not enough to change daily habits.

After eight weeks, the baseline and endline household food waste assessment, conducted using Indonesia's Metode Baku Perhitungan Sisa Pangan pada Ritel (Standar Nasional Indonesia 1995; Bachtiar et al. 2024), showed that households in RW 07 reduced their food waste by 32 percent (Table 1). In addition, there was a 34 percent reduction in edible food waste, meaning these interventions were particularly effective at helping people prevent avoidable waste. These changes also brought clear cobenefits, including saving money, avoiding food waste, and reducing GHG emissions.

Table 3. Results of the baseline and endline household food waste assessment and their impacts using Indonesia's Metode Baku Perhitungan Sisa Pangan pada Ritel in RW 07

	Baseline	Endline	Reduction (%)
Total food waste (kg/year)	53,938	36,893	32
Edible food waste (kg/year)	22,868	15,068	34
Inedible food waste (kg/year)	31,070	21,824	30
Economic loss (IDR/year)	429,827,093	385,420,467	10
Food wasted (portion/year)	14,202	12,655	11
GHG emissions (kg CO ₂ -eq/year)	135,030	119,841	11

Source: Authors' analysis.

Results of behavioral interventions

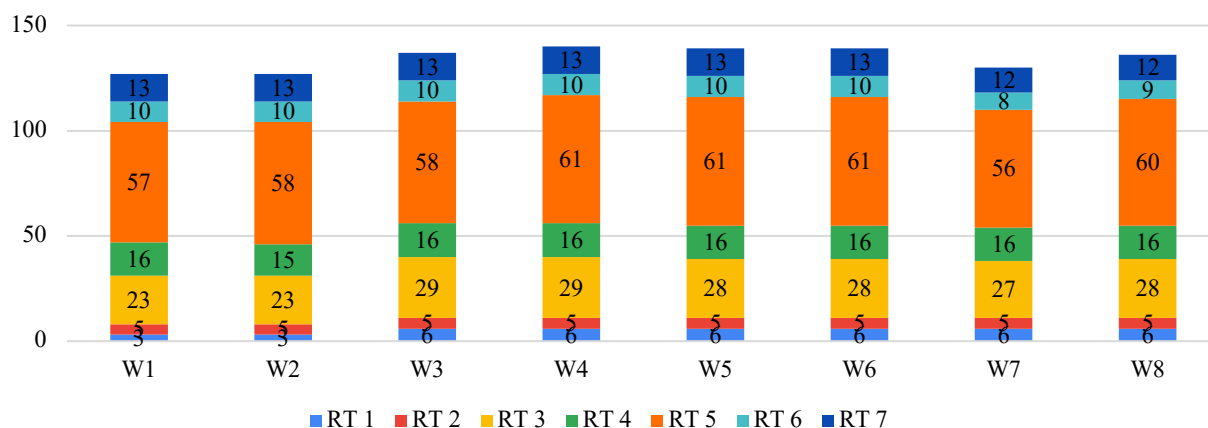
In addition to the baseline and endline household food waste assessment, weekly household food waste weighing was conducted throughout the eight-week intervention to monitor changes in household food waste generation and participation over time. The following sections present findings from these weekly monitoring data for behavioral intervention.

Economic incentive

Breaking down these interventions, the study found that 136, or 51.8 percent, of 263 households consistently sorted their food waste (Figure 1). Weekly food waste weighing conducted throughout the eight-week intervention showed an average 34 percent reduction in household food waste generation across participating neighborhood units (Table 2). The sticker coupon system worked well as a visual tracker, letting households see their progress and motivating them to continue. Consistent with previous research in Bandung, small, observable benefits can be a powerful motivator (Chairunissa et al. 2025), and the progress resulted not so much from the monetary value of the reward as from building a routine (Kivetz et al. 2006; Zou et al. 2024).



Figure 13. Distribution of households consistently sorting food waste across RTs



Source: Authors' analysis.

Social recognition

The friendly competition between RTs was also effective in bringing about change (Table 2). Public ranking of each RT's performance helped frame waste sorting as a collective goal rather than an individual chore, thereby increasing social pressure to conform to pro-environmental behavior (Mundt et al. 2024; Amir et al. 2025). This dynamic reinforced social pressure and made reducing food waste a community norm. This aligns with the social principle which emphasizes the role of social norms and peer comparison in shaping behavior (Service et al. 2014). In this context, the public display of performance may also evoke a fear of missing out or being left behind by others, further motivating participation.

Table 2. Weekly household food waste weighing data across participating neighborhood units during the eight-week intervention

Neighborhood Unit (RT)	Weekly average food waste per household (kg)								W8-W1 (kg)	Difference W8 and W1 (%)
	W1	W2	W3	W4	W5	W6	W7	W8		
RT 1	3.32	5.50	3.13	4.07	3.00	3.42	3.22	3.43	0.11	3.35
RT 2	2.60	2.58	2.20	1.86	1.52	1.84	1.64	1.72	–0.88	–33.85
RT 3	3.49	4.26	3.84	3.06	3.13	2.81	3.17	3.07	–0.41	–11.88
RT 4	5.12	3.25	3.19	2.84	2.07	2.55	2.39	2.13	–2.99	–58.46
RT 5	3.32	3.26	4.16	3.73	2.75	1.77	2.44	1.94	–1.38	–41.53
RT 6	3.06	2.50	2.17	2.16	1.82	1.70	2.23	1.94	–1.11	–36.35
RT 7	1.96	1.75	2.25	2.15	2.00	1.42	1.67	1.69	–0.27	–13.89
Average across RTs	3.39	3.25	3.53	3.18	2.58	2.11	2.51	2.23	–1.16	–34.14

Source: Authors' analysis based on weekly household food waste weighing records collected during the intervention.

Behavioral nudges

Posters and stickers had a significant positive impact on households' perception ($p=0.002$), willingness ($p < 0.001$), and perceived ability ($p=0.006$), but not on their factual knowledge ($p=0.456$), as shown in Table 3. This suggests they worked more as motivational cues rather than as educational tools. By framing the messages around moral, social, or religious values people already held, the posters and stickers were able to shape viewers' perception without having to convey complex information. Consistent with nudge theory, the materials reduced cognitive and motivational barriers by delivering messages at critical moments (timely), providing clear, simple actions (easy), and using concise, eye-catching designs (attractive) (Service et al. 2014).

Table 3. Collective poster exposure correlation with behavioral variables

Variable	r (rho)	p-value
Gender (1=female)	-0.040	0.739
Age	-0.277	0.020
Knowledge	-0.090	0.456
Perception	0.361	0.002
Willingness	0.482	0.001
Ability	0.326	0.006

Source: Authors' analysis.

Based on individual poster exposure, there was no significant correlation between knowledge and gender (Table 4).

Table 4. Ranks for individual poster exposure and correlation with behavioral variables

Message	Variable	p-value	Explanation
 278 portions of food are wasted daily in RW 07	Gender (1=female)	0.460	Descriptive local data. The most effective poster, showing the strongest and most consistent correlation with perception, willingness, and ability to change. The use of concrete and localized context strongly motivated respondents, particularly younger ones.
	Age	0.011*	
	Knowledge	0.629	
	Perception	0.001**	
	Willingness	<0.001**	
	Ability	0.001**	
 Order food in the right portion to avoid leftovers	Gender (1=female)	0.798	Action-oriented reminder. Strongly associated with perception and willingness, indicating that clear and practical prompts effectively encourage behavioral intention, especially in younger households.
	Age	0.013*	
	Knowledge	0.317	
	Perception	0.004**	
	Willingness	<0.001**	
	Ability	0.091	

Message	Variable	p-value	Explanation
Food waste reflects ingratitude toward God's blessings  Setiap makanan yang terbuang adalah nikmat yang tidak disyukuri Kurangi sisa pangan dan sampah makanan, mulai dari rumah	Gender (1=female)	0.576	Moral-religious framing. Consistently correlated with perception, willingness, and ability to change across age groups, suggesting that value-based and moral cues reinforced both motivation and perceived capacity to act.
	Age	0.280	
	Knowledge	0.740	
	Perception	0.024*	
	Willingness	0.002**	
	Ability	0.005**	
Energy from the food wasted in RW 07 could charge nine mobile phones  Energi dari sampah sisa makanmu dapat mengisi daya 9 ponsel Kurangi sisa pangan dan sampah makanan, mulai dari rumah	Gender (1=female)	0.354	Resource conversion. Moderately associated with perception, willingness, and ability. Linking food waste to resource loss supported motivation.
	Age	0.108	
	Knowledge	0.389	
	Perception	0.043*	
	Willingness	0.008**	
	Ability	0.040*	
The daily food waste in RW 07 could provide meals for 35 people  Makanan yang terbuang di RW 07 setiap harinya dapat memenuhi gizi 35 orang Kurangi sisa pangan dan sampah makanan, mulai dari rumah	Gender (1=female)	0.210	Collective impact framing. Showed significant but weaker associations across behavioral variables, suggesting that highlighting shared benefits encouraged motivation.
	Age	0.257	
	Knowledge	0.740	
	Perception	0.006**	
	Willingness	0.005**	
	Ability	0.032*	
Don't let food waste affect your appetite  Jangan biarkan bau mengganggu selera makanmu Kurangi sisa pangan dan sampah makanan, mulai dari rumah	Gender (1=female)	0.936	Affective reminder. The weakest poster that only associated with willingness, indicating that emotional cues alone triggered intention but did not shape perception or perceived ability.
	Age	0.083	
	Knowledge	0.299	
	Perception	0.093	
	Willingness	0.004**	
	Ability	0.156	

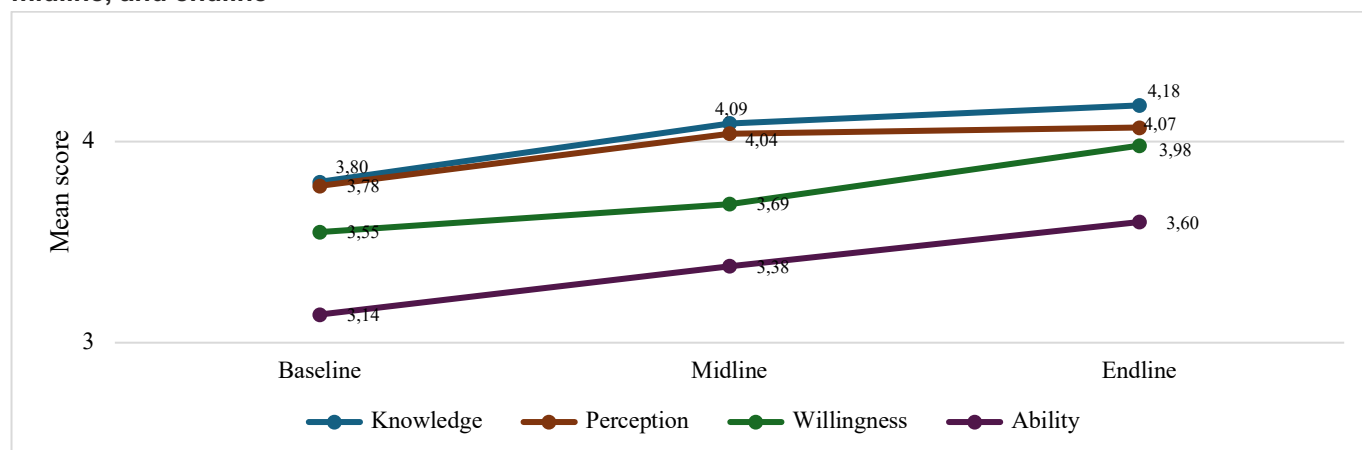
Notes: (*) indicates $p < 0.05$; (**) indicates $p < 0.01$

Source: Authors' analysis.

Knowledge, perception, willingness, and ability

Overall, households' knowledge, perception, willingness, and ability increased after the intervention. While most of them felt they knew enough about food waste, their actual knowledge was often limited to their own kitchen experiences rather than the broader environmental impacts. Post-intervention results indicate a clear improvement in willingness and perceived ability to act (Figure 2). While the willingness scores were relatively high, the persistent gap between willingness and ability suggests that intention alone is insufficient.

Figure 14. Changes in mean knowledge, perception, willingness, and ability scores across baseline, midline, and endline



Source: Authors' analysis.

Multivariate regression analysis indicates that willingness is the strongest predictor of perceived ability. In contrast, objective knowledge and sociodemographic variables are not significant predictors. These results confirm that behavioral readiness, rather than informational alone, is central to enabling household food waste management (Table 5).

Table 5. Multivariate regression predicting perceived ability

Variable	Coefficient	p-value
Knowledge score	0.03	0.893
Perceived knowledge score	0.53	0.001 **
Willingness score	0.72	<0.001 **
Neighborhood Unit (RT)	-0.12	0.365
Gender (Female = 1)	-0.38	0.458
Elderly (Yes = 1)	1.29	0.228
Disability (Yes = 1)	0.92	0.387

Source: Authors' analysis.

Moderation analysis shows that gender, disability, and elderly status do not alter the relationship between willingness and perceived ability. The positive effect of willingness on ability is consistent across all groups, indicating that motivation operates similarly regardless of social characteristics (Table 6).



Table 6. P-values of moderation regression models

Variable	Moderator		
	Gender	Disability	Elderly
Total knowledge score	0.775	0.859	0.393
Total perceived knowledge score	0.384	0.203	0.457
Total willingness score	0.021	<0.001	0.008
Moderator	0.650	0.425	0.213
Willingness × moderator	0.979	0.327	0.213

Source: Authors' analysis.

In-depth interviews

Interviews revealed that households typically went through four stages of change. First, it often started with a trigger, such as a disruption in waste collection or local environmental programs framing food waste as an immediate household concern, prompting people to think about their habits. Second, through community conversations, they began to see sorting waste as a shared responsibility. Third, the phase of trial and adaptation changes, such as cooking smaller meals, sharing leftovers, or giving waste to animals, to figure out what worked for them based on infrastructure, time, and household conditions. Lastly, with the support of regular collection schedules and social encouragement, new habits began to form.

This process shows that change sticks only when personal motivation, community norms, and practical support are all lined up. These findings are also consistent with a previous study, which found that behavior change is most durable when food waste management is reinforced as a shared social practice rather than an individual responsibility (Chairunissa et al. 2025).

Focus group discussion

The FGD revealed that households enjoyed the benefits of the intervention, including cleaner homes, greater knowledge about meal planning, and greater involvement of family members in sorting waste. These benefits were perceived as highly relevant and reinforced the adoption of new behaviors. Some participants even started composting or using food waste for animal feed, reflecting increased awareness and practical engagement with food waste management. These findings suggest that visible benefits play an important role in strengthening behavioral adoption at the household level.

These insights are supported by regression results, which show that willingness is the strongest and most consistent predictor of perceived ability to manage food waste, while objective knowledge and sociodemographic variables are not significant predictors. This indicates that behavioral readiness, rather than information alone, is central to enabling household food waste management. In other words, individuals with greater willingness to manage food waste are more likely to perceive themselves as capable of doing so, regardless of their actual level of knowledge or socio-demographic background.

Further moderation analysis confirms that the relationship between willingness and perceived ability is stable across gender, disability, and elderly groups. These effects suggest that sociodemographic characteristics do not alter how motivation translates into perceived capability. This implies that behavioral mechanisms operate relatively uniformly across different household groups, and that strengthening willingness may be broadly effective without requiring highly segmented approaches.

Overall, these findings are consistent with Graham-Rowe et al. (2014), who found that household food waste behavior is shaped by both motivational and contextual factors. The observed benefits in this study align with the “waste concerns” motivation, in which financial savings and perceived avoidance of waste serve as key drivers of





behavior change. In addition, improvements in food management practices reflect the importance of skills and perceived control in reducing household food waste.

However, the challenges identified, such as lack of space and own facilities, inconsistent participation from family members, and the old habit of cooking too much food, also mirror the constraints highlighted in previous literature, particularly convenience-driven behavior and entrenched household routines. Overcooking, for example, can be understood as a convenience-driven practice to avoid future effort, while inconsistent family participation reflects internal household dynamics that hinder collective action. Limited space and facilities further indicate structural constraints that restrict the adoption of food waste management practices. Together, these findings suggest that even when motivation is present, practical and social factors within the household can limit the sustainability of behavior change.

Conclusion

This study shows that simple, locally designed interventions can make a real dent in household food waste. By the end of the intervention, household food waste declined by 32 percent, with 51.8 percent of households consistently participating. This shows that when tailored to a specific community context, this behavioral intervention can be highly effective in reducing food waste at the household level.

The results also reveal that providing households with information or knowledge alone is not enough to change habits. What drove participation was a combination of seeing tangible benefits and having the practical means to sort and reduce food waste in people's busy lives. Motivation brought households to the door, but it was the enabling environment, such as the collection schedule, regular feedback, and community support, that kept them going.

Importantly, this study highlights the vital role of community systems. By transforming food waste management from an individual chore into a shared social practice through collective goals and social recognition, the change becomes more meaningful and sustainable. Connecting these small-scale behavioral interventions with larger food waste management systems can create more effective and scalable pathways for cities like Bandung to tackle their food waste problem.

Study limitation

The study is limited by the pilot design, which did not include comparisons of the effectiveness of individual interventions. Future research could address this limitation by testing each intervention separately.

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Psychological Predictors of Behavioral Intention toward Surplus Food Donation among Hotel Staff: A Case Study in Bandung, Indonesia

Peter Xandya Rudyan^{1,*}, Bergita Gusti Lipu¹, Hosiana Simamora¹, Lisandy Arinta Suryana¹, Muchammad Gumilang Pramuwidyatama², Romauli Panggabean¹, and Sri Noor Cholidah¹

¹ World Resources Institute (WRI) Indonesia, Jakarta, Indonesia

² Food Bank Bandung, Bandung, Indonesia

* Corresponding author: Peter.Rudyan@wri.org

Abstract

Hotels in Bandung still rely on buffets to serve breakfast. This serving style increases food production and food waste. Most leftover food from buffets is still edible, and hotel staff play a significant role in managing surplus food. This study utilized the theory of planned behavior to identify psychological factors that significantly influence surplus food donation among adult and youth staff. Results showed that hotel staff had the highest intention to participate in voluntary donation. Attitude was the most significant factor for hotel staff to participate in all donation schemes. Subjective norms significantly influenced youth in financial incentives donation, while perceived behavioral control influenced adults in donation linked to job performance evaluations. Results also showed that hotel staff preferred to repurpose, consume, and donate surplus food. This study suggests hotel management provide educational and logistical support, while higher education in hospitality should integrate food donation and food waste management into their curricula. Future research should investigate how policy acts as a barrier or motivator in adopting surplus food donation in hotels.

Keywords: food waste management; hospitality; surplus food donation; theory of planned behavior

Introduction

In the hospitality sector, hotel staff attitudes influence environmental programs, which influence hotel waste management activities (Park et al. 2014). These management activities are closely related to purchasing, storing, preparing, and serving food to hotel customers, which can be instruments to lower food waste (Goh et al. 2022). Food waste is potentially generated along the food chain in the hospitality industry. Hence, influencing the staff to get involved in food waste reduction, including training to build awareness and skills in reducing food waste, can be a good intervention. Attitudes and subjective norms influence the hotel staff awareness of the need to reduce food waste. Different cultures and organizations influence both factors. As such, there is no "one-size-fits-all" strategy to encourage hotel staff to participate in food waste reduction initiatives (Elkhwesky et al. 2024).

As a rapidly developing urban and tourism city, Bandung's hospitality sector plays a significant role in the local economy, contributing approximately US\$1 billion annually (BPS Bandung Municipality 2025). With more than 150 three- to five-star hotels relying on breakfast buffet services (Culture and Tourism Agency Bandung Municipality 2023), Bandung faces a growing challenge in managing food waste from hotels. Buffet-style operations are a major source of food waste due to over-preparation and limited capacity to reuse surplus food (Juvan et al. 2018). However, a study reported that around 15 percent of food waste is edible and could potentially be redistributed for donation (Gunawan et al. 2021). While some hotels have begun food donation initiatives with local food banks, success depends heavily on hotel staff participation, including food sorting, quality control, and coordination with food banks. Despite this critical role, hotel staff's intentions to engage in food donation remain unclear, and empirical research examining their behavioral intentions is still limited.





This study applied the theory of planned behavior (TPB), a psychological framework frequently used to explain and predict human behavior (Ajzen 1991), to examine hotel staff's behavioral intentions to participate in surplus food donation (SFD). Within this framework, intention is shaped by attitude, subjective norms, and perceived behavioral control. Accordingly, this study aimed to explore how psychological factors influence adult and youth hotel staff participation in SFD, while also identifying their preferences regarding surplus food handling practices.

Methodology

Questionnaire design

The questionnaire was developed using TPB (Ajzen 1991). There were 75 questions divided into three sections: sociodemographic characteristics; TPB factors, including attitude, subjective norms, and perceived behavioral control; and preference ranking for handling surplus food from leftover buffets and cooked food. The questionnaire was prepared in Bahasa Indonesia and utilized a Likert scale to collect responses. Before data collection, the questionnaire was tested by three hospitality respondents to ensure they could understand all the questions.

Data collection

The data collection was conducted in November–December 2024 involving 149 respondents from 67 hotels in Bandung. We purposely selected hotels in Bandung city center and collected data only from three- to five-star hotels, as they are known to offer buffet services consistently. Buffet-style operations tend to generate larger quantities of surplus food compared to à la carte services (Juvan et al. 2018), making these hotels the most relevant establishments for studying surplus food donation behavior. A purposive sampling method was used to select the respondents in this study. At least three respondents were selected from each hotel to ensure representation from the food and beverages (F&B) and non-F&B departments. The selection of respondents considered consent from their management and their availability.

Data and statistical analysis

Before data analysis, the data were checked for duplicates and missing values. Then, sociodemographic characteristics, TPB factors, and preference ranking for handling surplus food data were tested for normality. Following this step, descriptive statistics were calculated for each data variable. For sociodemographic characteristics, a frequency count was performed for each demographic characteristic category, such as age, gender, hotel star rating, education, work experience, and department.

A normality test of TPB factors was performed using the Shapiro-Wilk test. All variables in TPB factors, including attitude, subjective norm, and perceived behavioral control, showed a skewed distribution ($p < 0.05$). Intention data regarding participation in various donation schemes also showed a skewed distribution. Therefore, a logistic regression model was used to analyze the significance of TPB factors that influence hotel staff's intention to participate in donation programs.

Before the logistic regression, intention data were categorized as low (0) and high (1). A respondent was categorized as having low intention when they answered “strongly disagree,” “disagree,” or “neutral.” Conversely, intention was categorized as high when respondents answered “agree” or “strongly agree.” Then, the product composites of each TPB factor, namely attitude (A), subjective norms (SN), and perceived behavioral control (PBC), were calculated using the TPB equations developed by Ajzen (1991). The TPB equations are shown below:

$$A = \sum_{i=1}^N (b_i \cdot e_i) / N \quad (1)$$

Where: A = attitude; b = behavioral belief; e = outcome evaluation; and N = sample sizes





$$SN = \sum_{i=1}^N (n_i \cdot s_i) / N \quad (2)$$

Where: SN = subjective norm; n = normative belief; s = referent's significance to individual; and N = sample sizes

$$PBC = \sum_{i=1}^N (c_i \cdot p_i) / N \quad (3)$$

Where: PBC = perceived behavioral control; c = control belief; p = perceived power; and N = sample sizes.

The product composite scores were classified, based on their 33rd and 67th percentile cutoffs, into groups: weak (less than 12), moderate (12–16), or strong (more than 16). If a category contained fewer than 15 observations, that category was merged with the adjacent one. Following this step, a logistic regression model was used to analyze TPB factors. TPB factors were treated as model predictors, while intention was treated as the dependent variable. Factors were considered significant if the p-value was less than 0.05.

For preferences ranking in handling surplus food, the data were checked for normality. As the data showed a skewed distribution, non-parametric analyses were used. Mean and median values were calculated for each food handling method. Friedman tests were conducted to determine significant differences in ranking across food handling preferences. The Friedman tests showed a p-value of less than 0.001, indicating that food handling method preferences were ranked differently. This step was followed by a Conover post hoc pairwise comparison with Holm correction to identify significant differences in rankings between each food handling method. All data and statistical analysis were performed using Jeffreys's Amazing Statistics Program.

Results and discussion

A total of 149 hotel staff (aged 19–60) participated in this study, categorized as youth (18–34 years old) and adults (older than 34 years old). The study comprised staff from three-star (46.3 percent), four-star (31.5 percent), and five-star (22.2 percent) hotels. A significant majority (75 percent) of the participants represented F&B departments. Detailed sociodemographic and background information of respondents is provided in Table 1.

Table 4. Sociodemographic and background information of study respondents

	Category	Frequency (N)	Percent (%)
Age	Adult (>35 years old)	80	53.7
	Youth (18–35 years old)	69	46.3
Gender	Male	112	75.2
	Female	37	24.8
Education	Secondary education	64	43.0
	Higher education	85	57.0
Hotel star rating	3-stars	69	46.3
	4-stars	47	31.5
	5-stars	33	22.2
Work experience	< 5 years	48	32.2
	5–15 years	58	38.9
	> 15 years	43	28.9
Department	F&B	112	75.2
	Non-F&B	37	24.8

Source: Authors' analysis.





As Table 1 shows, the study's sample was dominated by males. This insight aligns with prior research suggesting that women are often stigmatized as unsuitable for kitchen roles due to their long hours and physical demands (Septiani and Siscawati 2023). Given this observed gender imbalance within the sample, this study further focused its analysis on comparing adult and youth staff to ensure equal participation across groups.

In this study, hotel staff's intention to participate in reducing food waste through donation programs was measured using TPB across four donation schemes. This study found that 74.5 percent of hotel staff have the highest intentions to participate voluntarily in SFD (Table 2). Their intention could be driven by altruistic religious values to donate food to people who are in need. This finding aligns with past research that the strongest predictor of individual intention to donate surplus food is genuine concern for others rather than personal gain (Habib et al. 2023).

Beyond voluntary donation, hotel staff also showed high intention to participate in recognition-based donation (73.2 percent) and donation tied to job performance evaluation (71.1 percent). In the recognition scheme, staff would receive appreciation for their participation in SFD, while in the job performance evaluation scheme, their participation would count as additional credit in the performance review. The high intention percentages in both schemes suggest that hotel staff intention could also be driven by positive feedback and performance reviews that benefit their career gained from their participation in SFD. This aligns with past research suggesting that intention to donate surplus food is also reinforced by self-interest, particularly when gaining personal benefits (Habib et al. 2023).

Table 5. Hotel staff's intention percentages in different donation schemes

Donation scheme	Intenders (%)
Voluntary	74.5
Recognition	73.2
Job performance evaluation	71.1
Financial incentives	53.0

Source: Authors' analysis.

In contrast, hotel staff are less likely to participate in donation with financial incentives as the reward (53 percent). Although financial incentives can be used to promote behavior change related to food waste initiatives (Sakaguchi et al. 2018; Mak et al. 2021), in this study, financial incentives did not increase the likelihood of hotel staff participating in SFD. This could be due to a conflict with their religious and altruistic values, where donating food means helping people who are in need and does not anticipate any return. This finding aligns with past research where financial incentives can be insignificant in influencing individuals' intention to donate surplus food, while altruistic and environmental approaches have significantly influenced intention to donate surplus food (Liao et al. 2019).

Three psychological factors influence hotel staff's intention to participate in SFD. Attitude (A) is the most significant psychological factor and has higher odds ratios than other factors in all four donation schemes (Table 3). A previous study observed that attitudes towards food waste can be perceived negatively and positively by hotel staff. A positive attitude can drive hotel staff to utilize food according to its purchase date, while a negative attitude can appear as feeling guilty when wasting food (Goh and Jie 2019). This result aligns with past studies that individual attitudes can be influenced by pro-environmental behavior (Habib et al. 2023; Elkhwesky et al. 2024).

To participate in SFD, hotel staff intentions can be influenced by subjective norms (SN), which represent their perceptions of the opinions and approval of people in the workplace who are important to them. These people could be their colleagues, friends, superiors, or subordinates (Chawla et al. 2022). In this study, SN influenced hotel staff intentions significantly in the voluntary scheme, while it was insignificant in other donation schemes (Table 3). This result shows that there was already a social expectation to donate food voluntarily in the workplace.



These findings align with past studies where the intention to reduce food waste is influenced by social judgment (Mak et al. 2021).

SN also strongly influenced youth staff intentions in the financial incentive scheme; among youth respondents (n = 69), 59 percent of youth respondents have a strong intention while 41 percent have low intention toward this scheme. This finding aligns with previous research suggesting that early career staff in hospitality tend to appreciate financial rewards more than senior staff (Ghani et al. 2022). Further, financial incentives can increase youth staff participation and improve their commitment to environmental initiatives (Aden 2023). However, to increase their commitment in this donation scheme, youth must be paired with peers, because they frequently seek approval for their behavior from friends and colleagues (Goh and Jie 2019). Therefore, SN remains a critical driver among youth staff for their engagement in SFD with financial incentives.

Table 6. Psychological factors influencing hotel staff's intentions across various donation schemes

Factors	All		Adult		Youth	
	OR	p-value	OR	p-value	OR	p-value
Voluntary						
A (moderate)	Ref	-	Ref	-	Ref	-
A (strong)	5.640*	<.001	5.261**	0.032	8.295*	0.006
SN (moderate)	1.780	0.292	1.218	0.792	3.227	0.226
SN (strong)	4.579**	0.013	2.714	0.297	4.915	0.057
PBC (moderate)	1.267	0.672	1.614	0.493	2.919	0.407
PBC (strong)	4.328**	0.041	1.484×10 ⁸	0.992	1.101	0.912
Recognition						
A (moderate)	Ref	-	Ref	-	Ref	-
A (strong)	26.341*	<.001	84.772*	<0.001	11.206*	<.0001
SN (moderate)	0.624	0.505	0.062	0.054	1.229	0.825
SN (strong)	1.097	0.886	0.174	0.177	1.560	0.596
PBC (moderate)	1.239	0.750	14.654	0.073	1.532	0.601
PBC (strong)	0.708	0.612	2.602	0.387	1.952	0.507
Job performance evaluation						
A (weak)	Ref	-	Ref	-	Ref	-
A (moderate)	3.313**	0.029	4.163	0.050	2.599	0.366
A (strong)	58.851*	<0.001	41.774*	<0.001	2.049×10 ⁹	0.994
SN (moderate)	1.516	0.498	0.472	0.422	1.373	0.790
SN (strong)	1.208	0.738	0.190	0.080	4.295	0.150
PBC (moderate)	2.106	0.237	14.073*	0.008	0.198	0.272
PBC (strong)	1.203	0.752	6.967**	0.030	0.286	0.283
Financial incentives						
A (moderate)	Ref	-	Ref	-	Ref	-
A (strong)	4.931*	<0.001	4.606*	0.005	6.366*	0.003
SN (moderate)	1.090	0.872	1.209	0.786	0.801	0.788
SN (strong)	2.024	0.158	0.956	0.952	5.135**	0.020
PBC (moderate)	0.978	0.963	0.435	0.229	1.353	0.668
PBC (strong)	3.307**	0.040	2.806	0.164	1.934	0.439

Notes: * significant at p < 0.05. ** significant at p < 0.01. OR = odds ratio. A = attitude. SN = subjective norms. PBC = perceived behavioral control.

Source: Author's analysis.



Perceived behavioral control (PBC) influenced all hotel staff intentions, particularly in voluntary and financial incentive schemes. PBC is an individual's ability to perform a given behavior (Ajzen 1991), and in this study, it refers to an individual's ability to perceive and manage time. PBC is an important psychological factor in balancing daily work routines with the time and effort required for volunteering in food donation, which affects staff's perceived ability to participate. In a previous study, time was a major constraint for restaurant staff wishing to donate leftovers as they must be available during surplus pick-ups by charitable organizations (Sakaguchi et al. 2018).

PBC is also significant for adult staff when donations are tied to job performance evaluations. Adult staff tend to prioritize career development more than financial incentives (Ghani et al. 2022). To successfully participate in this donation scheme, adult staff, particularly those in managerial or leadership positions, require strong time management. Time acts as a primary barrier for these staff members, as they need to allocate a specific schedule for these routines, and food waste initiatives are time-consuming for them (Goh et al. 2022).

Surplus food in the hospitality sector consisted of leftover food from buffets and cooked food that had not been displayed. For leftovers, hotel staff preferred repurposing, staff consumption, and donation (Table 4). There were no significant differences between these three handling methods ($p < 0.001$). For cooked food, however, hotel staff preferred to repurpose the food before staff consumption and donation. These results suggest that respondents understand food waste hierarchy, which prioritizes human consumption and reuse over recycling and disposal (Papargyropoulou et al. 2014).

Table 7. Hotel staff's preferences ranking in handling surplus food

Handling method	Preferences in handling surplus food	
	Leftover food	Cooked food
Repurpose	1	1
Consumed by staff	1	2
Donation	1	2
Recook	2	3
Disposed in organic trash bins	2	3
Sell at discounted prices	3	4
Disposed in mixed trash bins	4	5

Notes: Rankings are based on staff preferences, where 1 = most preferred, and 5 = least preferred. Tied rankings indicate equal preference among handling methods.

Source: Authors' analysis.

However, selling food at discounted prices was the second least preferred method. This approach remains uncommon in Bandung, and hotel staff are still unfamiliar with such handling practices. To address this, there is an emerging startup named Surplus Indonesia that facilitates the sale of discounted surplus food, allowing customers in Bandung to purchase surplus food from hotels, restaurants, cafés, and retailers (Adhariani 2024; Eitiveni et al. 2025). Commercializing surplus may also contradict respondents' altruistic values, as they prioritize voluntary donation for those in need over profit-driven interest (Habib et al. 2023).

Several key managerial implications from this study will support the adoption of SFD in the hospitality sector. Time is a major constraint for hotels to participate in SFD schemes when they are also expected to perform well in daily routines. Developing a voluntary shift schedule may help hotel staff participate in donation schemes. The human resources department needs to be involved in scheduling to allocate manpower and ensure staff availability, particularly during leftover pickups by food banks or charitable organizations (Mak et al. 2021; Kasavan et al. 2022; Goh et al. 2022).

While participating in SFD, hotel staff need foundational skills, such as surplus food sorting, storage, and food safety management, to effectively handle and donate surplus food. Not all staff have the same background or





experience in this field. Therefore, providing incentives for staff to attend sustainability and surplus food management courses may be beneficial, as these equip them with the relevant skills in managing surplus food in the hospitality sector. A prior study suggested that incentives from the management positively affect hotel staff attitudes towards food waste reduction initiatives (Mak et al. 2018). Other potential incentives for hotel staff relate to daily logistics, such as providing specific spaces and equipment for leftover collection, sorting, and cold storage (Mak et al. 2018; Demetriou 2022). Support and incentives from management, particularly managers responsible for leading their teams, will improve hotel staff motivation to participate in food waste reduction initiatives (Goh et al. 2022).

Aside from the implications in hospitality management, this study also suggests implications for higher education institutions that offer hospitality programs. Hospitality students are part of a new generation that will hold managerial positions in the future. Therefore, hospitality education institutions should integrate sustainability and food waste management into their curricula. The curricula should combine theoretical and practical courses (Vuksanović et al. 2025). In addition to students, hospitality educators should adapt their curricula based on practical evidence that reflects the current situation and improves current practices through research (Ko and Lu 2022). Integrating food surplus management in higher education will prepare students for hotel professional settings, particularly for managing food waste.

Conclusion

In Bandung, hotel staff intentions toward SFD are influenced by altruism, which aligns with their religious values. The study shows that the voluntary donation scheme is the most viable option for Bandung, as it shows a higher proportion of intenders compared to others. Attitude is the primary psychological factor influencing hotel staff intentions across all donation schemes. In contrast, subjective norms are only significant for younger staff in financial incentive schemes. Further, perceived behavioral control primarily affects adult staff, particularly regarding job performance evaluations. To support the adoption of SFD in hotels, this study recommends a rotation system for volunteering in SFD, educational support, and logistical incentives. At an academic level, integrating food waste management into higher education hospitality programs would bridge the skill gap in the younger generation in hospitality careers.

This study is limited as it did not explore the role of policy in using SFD to reduce food waste. Currently, Bandung lacks policies regulating SFD, specifically concerning liability and protection for donors and beneficiaries. Future research should investigate food safety regulations and donation policies as potential barriers or drivers of staff participation.

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Local Wisdom and Sustainable Livelihoods in the Subayang River Landscape: Insights from Riau, Indonesia for Climate Resilience

Indry Chahyana^{1,*}, Hari Novar¹, Amy Jesscia Pakpahan¹, and Veronika Lestary Silaen

¹ Indonesia Youth Education and Social (IYES)

* Corresponding author: indrycahyana@gmail.com

Abstract

The Subayang River landscape in the Bukit Rimbang Baling Wildlife Reserve in Riau, Indonesia, represents an important biodiversity area and a socioecological system where indigenous and local communities depend on forest and river resources for their livelihoods. Increasing environmental pressures and climate variability pose growing challenges to the sustainability of these livelihood systems. Understanding how local ecological knowledge supports adaptive strategies is therefore crucial for strengthening community-based resilience. This study examines local wisdom and livelihood practices in three villages (Terusan, Pangkalan Serai, and Subayang Jaya) along the Subayang River. A qualitative approach was used, including field observations, semi-structured interviews, focus group discussions with customary (*adat*) leaders, women, youth, and farmers, and participatory community engagement activities. The research addresses two key questions: how communities utilize natural resources to sustain livelihoods while maintaining ecological balance, and which traditional practices contribute to adaptive capacity under climate stressors. The findings reveal diverse strategies integrating ecological and cultural knowledge. Agroforestry systems combining rubber with stink beans, dog fruit, and coffee support income diversification while maintaining soil fertility and forest cover. The practice of *lubuk larangan* (temporary fishing restrictions) functions as a community-based mechanism for regulating aquatic resources. Non-timber forest products, including *sialang* honey, rattan, and *umbai* weaving, remain important for household economies, and ecotourism is emerging as an alternative livelihood option. Overall, these practices demonstrate a locally embedded framework linking conservation with social and economic functions, highlighting the Subayang River landscape's potential as a model for community-driven sustainable livelihoods.

Keywords: local wisdom; Subayang River; sustainable livelihoods; agroforestry; climate resilience; community-based adaptation; ecosystem-based adaptation

Introduction

Climate change and global environmental degradation increasingly threaten communities that depend directly on natural resources (Garai 2025). Climate variability, biodiversity loss, and ecosystem decline undermine the socioecological sustainability of rural livelihoods, particularly in forest- and river-based landscapes (Dofee 2023; Norgie et al. 2024). In response, adaptation approaches that integrate ecological conservation with community participation have gained attention, especially ecosystem-based adaptation (EbA) and community-based adaptation (CbA).

Indonesia reflects these global challenges. Forest clearance for agriculture and plantations has contributed to significant deforestation and ecosystem degradation, affecting biodiversity, carbon stocks, and local livelihoods (Utami et al. 2017; Hidayah 2025; Basir 2025; Powa 2025). According to the Ministry of Environment and Forestry (2022), Indonesia retains more than 96 million hectares (ha) of forest. However, approximately 6 million ha were lost between 2000 and 2020, with primary forest loss reaching 6.7 million ha by 2024. This decline has increased carbon emissions and ecological vulnerability (Pamungkas and Andriani 2023; Gunawan et al. 2024). Although community-based conservation and social forestry initiatives have been promoted as potential ways to address these pressures, their effectiveness often depends on the extent to which local ecological knowledge is integrated





into adaptation strategies. Therefore, strengthening the link between local knowledge systems and formal climate adaptation frameworks becomes essential.

From a socioecological systems perspective, adaptation is not solely a technical intervention but a dynamic interaction between social institutions and ecological processes (Salgueiro-Otero 2020). EbA emphasizes the use of ecosystem services to reduce climate vulnerability, while CbA highlights the role of local communities in designing context-specific responses. In practice, these approaches often overlap, particularly in rural landscapes where customary institutions, cultural values, and ecological practices shape resource governance. Integrating EbA and CbA within existing local knowledge systems offers a pathway toward sustainable and low-carbon adaptation (Dhar and Khirfan 2016; Reid, 2016).

The Subayang River landscape in the Bukit Rimbang Baling Wildlife Sanctuary in Riau Province, Indonesia, represents a complex socioecological system where communities depend on forests, rivers, and agricultural and plantation areas to sustain their livelihoods. Villages such as Terusan, Pangkalan Serai, and Subayang Jaya maintain customary governance structures that regulate land use, forest access, and aquatic resources. However, climate variability, economic pressures, and conservation-related land restrictions have introduced new uncertainties to these livelihood systems. Understanding how local wisdom supports adaptive strategies in this context is therefore critical.

Although studies increasingly examine social-ecological systems (SES) in the context of climate change, comprehensive analyses integrating feedback from SES into practical adaptation pathways remain limited, with many focusing primarily on vulnerability assessment. Addressing this gap, this study analyzes livelihood diversification, customary conservation mechanisms, and agroforestry systems in the Subayang River landscape to demonstrate how local ecological knowledge (LEK) underpins an integrated adaptation model that links LEK, CbA, and EbA. The findings highlight how community-driven SES can simultaneously support sustainable livelihoods, ecosystem conservation, and climate resilience in tropical conservation landscapes.

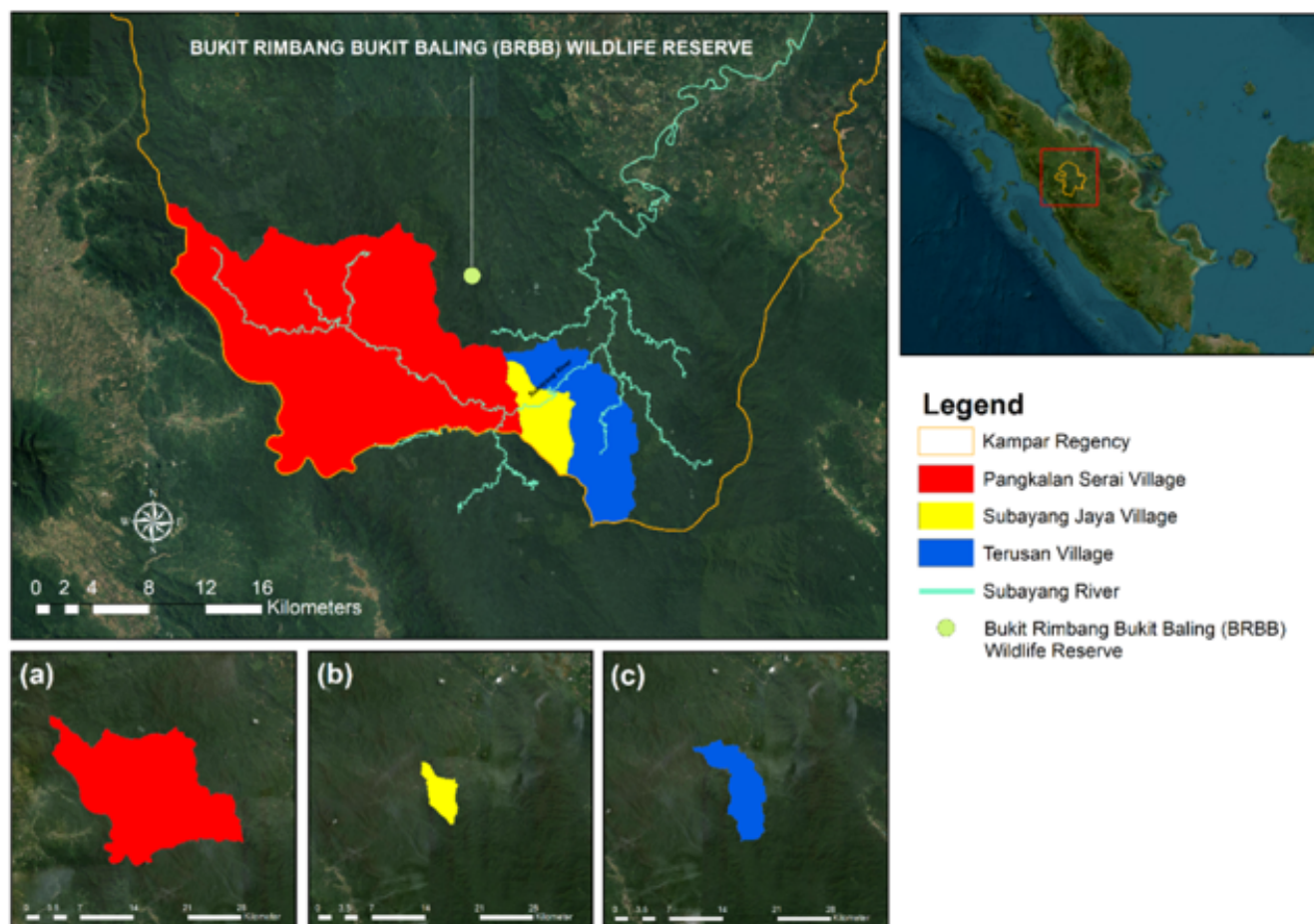
Methodology

Study area

This research was conducted in several villages within the Subayang River landscape in Kampar District, Riau Province. Administratively, the Subayang River landscape falls within the Bukit Rimbang Baling Wildlife Sanctuary. Several villages directly border this conservation area, including Terusan, Pangkalan Serai, and Subayang Jaya.



Figure 1. Map of the study area



Source: Authors, based on Google Earth (2025) and processed using ArcGIS.

This research is part of a community service initiative called the Indonesia Youth Education and Social (IYES) Mengajar program, which took place over several periods in 2022, 2023, and 2024 in three villages along the Subayang River: Terusan, Pangkalan Serai, and Subayang Jaya. These locations were selected because they are situated within the Bukit Rimbang Baling Wildlife Sanctuary, and the communities still rely on forest, river, and agroforestry resources, making them concrete examples of complex SES.

Data collection and analysis

Data were collected using a qualitative case study approach. Primary data were obtained through in-depth semi-structured interviews, participant observation, and focus group discussions (FGDs). A total of 45 participants were involved in this study, including traditional elders, village government officials, heads of households, indigenous women, indigenous youth, and other community leaders. In-depth interviews were conducted with eight key informants in each village, and three FGDs were organized, each consisting of 10–15 participants. The interview questions focused on livelihood strategies, socioeconomic activities, and the role of local wisdom in environmental management. Participant observation was employed to understand the community's daily practices in managing natural resources, such as agroforestry and the regulation of forbidden pools, and how these practices contribute to socioecological resilience.



Secondary data were also collected through desk research to provide ecological, social, and economic context, drawing on government documents, conservation agency reports, and related publications. Data analysis was conducted using content analysis, with findings grouped into categories aligned with the theoretical frameworks of SES, sustainable livelihoods, and the integration of EbA and CbA. The findings were analyzed to highlight the relationships among local wisdom, livelihood diversification, and community socioecological adaptation strategies.

Results and discussion

This study reveals the dynamics of the social-ecological system in the Subayang River landscape, reflecting the close relationship between communities and their environment in sustaining their livelihoods. Through field observations, in-depth semi-structured interviews, and focus group discussions (FGDs), it was found that communities in the Subayang River landscape, particularly the Terusan, Pangkalan Serai, and Subayang Jaya villages, have developed adaptation strategies that combine local wisdom, traditional ecological practices, and natural resource-based economic innovations. This integration illustrates how communities build resilience to climate change and to structural pressures resulting from conservation policies.

Socioecological characteristics of the Subayang landscape

The Subayang River landscape represents a complex socioecological system in which forests, rivers, and agroforestry lands underpin community livelihoods (Wijayanto et al. 2025). The area functions ecologically as a carbon sink, a biodiversity habitat, and a hydrological regulator (Syamsuardi et al. 2022), while socially it is governed by a customary institution known as the Kekhalifahan Batu Sanggan.

The community recognizes distinct territorial categories, including prohibited forests, productive agroforestry zones, and regulated river sections. Logging and cultivation are restricted in protected forest areas, while mixed gardens are allocated for perennial crops such as rubber (*Hevea brasiliensis*), petai or stink beans (*Parkia speciosa*), and *jengkol* or dog fruit (*Archidendron pauciflorum*). Similar zoning arrangements in riverine communities have been shown to strengthen ecological stewardship and local fisheries governance, suggesting that customary regulation plays a stabilizing role in socioecological systems (Utami and Oue 2021).

The Subayang River functions not only as a source of fisheries and transportation but also as a social and cultural space. Practices that regulate fishing areas and maintain riparian vegetation illustrate how environmental management is institutionalized within customary norms rather than being externally imposed. Such arrangements demonstrate the interaction between social institutions and ecological processes characteristic of SES strategies (Hossain et al. 2024).

However, climate variability, shifting seasonal patterns, and land-use limitations associated with conservation status have introduced new pressures on local livelihoods (Taryono et al. 2022; Marta et al. 2024). Fluctuating agricultural yields and restricted land access increase economic uncertainty, reinforcing the importance of adaptive strategies rooted in local knowledge. Within this context, the Subayang landscape provides a relevant case for examining how socioecological governance structures support community-driven climate adaptation.

Livelihood strategies

Communities in the Subayang River landscape sustain their livelihoods through diversified strategies closely embedded within local socioecological dynamics. Households combine mixed agroforestry systems, river-based activities, and non-timber forest products, including rubber tapping, cultivation of petai, dog fruit, and durian (*Durio zibethinus*), as well as the harvesting of *sialang* honey and forest materials. This portfolio-based system reduces dependence on single commodities and enhances flexibility amid fluctuating market prices and climate variability (Sati et al. 2014).





Diversification in Subayang is not merely an economic adjustment but an adaptive practice grounded in ecological knowledge. Households shift emphasis between rubber, perennial crops, and forest products depending on seasonal conditions and price dynamics, while maintaining tree cover that supports soil stability and microclimate regulation. These practices illustrate how livelihood decisions are calibrated to environmental cycles rather than short-term extraction.

Seasonal fisheries further demonstrate this ecological attunement. During the dry season, when water levels decline and fish concentrate in residual pools, fishing intensifies. Conversely, rising water levels during the rainy season reduce catch efficiency, prompting households to shift toward gardening or forest product collection. This cyclical adjustment reflects adaptive capacity rooted in intimate knowledge of hydrological dynamics.

A distinctive dimension of this adaptive system is the role of indigenous women in utilizing *umbai* leaves (*Scirpodendron ghaeri*) for weaving and handicraft production. Women harvest and process *umbai* leaves into a range of products, including traditional mats, small bags, pouches, and food covers, which serve both practical household and cultural functions. These products are collectively produced and marketed through local markets and small-scale community trade networks, including a dedicated outlet, “Keda Umbai,” located in the subdistrict capital of Kampar Kiri Hulu. Sales are often conducted either directly by women producers or through informal intermediaries, reflecting a localized, semi-formal distribution system. This process generates supplementary income while reinforcing social cohesion. The collective processing spaces function as arenas for intergenerational knowledge transmission and mutual support. In this sense, *umbai*-based activities represent more than household income strategies; they constitute an eco-social adaptation mechanism in which ecological knowledge, gendered labor, and communal solidarity intersect.

Through *umbai* weaving, women act as key agents in linking livelihood diversification with cultural continuity and ecological stewardship. Their engagement demonstrates that adaptive capacity in Subayang is relational and socially embedded, rather than purely economic. This gendered dimension of livelihood strategy highlights how local ecological knowledge operates through everyday practices and community networks.

From a sustainable livelihood framework perspective, Subayang’s adaptive system rests on natural capital (forests and rivers), social capital institutionalized in customary governance, and human capital expressed through locally embedded ecological knowledge. Diversified perennial crops help maintain vegetation cover, while customary restrictions on resource use limit ecological degradation. Consequently, livelihood diversification functions simultaneously as an economic buffer and as a community-driven climate mitigation mechanism.

However, the sustainability of these strategies depends on enabling structural conditions. Limited access to education, infrastructure, and financial services constrains the scaling of sustainable practices (Ensor et al. 2013; Jatav 2024; Nyathi 2025). Strengthening institutional recognition and support systems is therefore essential to ensure that community-based diversification, particularly women-led initiatives such as *umbai* weaving, can contribute more effectively to long-term climate resilience.

Integrating LEK into CbA and EbA strategies

LEK in Terusan, Pangkalan Serai, and Subayang Jaya villages is embedded within a shared socio-customary system under the customary authority of the Kekhalifahan Batu Sanggan. This institution structures resource governance and reflects a collective understanding that human well-being depends on forest and river sustainability. Consequently, environmental management practices are oriented toward balancing livelihood needs with ecological continuity.

One prominent expression of LEK is the practice of *lubuk larangan*, which are designated river sections protected through customary decrees. Beyond conserving fish stocks, this system safeguards riparian vegetation and reinforces community-based aquatic governance (Hadi et al. 2017; Titisari et al. 2025; Purnama et al. 2025).





Ritualized opening ceremonies and symbolic acts, such as returning part of the catch to the river, embed ecological restraint within spiritual and social norms. In this way, conservation is institutionalized culturally rather than externally imposed.

Land management follows a traditional mixed agroforestry system combining perennial crops such as petai, dog fruit, and durian with rubber. Maintaining shade trees and avoiding complete forest clearing preserve soil fertility and reduce the risks of degradation (Sahuri 2019; Febryano et al. 2024). Knowledge of soil characteristics further guides crop placement, preventing over-exploitation and sustaining long-term productivity. Such practices demonstrate how LEK operationalizes ecosystem-based adaptation at the landscape scale. Several studies have shown that incorporating traditional knowledge into agroforestry practices can support sustainable land management strategies (Horamo et al. 2021; Dako et al. 2025) and enhance climate resilience by strengthening community adaptive capacity (Harrahap and Vitor 2024; Sari and Jumiyati 2025).

Ecological knowledge is also reflected in the management of the *sialang* honey forest (*imbo kepungan sialang*). Harvest timing follows flowering cycles, and climbers operate under customary permission to ensure the sustainability of bee colonies and host trees. By regulating access and maintaining forest integrity, this system supports pollinator habitats and reinforces vegetation continuity.

Collectively, these practices illustrate LEK as an integrated governance-knowledge system linking ecological stewardship, social regulation, and spiritual values. Rather than functioning as isolated traditions, *lubuk larangan*, agroforestry, and honey forest management form interconnected mechanisms that stabilize the socioecological system while sustaining low-emission, resource-sensitive livelihoods.

Subayang community adaptation model for climate change integrating LEK into CbA and EbA approaches

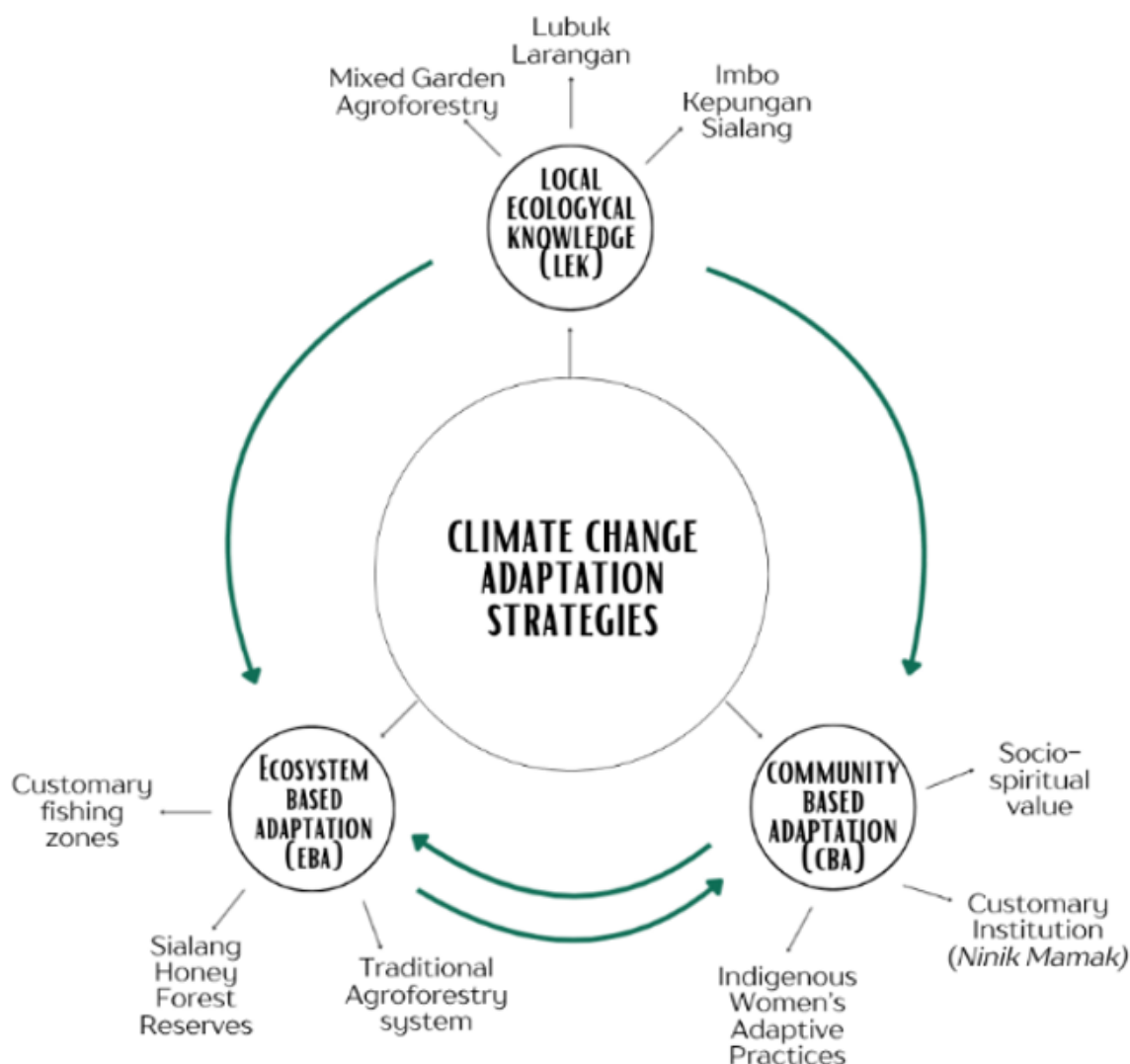
Community adaptation strategies in the Subayang River landscape are grounded in LEK systems, which have been passed down through generations and embedded within customary institutions. LEK is integrated into adaptation practices through two main pathways: CbA, which emphasizes social and institutional dimensions, and EbA, which focuses on ecological functions that support life. The integration of these two approaches forms a holistic adaptation model, in which communities collectively manage natural resources to achieve a balance between economic well-being, ecosystem sustainability, and climate change mitigation.

In the CbA approach, customary institutions play a central role in regulating resource governance through norms such as the management of *lubuk larangan* and *imbo kepungan sialang*, a customary protected forest area designated to conserve *sialang* trees, which host wild honeybee colonies. Customary deliberations determine harvest times, utilization rules, and the distribution of resources, all aimed at maintaining social and ecological balance. Furthermore, women play distinct socioecological roles through the use of local resources, particularly *umbai* leaves, as discussed earlier. These activities contribute to household income while strengthening social cohesion and cultural identity. The collective harvesting and processing practices reflect adaptive livelihood strategies grounded in ecological knowledge and communal solidarity, thereby strengthening the community's capacity to respond to climate change.

From an EbA perspective, the community implements ecosystem management practices that maintain the ecological functions of the landscape. The *imbo kepungan sialang* area is traditionally protected and can be accessed only on a limited basis due to its crucial role as a bee habitat and natural carbon sink. A mixed garden system that combines perennial and annual crops helps maintain soil fertility and reduces the need to clear new land. The practice of *lubuk larangan* further supports the rivers' ecological functions by protecting riparian vegetation and maintaining water quality. These three practices exemplify the application of EbA principles, which contribute directly to climate change mitigation through vegetation conservation and the reduction of emissions from land degradation. The integration of CbA and EbA, along with the role of LEK, is illustrated in Figure 2.



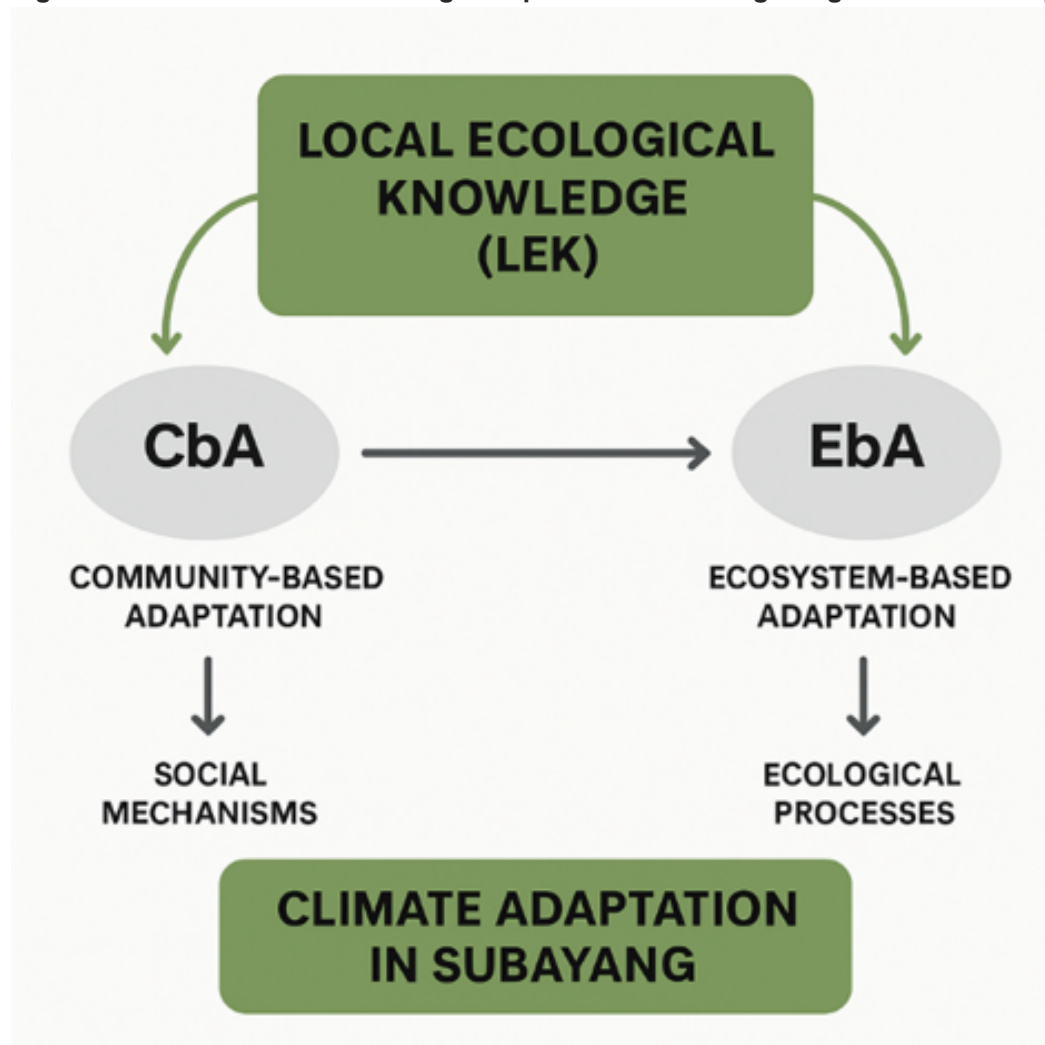
Figure 2. The framework to integrate LEK, CbA, and EbA for climate adaptation in the Subayang River landscape



Source: Authors' analysis.

Figure 3 illustrates a conceptual model in which the integration of LEK, CbA, and EbA forms a holistic, low-carbon adaptation model for the Subayang community. Local knowledge provides the foundation for decision-making, customary institutions ensure its social implementation, and the ecosystem serves as the space in which adaptation strategies are realized. This model demonstrates that climate adaptation and mitigation can emerge from local, value-based socioecological systems rather than relying solely on external interventions. With adequate policy and infrastructure support, as well as enhanced education, this adaptation model can serve as an example of the sustainable application of an integrated CbA and EbA approach grounded in local wisdom in tropical upstream river landscapes such as Subayang.

Figure 3. LEK-based climate change adaptation model integrating CbA and EbA approaches



Source: Authors' analysis.

Conclusion

Research in the Subayang River landscape demonstrates that communities build resilience to climate change by integrating social systems, ecological management, and local knowledge. The incorporation of LEK into CbA and EbA practices creates livelihood systems that not only support economic well-being but also maintain ecological balance. Customary practices such as *lubuk larangan*, *imbo kepungan sialang*, and mixed garden systems illustrate that communities in Terusan, Pangkalan Serai, and Subayang Jaya villages possess natural resource management strategies that function as both adaptation and mitigation measures for climate change through vegetation conservation and carbon sequestration.

This research confirms that effective adaptation and mitigation strategies do not necessarily have to originate from external interventions but can emerge from the values, experiences, and ecological ethics of the community itself. Strengthening these local systems requires policy support that recognizes customary institutions, improves education, enhances rural infrastructure, and expands access to technology and financing. By positioning LEK as the foundation of CbA and EbA approaches, the Subayang community adaptation model demonstrates that rural communities have significant potential to build sustainable climate resilience without compromising their cultural identity or ecological balance.



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Energy Trilemma in Reducing Marine Air Pollution: Indonesia's Adoption of Palm Oil-Based Biodiesel for Ships

Dikara Maitri Pradipta Alkarisya^{1,*}

¹ Alumna, Department of Public Policy and Management, Faculty of Social and Political Science, Universitas Gadjah Mada, Yogyakarta, Indonesia

*Corresponding author: alkarisya.dikara@gmail.com and dikaramaitripradipta@mail.ugm.ac.id

Abstract

This paper examines Indonesia's efforts to reduce marine air pollution from sea shipping through the lens of the energy trilemma, focusing on the adoption of palm oil-based biodiesel as a response to tighter global emission standards under the International Convention for the Prevention of Pollution from Ships (MARPOL) Annex VI on air pollution and exhaust emissions. Using an integrative literature review, the study synthesizes evidence from international maritime regulations, Indonesia's domestic policy instruments, academic research, and policy reports. Findings show that palm oil-based biodiesel is frequently framed as a readily available transition fuel to meet compliance requirements, yet it generates significant trade-offs across the three pillars of the energy trilemma: energy security, energy equity, and environmental sustainability. The paper contributes a cross-domain synthesis that connects maritime decarbonization policy to broader energy and sustainability governance challenges, and it outlines policy implications for improving regulatory coherence and managing trade-offs in the energy transition of Indonesia's shipping sector.

Keywords: energy trilemma; marine air pollution; IMO; MARPOL Annex VI; palm oil-based biodiesel

Introduction

The World Health Organization (WHO) identifies air pollution as one of the most serious public health threats, responsible for a substantial number of premature deaths each year and projected to impose an increasing health burden in the coming decades (Viatte et al. 2020). Along with the expansion of access to information and rising public awareness, public pressure on governments to prioritize air pollution as a policy issue has intensified.

In Indonesia, however, public perception of air pollution remains largely focused on land-based sources such as coal-fired power plants, motor vehicle emissions, and open burning of waste. In contrast, the contribution of the maritime sector, particularly emissions from ship fuel combustion, has received comparatively limited attention. This oversight is notable given that the ocean is a vital ecosystem for human life and simultaneously serves as an accumulation point for various forms of pollution and the impacts of climate change. Marine pollution extends beyond water contamination, such as oil spills or solid waste, to include air pollution generated by human activities in coastal and offshore areas, including shipping operations and port activities (Viatte et al. 2020).

In the context of marine air pollution, emissions from ships contain a range of pollutants that contribute to deteriorating air quality, including sulfur dioxide (SO₂), nitrogen oxides (NO_x), carbon monoxide (CO), ammonia (NH₃), and particulate matter with diameters of less than 10 and 2.5 micrometers (PM₁₀ and PM_{2.5}, respectively) (Viatte et al. 2020). Bayazit and Kaptan (2023) emphasize that ship operations are a significant contributor to marine environmental pollution through the release of pollutants into seawater and the atmosphere. As a result, the control of maritime emissions has become an increasingly salient issue.

From an economic perspective, the shipping sector serves as the backbone of global trade. Approximately three-quarters of the world's traded goods are transported by sea, making shipping activities inseparable from global logistics dynamics and economic growth (Gössling et al. 2021). Nevertheless, the intensity of these activities also





entails environmental consequences. Emissions from ships at sea, as well as those generated in ports during loading and unloading operations, increase pollutant exposure, particularly for communities residing in port-adjacent areas (Ducruet et al. 2024). Research on environmental health shows that environmental factors may cause respiratory diseases. The issue of health in a port cannot be separated from the environment and must be considered (Jeanjean et al. 2021, as cited in Ducruet et al. 2024). Although the contribution of shipping to overall air pollution is often considered smaller than that of other sectors, its relative importance is projected to grow toward the middle of this century, in line with increasing cross-sectoral demands for decarbonization (Gössling et al. 2021). Consequently, controlling marine air pollution is not only an environmental concern but also an issue of transport governance, logistics management, and public health.

Globally, efforts to control ship-based pollution are framed within an international regulatory regime, most notably the International Convention for the Prevention of Pollution from Ships (MARPOL). MARPOL Annex VI specifically addresses the prevention of air pollution from ships by establishing emission standards and fuel requirements (EPA.gov n.d). As a member of the International Maritime Organization (IMO), Indonesia is obligated to adopt and implement MARPOL provisions, including Annexes III, IV, V, and VI (IMO 2012). IMO also targets to cut greenhouse gas (GHG) emissions by 40 percent from the 2008 level by 2030 (Roy and Chakraborty 2025).

One of Indonesia's policy approaches to reducing marine air pollution is the promotion of fuel blending, particularly the mixing of conventional diesel with biofuels. In Indonesia, biodiesel derived from palm oil or crude palm oil (CPO) has been produced and promoted as a more environmentally friendly alternative. The implementation of this policy in the transport sector, including its potential use in shipping, has been pursued through the B30 blending scheme, which mixes 30 percent biodiesel and 70 percent diesel from fossil fuel, with plans to gradually increase the blending ratio over time (Purwanto and Lutfiana 2022). However, the effectiveness of palm oil-based biodiesel cannot be assessed solely from downstream engine performance. Rather, the policy's consequences are shaped by all upstream-to-downstream sectors, encompassing feedstock availability, price dynamics, and the social and environmental impacts of palm oil production itself.

Against this backdrop, this study aims to address a literature gap by linking marine air pollution in the shipping sector with the energy trilemma perspective. To date, relatively few studies have explicitly mapped how maritime emission reduction policies, including the adoption of palm oil-based biodiesel, generate challenges and trade-offs across the three pillars of the energy trilemma: energy security, energy equity, and environmental sustainability. Accordingly, this study poses the following research question: *How do the three pillars of the energy trilemma shape the challenges and trade-offs in Indonesia's adoption of palm oil-based biodiesel to reduce marine air pollution?* This research contributes to the development of a critical synthesis of cross-domain literature spanning energy studies, public policy, and environmental sustainability, thereby moving beyond descriptive summaries toward evidence-based policy implications and recommendations.

Methodology

Research design

This study employs an integrative literature review method using an integrative review approach that combines diverse types of sources to develop a comprehensive understanding and generate a critical synthesis across perspectives (Snyder 2019). The data sources include peer-reviewed academic articles and policy documents, allowing for a holistic examination of the research problem. This approach is particularly appropriate given that the research question requires exploration of the interconnections between maritime regulation, domestic energy policy, and sustainability outcomes; these relationships cannot be adequately addressed by a single discipline or body of evidence.

The analytical process involves the systematic collection and mapping of key findings from relevant literature and policy documents. These findings are then synthesized narratively to identify recurring patterns, challenges, and



trade-offs in the adoption of palm oil-based biodiesel within the shipping sector. The analytical framework is structured around the three pillars of the energy trilemma—energy security, energy equity, and environmental sustainability—as defined by the World Energy Council (WEC) and further elaborated in studies on Indonesia’s energy trilemma (WEC 2024; Gunningham 2013).

Data extraction and analytical process

The analysis was conducted in three stages the research question. The review includes four policy documents, three reports published by key organizations, and nine academic articles. The keywords are selected based on the research focus to identify the challenges of palm oil-based biodiesel policy. These are “palm oil policy,” “palm oil biodiesel policy,” “Indonesian biodiesel policy,” “trilemma energy,” “energy security and biodiesel,” “environmental and biodiesel policy,” “energy equity and palm oil,” “port pollution and health,” “port pollution and environmental issues,” and “biodiesel policy and energy”. These keywords are used to collect the articles or early stage before continue to be inserted on the matrix. First, each source was systematically reviewed and extracted into an evidence matrix to maintain an audit trail and ensure transparency in the review process. The matrix captured core information, including the type of source, case study context, research questions, aims and objectives, key findings or arguments, and relevance to trilemma. The articles are collected from Elsevier Scopus, ScienceDirect, Springer, Sage Journals, Google Scholar, and Open Access Journals.

Second, deductive thematic coding was applied using the three pillars of the energy trilemma: energy security, energy equity, and environmental sustainability as a priori codes. Recurring findings that did not fit neatly into a single primary code were grouped into sub-themes, such as CPO price volatility, ship engine readiness, land-use conflicts, or emission risks associated with land-use change, and subsequently linked to the most relevant trilemma pillar. Third, all findings were integrated through narrative synthesis to construct relationships across sources, identify consistencies and contradictions, and map policy trade-offs associated with the adoption of palm oil-based biodiesel in the shipping sector (Snyder 2019).

Results and discussion

This section presents two sets of document-based findings, i.e., regulatory mapping and literature mapping. The regulatory mapping aims to examine the direction of Indonesia’s maritime decarbonization policies and how they respond to the requirements of MARPOL Annex VI. In parallel, the literature mapping seeks to elucidate ship-generated marine pollution and the consequences of prioritizing palm oil-based biodiesel through the lens of the energy trilemma. The presentation of these findings adopts a narrative synthesis approach, integrating evidence from multiple sources, including regulatory frameworks, academic studies, and reports produced by relevant institutions.

The document set is organized into two broad categories: international and national regulations, and academic and institutional publications. The regulatory corpus includes four key policies from the IMO and the Indonesian government. First, the IMO adopted MARPOL 73/78 Annex VI (2005), which addresses air pollution concerns by setting emission-related requirements and promoting cleaner fuel use to protect human health and the environment (EPA.gov, n.d.). Indonesia subsequently issued Presidential Regulation No. 29/2012, formalizing the government’s commitment to implement Annexes III, IV, V, and VI as part of its broader efforts to prevent ship-generated pollution in both marine and atmospheric environments. This commitment was followed by Ministry of Transportation Regulation No. 58/2013, which emphasizes reducing shipping-related emissions in waterways and ports while encouraging the adoption of cleaner maritime technologies, including exhaust gas cleaning systems and low-sulfur fuels. Finally, the Ministry of Energy and Mineral Resources Regulation No. 12/2015 reinforces the national commitment to reducing sulfur levels while advancing biodiesel supply by increasing palm oil-based biodiesel production.



The second category includes academic studies and institutional reports that address marine pollution risks, energy policy trade-offs, and the environmental and social implications of palm oil-based biodiesel. Bayazit and Kaptan (2023) argue that ships are major contributors to both water and air pollution, with adverse effects on marine ecosystems. Building on this concern, the study assesses the risk of marine environmental pollution in water and air from routine ship operations by applying a hybrid bow tie-based Fuzzy Bayesian Network to estimate the probability that specific operational stages may trigger pollution events. Beyond operational risks, the publication also highlights the governance dilemmas associated with energy transitions. Gunningham (2013) emphasizes that the energy trilemma to balance affordability, security, and sustainability creates persistent policy tensions, particularly in developing countries that tend to prioritize lower-cost energy resources. Austin et al. (2019) further show, using spatial evidence, that approximately 23 percent of deforestation in Indonesia has been driven by the expansion of palm oil plantations between 2001 and 2016.

Other studies deepen the discussion by examining system-level energy performance and socioenvironmental conflict. Ackom et al. (2010) explain how energy balance accounting can be used to evaluate energy flows across industrial systems. In this context, energy efficiency is frequently used to compare biofuels with fossil fuels, with palm oil often described as having relatively lower energy efficiency than other biofuel pathways. Raharja et al. (2020) document land conflicts among local communities, palm oil companies, and local governments, including challenges related to unregistered smallholders and plantations located within protected forest areas. Tocock (2023) conceptualizes the energy trilemma as the intersection of reliability, affordability, and renewable energy, illustrating how trade-offs become more visible under real-world policy constraints. Similarly, palm oil remains the dominant biodiesel feedstock despite multiple associated risks, underscoring the importance of robust regulatory frameworks and stringent policy measures to safeguard environmental stability (Pranyoto 2024).

Institutional reports reinforce these academic insights by highlighting policy implementation challenges and downstream consequences. A policy brief by the Center for Indonesian Policy Studies (CIPS) notes that the mandatory B30 biodiesel policy has intensified palm oil demand and land-use pressures, contributing to deforestation risks, while also exposing biofuel affordability to volatility in global CPO prices (Amir et al. 2022). Reports from the Institute for Essential Services Reform (IESR) further emphasize that land conflicts frequently stem from disputed land claims and weak compensation mechanisms and that the loss of forest functions disrupts traditional livelihood systems by limiting communities' access to subsistence resources, thereby increasing socioeconomic vulnerability.

Palm oil-based biodiesel in the framework of the energy trilemma

Internationally, the IMO's decarbonization agenda is primarily articulated through fuel-neutral performance standards and emerging market-based measures. Indonesia's domestic approach, however, tends to operationalize decarbonization and control emissions through fuel substitution, most notably palm oil-based biodiesel in the transport sector, including maritime activities. Viewed through the energy trilemma framework, this divergence suggests that Indonesia's pathway pursues affordability and energy security alongside decarbonization objectives, thereby sharpening the potential trade-offs with environmental sustainability (Gunningham 2013; Tocock 2023).

To facilitate reductions in GHG emissions from ships, the IMO has developed a set of regulatory instruments encompassing both technical and economic components, ranging from goal-based standards aimed at lowering fuel emission intensity to potential options for maritime emission pricing mechanisms (IMO 2023). As these regulations are binding for member states, including Indonesia, which has been a member since 1961, IMO policies generate compliance pressures that are subsequently translated into domestic policy instruments and operational practices at ports and within shipping fleets (IMO 2012).

In Indonesia, the government must understand that palm oil-based biodiesel should not be understood merely as a technical solution to reduce emissions in the transport sector. Rather, it constitutes an energy policy with cross-





sectoral implications, including impacts on water and soil quality, deforestation, and food security, which result in a range of policy trade-offs (Purnama et al. 2025). The following section presents a thematic synthesis to address the research question in its relation to the three concepts of the energy trilemma.

Energy security

Policy choices tend to favor the use of palm oil-based biodiesel as a transitional instrument, as it is perceived to be domestically available and readily integrated into the national energy supply chain (Hidayatno et al. 2025). However, when examined through the energy trilemma framework, the adoption of palm oil-based biodiesel for shipping cannot be understood as a standalone or inherently sustainable environmental policy. Instead, this policy choice intersects with the imperative to maintain energy supply, thereby engaging directly with the energy security dimension.

The energy security framework provides a critical lens for assessing decarbonization policies that rely on fuel substitution through palm oil-based biodiesel and low-sulfur fuels. In particular, it enables an evaluation of the extent to which the government can ensure the stability and continuity of CPO availability for shipping and the supply of low-sulfur fuels. Elkind and Pascual (2009) argue that energy security must extend beyond traditional supply concerns to encompass environmental sustainability. Accordingly, the concept of energy security should incorporate four interrelated elements: availability, reliability, affordability, and sustainability.

In terms of availability, Indonesia is the world's biggest palm oil producers (UNDP n.d). Yet this comparative advantage should not lead the government to assume that domestic palm oil supply is inherently secure. Policymakers should not overlook persistent domestic challenges in the palm oil sector. Indonesia has experienced CPO shortages driven by multiple factors especially in early 2022 (Meuthia and Rahmahdian 2023). This challenge led to difficulties in getting bulk palm oil which previously easily buy in traditional markets suddenly disappear. The same problem also found in mini markets or other stores including to get branded palm oil package. This experience highlights the potential risks of increasing dependence on palm oil as an energy source. Substituting conventional fuels with palm oil-based biodiesel introduces new vulnerabilities because palm oil is a global commodity that is highly sensitive to international market dynamics (Amir et al. 2022; Gapki 2025). Price volatility in palm oil constitutes a tangible energy security risk. Domestic CPO prices are influenced by international prices, which can render biodiesel costs unstable over the medium term (Amir et al. 2022). This becomes particularly problematic if palm oil-based biofuels are positioned as a core alternative fuel for the maritime sector.

A further challenge is that the government must recognize the risk of insufficient palm oil supply, which can affect blending mandates such as B20 and B30. Based on the CIPS report authored by Amir et al. (2022), Indonesia continues to prioritize exports, with approximately 65 percent of national production going to exports, leaving around 35 percent of output for domestic use. When a larger share of CPO is allocated to the B30 mandate, it can contribute to shortages of cooking oil for household consumption (IESR 2021; Amir et al. 2022).

These vulnerabilities form an important pattern of trade-offs central to this study's research question. Efforts to reduce emissions through palm oil-based biodiesel may strengthen short-term environmental compliance yet simultaneously create a complex triangle for the maritime sector, i.e., how to meet emission standards, maintain supply continuity, and contain cost escalation. This illustrates that the energy security pillar does not stand alone; rather, it provides an entry point for understanding how transition costs and infrastructure readiness (energy equity), as well as the upstream and downstream impacts of palm oil (environmental sustainability), increasingly shape the success or failure of biodiesel-based strategies to reduce marine air pollution.

Energy equity

Within the energy trilemma framework, energy equity extends beyond the notion of cheap energy for all to address who bears the costs of transition and whether a policy change generates uneven social and economic impacts.





Literature drawing from the WEC framework commonly frames equity in terms of the affordability and accessibility of energy services, while also incorporating broader dimensions, such as health impacts, safety concerns, and the social consequences of energy choices.

The most significant equity-related barriers relate to infrastructure readiness, technological capacity, and cost distribution. At the technical level, ships require newer-generation engines to comply with emission standards and fuel compatibility requirements, yet such investments are costly. Moreover, many vessels operating in Indonesia are second-hand ships imported from Japan and South Korea that are not compatible with palm oil-based biofuels. Consequently, adopting palm oil-based biodiesel in shipping is not simply a matter of biodiesel availability; it also depends on the capacity of shipping operators, particularly small and medium-sized ones, to finance repowering, component replacement, and operational downtime (IESR 2021). At this point, equity trade-offs become evident: the faster standardization and adoption are enforced, the greater the risk that transition costs will be concentrated among financially vulnerable actors, with downstream implications on freight tariffs and regional connectivity.

This dynamic is compounded by the fact that private shipowners are expected to bear higher costs to make their fleets more environmentally compliant. Shipowners face difficult choices: retrofitting existing engines, replacing engines, or acquiring vessels equipped with newer engines that meet environmental standards (Lloyd's Register 2024). For maritime actors, equity considerations also entail operational risks and uncertainties associated with the use of palm oil-based biodiesel. According to a review by Lloyd's Register (2024), biofuel use in shipping still faces several challenges. First, a single biofuel type cannot serve as a universal benchmark for all vessel categories, and performance outcomes are unlikely to be uniform given the diversity of ship types and operational functions. Therefore, vessel performance and fuel compatibility must be evaluated prior to sea trials for new vessels. Another practical consideration is that biodiesel typically delivers approximately 10 percent lower energy content, which may reduce vessel productivity and, in some cases, require higher fuel consumption during voyages.

Environmental sustainability

Within the energy trilemma framework, environmental sustainability refers to strategies aimed at shifting away from fossil fuels and requires a holistic understanding of environmental impacts (WEC 2024). The concept of environmental sustainability is driven by the efforts to mitigate climate change, reduce GHG emissions, and minimize ecological degradation (Giwah et al. 2024). Achieving GHG emissions reduction requires not only the adoption of clean energy but also improvements in energy efficiency and effective management of renewable sources.

Within the environmental sustainability pillar, the adoption of palm oil-based biodiesel in the shipping sector presents a clear trade-off: while tailpipe emissions from ship exhausts may decline, the environmental footprint across the life cycle may undermine claims of biodiesel as a “clean fuel.” The literature reviewed in this study indicates that palm oil production in Indonesia has been widely criticized for its social and environmental sustainability impacts (IESR 2021). The most frequently cited issues include deforestation and land-use change, along with associated social consequences, such as land tenure conflicts, inequitable contractual arrangements, and labor conditions.

A study by Austin et al. (2019) demonstrates that palm oil expansion has been a significant driver of deforestation. Study by Cisneros et al. (2021) found explained that deforestation in Indonesia accelerated 13% since 2000 that also marked the beginning of palm oil rise in Indonesia. This finding is often used to explain how rising demand for palm oil can intensify pressures for land conversion. A direct implication of the adoption of palm oil-based biodiesel in shipping is that the greater the reliance on such biodiesel as a compliance instrument for emission targets, the higher the risk that maritime decarbonization policies may inadvertently accelerate land conversion and erode forest ecological functions. This risk is particularly present in places where plantation governance and protection of high conservation value areas remain weak (IESR 2021).





Sustainability critiques become more pronounced when palm oil-based biofuels are assessed through a life-cycle emission and land-use change perspective. The literature emphasizes that claims that biofuels reduce emissions become fragile once emissions from land-use change are included in the overall calculation. In other words, palm oil-based biodiesel policies for the shipping sector risk producing a fundamental trade-off: while marine air pollution may be reduced in the short term, the overall ecological footprint may increase if feedstock expansion drives deforestation, land conflicts, and high levels of indirect emissions (Austin et al. 2019; IESR 2021).

These critiques also challenge studies that overlook the environmental externalities of palm oil-based biodiesel. Although biodiesel is often promoted as a renewable substitute for fossil fuels, its climate and ecological benefits depend on upstream land-use conditions. In producer countries where oil palm expansion occurs on peatlands, associated land conversion can generate substantial emissions and heighten the risk of severe ecosystem degradation.

Conclusions

This study reaffirms that the adoption of palm oil-based biodiesel to reduce marine air pollution in Indonesia should not be interpreted merely as a technical solution to comply with global emission standards. Rather, it constitutes an energy policy choice that generates a series of cross-sectoral trade-offs. The three pillars of the energy trilemma shape distinct yet mutually reinforcing challenges. The energy security pillar highlights issues of supply resilience and price volatility; energy equity draws attention to the distribution of transition costs and fleet readiness; and environmental sustainability underscores impacts from upstream to downstream in the palm oil supply chain and the implications of life-cycle emissions accounting. Accordingly, pressures to comply with MARPOL Annex VI and shifting global emission standards may push domestic policy to move rapidly, yet the consequences of such acceleration cannot be fully explained without an energy trilemma lens.

From the energy security perspective, substituting conventional fuels with palm oil-based biodiesel introduces new vulnerabilities because palm oil is a globally traded commodity influenced by international market dynamics. Dependence on CPO prices and production allocation policies increases the risk of energy cost volatility for the maritime sector, particularly when domestic demand must compete with export orientation and biodiesel blending targets. From the energy equity perspective, fuel transition in the shipping sector requires technological and infrastructural readiness that is far from cost-neutral. These impacts extend beyond the shipping industry, potentially affecting freight tariffs, regional connectivity, and broader logistics costs. Meanwhile, within the environmental sustainability pillar, claims that biodiesel is a clean fuel become less convincing once supply chain dimensions are incorporated. Risks related to deforestation, land-use change, social conflicts, and indirect emissions suggest that reductions in ship tailpipe emissions may be paid for by increased upstream ecological footprints, potentially compromising long-term climate objectives.

This study has a key limitation: as an integrative review, it depends on the availability and accessibility of relevant literature and policy documents, which means that certain aspects of on-the-ground implementation could not be empirically tested. Future research could include estimating fleet transition costs by vessel type and route, mapping fuel demand for domestic shipping, and conducting life-cycle assessment analyses tailored to Indonesia's maritime context. Strengthening such empirical evidence would enable more precise policy design to balance energy security, energy equity, and environmental sustainability in efforts to reduce marine air pollution.





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Why Jakarta's Urban Food System Fails to Adapt: Insights from a Participatory System Analysis

Aulia Izzah Azmi^{1,*}

¹ Department of Sociology, Universitas Indonesia, Depok, Indonesia

* Corresponding author: auliaiz29@gmail.com

Abstract

Urban food systems in rapidly urbanizing cities are increasingly challenged by climate change, socioeconomic inequality, and fragmented governance. In Jakarta, Indonesia, despite the expansion of urban agriculture regulations and local initiatives, the urban food system continues to exhibit limited adaptive capacity and persistent exclusion. This study investigates why Jakarta's urban food system fails to adapt by examining the systemic interactions shaping food production, access, and governance under climate stress. Using a participatory research approach, the study engages farmers and local government actors as cocreators of knowledge, drawing on lived experience and collective sense-making. Soft systems methodology (SSM) is applied to address system complexity through qualitative systems modeling, employing tools such as rich pictures, root definitions, and customers, actors, transformation process, worldview, owners, and environmental constraints (CATWOE) analysis, which are further synthesized into causal loop diagrams to represent system feedback and interdependencies. The findings reveal that maladaptation is driven not by the absence of initiatives, but by the interaction of economic exclusion, technocratic governance, class-based participation, and spatial restructuring. Green policies often function as instruments of green branding, reinforcing climate gentrification and marginalizing long-term farming communities. The study highlights the need for dialogic, process-oriented system change to support more just, climate-resilient urban food systems.

Keywords: urban food systems; climate adaptation; participatory systems analysis; climate gentrification

Introduction

Rapid urbanization in Jakarta, Indonesia, has intensified pressures on urban food systems, raising concerns about food security, spatial inequality, and environmental sustainability. As one of the world's largest metropolitan areas, Jakarta is home to over 10.5 million residents, with more than 30 million in the Greater Jakarta (Jabodetabek, the acronym for Jakarta, Bogor, Depok, Tangerang, and Bekasi) region (BPS 2023), creating high demand for stable and equitable food distribution. However, access remains uneven, particularly for low-income populations, with urban poor households spending 50–60 percent of their income on food, making them vulnerable to price volatility and supply disruptions (World Bank 2020; BPS 2022).

The coexistence of formal supply chains and extensive informal food networks characterizes the system. Informal actors, including street vendors, traditional markets, and small-scale distributors, dominate food provisioning, distributing over 70 percent of fresh food (Reardon et al. 2015). These networks provide affordable, accessible options, particularly in dense, low-income areas, and often serve as the primary source of daily food. Despite their central role, informal actors remain marginalized in urban planning and policy frameworks (McCarthy et al. 2012).

In recent years, urban food governance has been increasingly linked to sustainability agendas through the promotion of urban farming. In South Jakarta, the 2023 Agricultural Census recorded 2,568 millennial farmers, many operating as “agripreneurs” using hydroponic and rooftop systems (BPS 2023) (Figure 1). Nationally, approximately 27,000 young farmers have emerged, earning IDR15–20 million (US\$836–1,111) per month using digital technologies, reflecting a shift toward high-tech, market-oriented agriculture.



Figure 1. South Jakarta's urban farming sites



Source: Google Maps.

At the same time, key actors are increasingly institutional. Regionally owned enterprises such as Food Station Tjipinang Jaya and Pasar Jaya manage food supply and price stabilization, while commercial and educational institutions integrate agriculture into urban infrastructure. Initiatives such as rooftop farming in commercial buildings and training hubs like state vocational high school SMKN 63 Jakarta illustrate the expanding ecosystem, supported by public housing programs and local government agencies.

Despite these developments, current policies—particularly in South Jakarta—reflect a structural bias toward high-tech and capital-intensive models. Regulations such as Governor Regulation No. 31/2022, Governor Regulation No. 54/2022, and Governor Instruction No. 14/2018 promote urban agriculture within a “smart city” framework but prioritize technologically advanced systems often inaccessible to conventional small farmers. While enabling expansion in commercial settings, these policies offer limited protection for traditional farmers facing rapid land conversion.

This results in a “high-tech bias,” where policy incentives favor actors with capital and technical capacity, widening knowledge and digital gaps. Conventional practitioners, who often come from low-income or migrant populations, remain marginalized due to insecure land tenure, limited access to technology, and weak institutional support. Consequently, the system risks becoming more commercialized and exclusionary, favoring agripreneurs over traditional actors who have historically supported local food security.

Existing studies have largely focused on policy or specific interventions, with limited attention to systemic relationships and feedback mechanisms among diverse actors (Ericksen 2008; Battersby and Watson 2019). This creates a gap in understanding how emerging actors interact with informal networks within a complex system.

To address this, this study applies the soft systems methodology (SSM) to analyze Jakarta’s urban farming system. By structuring stakeholder perspectives, it develops a qualitative model using a causal loop diagram to identify feedback mechanisms and leverage points.



The study asks: how does urban farming function within Jakarta's urban food system, and to what extent does it address food access and inequality? The research contributes to a more holistic understanding of urban food interventions and supports more inclusive policy design.

Methodology

This study adopts a participatory research approach to examine the systemic conditions shaping Jakarta's urban food system and its limited adaptive capacity. It positions participants as cocreators of knowledge, recognizing the importance of lived experience and situated practices in understanding complex systems (Cornish et al. 2023; McAllister et al. 2023). Through dialogue, reflection, and iterative sense-making, the approach captures social, institutional, and spatial realities while fostering collaboration (Smith 2023; Ohly et al. 2023). A total of 11 participants, comprising 10 urban farmers and one facilitator from the Agency for Food Security, Maritime, and Agriculture (Dinas KPKP, from its initials in Bahasa Indonesia), were purposively selected. Conducted in South Jakarta between July and August 2024, this study collected data through participatory discussions and system-mapping exercises.

To operationalize this participatory orientation, the research employs SSM as its primary analytical framework. SSM addresses complex, ill-structured, human-centered problems by examining how systems are socially constructed and contested among actors with differing values and power positions, making it well-suited for analyzing fragmented and unequal urban food systems (Checkland and Poulter 2006). Within the SSM process, analytical tools are used to structure inquiry, facilitate shared understanding among participants, and identify competing system logics and the interests that are prioritized or marginalized (Checkland 2000). Rich pictures visually map relationships, conflicts, and flows across actors, institutions, and spatial contexts, allowing implicit assumptions and power dynamics to surface. At the same time, root definitions and customers, actors, transformation process, worldview, owners, and environmental constraints (CATWOE) analysis clarify how stakeholders define system purposes, boundaries, and desired transformations. Building on these qualitative representations, the study integrates collaborative system modeling by translating insights from participatory discussions into causal relationships that are synthesized into a causal loop diagram. These diagrams are used to identify reinforcing and balancing feedback loops shaping system behavior over time, supporting the identification of leverage points to address cycles of exclusion, weak feedback, and maladaptive governance while remaining grounded in locally articulated realities (Checkland 2000).

Results and discussion: Intervention, social, and power analysis of Jakarta's urban food system

This study conceptualizes Jakarta's urban food system as a socioecological system shaped by ecological, economic, spatial, sociocultural, and governance dynamics. Adaptation failures arise not from the absence of policies but from exclusionary governance, class-based participation, and spatial restructuring, aligning with critiques that sustainability initiatives reproduce inequality when power relations remain unaddressed (Béné et al. 2022; Clapp et al. 2022).

Intervention analysis: From technical fixes to structural constraints

From the ecological perspective, participants identified farmland loss and declining ecological functions as key challenges, driven by urban planning that prioritizes aesthetics, commercial development, and branding over regeneration (Table 1). Green spaces (RTH, from its initials in Bahasa Indonesia) are often decorative, limiting ecological impact, consistent with global critiques (Anguelovski et al. 2022). This intersects with economic exclusion, as middle-class actors dominate urban farming, while small-scale farmers face barriers to land and markets. Programs like Jakpreneur reinforce inequalities shaped by class and social capital (Tornaghi and Dehaene 2022; Horst et al. 2023).





Table 1. Intervention analysis

Theme	Problem	Causes	Existing intervention	Recommended intervention
Environmental/ecological	Loss of ecological function and farmland	Urban expansion prioritizes aesthetics and development	Governor Instruction 14/2018; RTH targets decorative, not ecological impacts	Enforce Spatial Development Plan (RTRW, from its initials in Bahasa Indonesia); community-based green spaces; integrate climate resilience indicators
Economic	Middle-class dominance; small farmers marginalized	Limited access to capital, markets, tech	Jakpreneur (unequal access)	Revolving fund; food cooperatives; inclusive training on green enterprises
Spatial/urban	Green gentrification	Green infrastructure used for branding and investment	RTH zoning is weak; hydroponic pilots are aesthetic-focused	Impact assessments; protect community gardens; inclusive urban farming corridors
Social and cultural	Loss of local knowledge and cultural farming practices	Programs emphasize tech over heritage	Small-scale cultural initiatives exist	Urban agri learning centers; cultural indicators; support local food heritage
Political/governance	Top-down, technocratic policies; exclusion of communities	No participatory mechanisms; low political will	Bureaucratic pilot farms; no farmer consultation body	Participatory regulation; urban farmers forum; strengthen participatory governance
Climate/sustainability	Climate policy disconnected from food systems	Urban farming not in climate plans	Regional Action Plan for Climate Change Adaptation (RAD-API, from its initials in Bahasa Indonesia) excludes food systems	Integrate farming into climate plans; incentives for mitigation practices; climate justice framework

Source: Author's analysis.





Meanwhile, spatial dynamics complicate adaptation as green projects, including urban farming and park revitalization, often drive gentrification and displacement rather than community well-being. Such initiatives frequently serve city-branding and investment goals, rather than food security, aligning with the green gentrification literature (Anguelovski et al. 2022; Shi et al. 2023). To address this, participants proposed protecting community access.

Meanwhile, the sociocultural dimension reveals erosion of local knowledge as urban agriculture programs prioritize technological solutions over traditional and intergenerational practices. Older farmers experience alienation within technocratic frameworks, reflecting critiques of sustainability governance privileging innovation over lived knowledge (Turnhout et al. 2023). Participants proposed integrated learning centers and support for cultural food heritage to counter this. Governance issues persist as Jakarta's urban food system remains largely top-down despite participatory rhetoric. Decision-making is dominated by bureaucratic institutions, with participation limited to implementation rather than codesign, or what is called symbolic participation (Norström et al. 2022). Participants recommended institutionalizing participatory forums, embedding consultation in policy, and allocating budgets for community-managed green infrastructure.

Finally, climate emerged as a cross-cutting yet weakly integrated dimension. Climate adaptation policies in Jakarta rarely engage meaningfully with food systems, focusing instead on infrastructure and emission reduction. This disconnect reflects broader trends in climate governance that depoliticize adaptation and overlook distributive justice (Eriksen et al. 2022; Sovacool et al. 2022). Participants suggested explicitly integrating urban farming into climate action plans and adopting a climate justice framework that recognizes uneven exposure to climate risks and unequal access to adaptive resources.

Social analysis: Fragmented responsibilities and limited coordination

The social analysis maps the diverse stakeholders involved in Jakarta's urban food system and reveals a pattern of fragmented responsibilities with limited coordination (Table 2). At the national level, the Ministry of National Development Planning (Bappenas, its acronym in Bahasa Indonesia) holds a strategic mandate to ensure cross-sectoral alignment among development, climate, and food policies. However, community-based urban farming remains weakly embedded within national frameworks. The Ministry of Agriculture provides guidance on production standards and farmer capacity but has not sufficiently prioritized agroecological or community-led approaches. Similarly, the Ministry of Environment and Forestry contributes through circular economy and climate programs, yet these programs remain poorly connected to food systems, particularly at the neighborhood scale.

Table 2. Social Analysis

Stakeholder	Role	Value to the system	Norm/ mandate	Recommendations (responsibility)
Bappenas	National cross-sector coordination and budgeting	Mainstreaming agroecology in national development	National development plan and alignment of SDGs	Include community urban farming in climate and food strategies (Bappenas)
Ministry of Agriculture (MoA)	Guidance on urban agriculture and production standards	Improved food security and farmer capacity	National food security and agri standards	Incentivize agroecology and community farmers (MoA)
Ministry of Environment and Forestry (MoEF/KLHK)	National circular economy and climate adaptation	Reduced waste and healthy ecosystems	Environmental regulation and climate policy	Embed organic waste composting in Nationally Determined Contributions (NDCs) and urban climate plans (MoEF)



Food Security and Agriculture Agency (Dinas KPKP)	Technical assistance and farm infrastructure	Urban food resilience	Urban agri policy	Scale support for new farmers and equipment (KPKP)
Regional Environmental Agency (DLH)	Waste collection, composting, circularity	Reduced landfill loads	Waste and climate adaptation policy	Secure organic waste flow for compost production (DLH)
Parks and Urban Forestry Office	Provision of public green land	Legal, inclusive land access	Green space planning	Formal permits for community gardens (Parks Office)
Regional Development Planning Agency (Bappeda)	Local development integration	Cross-agency alignment	Targets in Medium-term Regional Development Plan (RPJMD)	Include community farms in city development indicators (Bappeda)
Farmer communities	Production and compost utilization	Soil health and food access	Community stewardship norms	Strengthen cooperatives & collective marketing (farmer groups)
NGOs and supporting organizations	Community organizing and training	Inclusion, participation, rights-based support	Social development and CSS mandates	Build farmer advocacy and negotiation capacity (NGO partners)
Business actors	Compost processing technology and market	Innovation and supply chain	Business regulations	Partner with farmers for scalable compost loops (SMEs)

Source: Author's analysis.

At the provincial and municipal levels, agencies such as Dinas KPKP and the Regional Environmental Agency (DLH, from its initials in Bahasa Indonesia) play central operational roles. However, coordination between food production and waste management remains fragmented, limiting the potential for circular systems such as compost-based urban farming. The Parks and Forestry Office controls access to public green land, yet unclear permitting processes restrict community use. Beyond the government, cooperatives, planning offices, and subdistrict administrations influence land access and facilitation, while farmer groups, women's collectives, and youth farmers hold practical knowledge but limited institutional power. Non-governmental organizations (NGOs) and small and medium enterprises (SMEs) contribute training and innovation but remain peripheral in formal planning processes, reflecting patterns observed in other Southeast Asian cities (Padawangi and Douglass 2022; Rachmawati et al. 2023).

Power analysis: Structural, relational, and symbolic dynamics

The power analysis synthesizes these findings by examining how structural, relational, and symbolic power shape Jakarta's urban food systems. Structural power is exercised through bureaucratic control over policy, budgets, and land-use regulation. Centralized decision-making and weak public consultation limit community participation. To address these issues, participants proposed institutionalizing participatory governance through a Jakarta Urban Farming Forum, embedding consultation mandates in green space policies, and allocating budgets for community-managed green infrastructure.



Relational power operates through social networks and representation. According to the 2023 Census of Agriculture, Jakarta has over 13,019 individual agricultural units. Significant income disparities exist between traditional farmers earning approximately IDR 105,385 daily and tech-integrated agripreneurs earning IDR 15–20 million monthly (BPS 2023). To address these disparities and the dominance of middle-class actors, recommendations include implementing 30–50 percent inclusion quotas for marginalized farmers and mandating community benefits in urban farming partnerships with companies under corporate social responsibility programs (BPS 2023).

Symbolic power shapes whose knowledge and identities are valued. “Green city” branding privileges aesthetics and technocratic expertise, marginalizing local knowledge. Participants proposed reframing narratives toward equity and resilience, institutionalizing coproduction through participatory mapping and citizen science, and promoting heritage-based narratives that recognize farming as an ethic of care rather than a backward practice.

Root definition: Multi-level transformation of urban food governance

The root definition conceptualizes Jakarta’s urban food system across three interconnected levels: macro, meso, and micro, highlighting how governance fragmentation and power asymmetries shape outcomes. At the macro level, the system is formally owned by the Provincial Government of Jakarta, particularly agencies responsible for development planning, food security, and environmental management. The intended transformation at this level is to shift from fragmented, technology-biased greening initiatives toward an integrated urban food governance framework that explicitly prioritizes ecological resilience, social equity, and climate justice. This shift requires aligning spatial planning, climate adaptation, and food security policies, recognizing food systems as essential parts of urban infrastructure rather than peripheral social programs.

At the meso level, municipal and district authorities, such as food security and environmental agencies and subdistrict administrations, translate provincial policies into practice. This level functions as a critical interface where inclusion can either be enabled or undermined. Transformation here involves strengthening cross-agency coordination, facilitating access to land and resources for community farming, and embedding participatory mechanisms into program implementation. Without such reforms, policy intent risks being diluted through bureaucratic silos and procedural barriers.

At the micro level, the system is enacted through the everyday practices of farmers, women’s farming groups, youth initiatives, NGOs, and households. Transformation at this scale centers on producing knowledge together, sustaining diverse farming practices, and strengthening collective economic arrangements such as cooperatives. The root definition thus reframes urban food resilience as an emergent property of social relations and lived experience, rather than a technical output. Across all levels, the purpose of the system is not merely to increase food production but to foster an inclusive, resilient, and socially embedded urban food system responsive to community priorities and ecological limits.

CATWOE analysis: Actors, worldviews, and constraints

The CATWOE analysis clarifies dynamics within Jakarta’s urban food system by identifying stakeholders, transformations, and constraints. The primary customers are urban residents affected by food insecurity, land-use change, and climate vulnerability, particularly low-income households and farming communities, as CATWOE emphasizes those experiencing system outcomes (Checkland and Poulter 2006). This finding aligns with studies highlighting the disproportionate burden borne by vulnerable urban populations in food systems, while also reinforcing critiques that such groups remain underrepresented in policy processes (Battersby and Watson 2019).

Actors operate across multiple levels, from national ministries and international organizations to local governments, enterprises, and community actors. This multi-scalar configuration reflects existing literature on urban food governance as a fragmented system shaped by overlapping authorities and interests (Ericksen 2008). This study



further demonstrates how micro-level actors actively negotiate and sustain the system, extending beyond their passive representation in policy-focused analyses.

The transformation envisioned involves shifting from technocratic, market-oriented approaches toward socioecological and justice-oriented models. While this aligns with calls for more inclusive urban food governance (Sonnino 2016), the findings reveal persistent gaps between policy rhetoric and practice, particularly in recognizing community-based knowledge and securing land access.

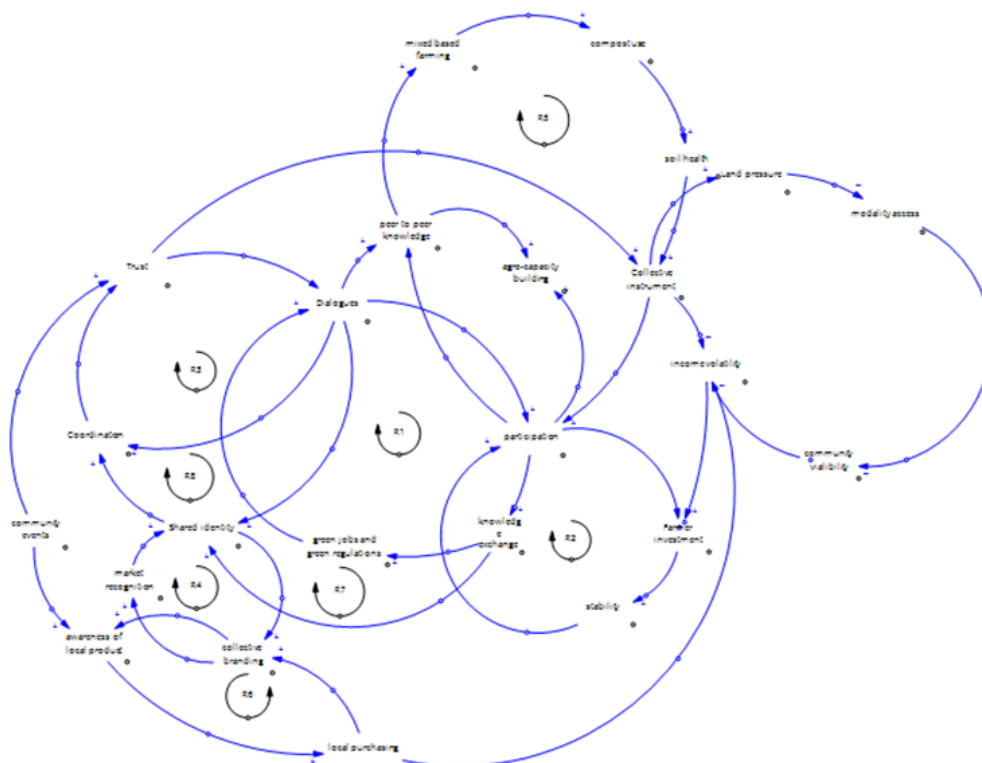
The system perspective frames urban food systems as socioecological practices sustaining livelihoods and resilience. Consistent with critical urban studies (McCarthy et al. 2012), the findings show uneven ownership, where formal authority contrasts with limited control among communities facing structural constraints and marginalizing development narratives.

Causal loop diagram: Reinforcing dynamics and leverage points

The causal loop diagram highlights two dominant reinforcing dynamics shaping Jakarta's urban food system. The first is a reinforcing loop of capital-intensive urban farming, where policy support for high-tech agriculture increases technological adoption and entry barriers, favoring well-resourced actors (Figure 2). This finding aligns with studies showing that urban agriculture often reproduces class-based inequalities, privileging actors with greater access to capital and institutional support (Tornaghi and Dehaene 2022; Horst et al. 2023).

A second reinforcing loop centers on land conversion and declining local food capacity. Ongoing urban development reduces agricultural land, weakening local production and increasing dependence on external supply chains. This reflects broader research demonstrating how urban expansion undermines food system resilience and ecological functions (Anquelo et al. 2022).

Figure 2. Causal loop diagram



Source: Author's analysis.



A weaker balancing dynamic emerges through informal and community-based practices that sustain food access and local knowledge, echoing findings on the resilience of informal food networks (Battersby and Watson 2019). Together, these loops indicate that inclusive governance, land access, and community-based farming are critical leverage points. However, persistent structural constraints continue to reinforce exclusionary dynamics.

Conclusion

This study examined why Jakarta's urban food system continues to demonstrate limited adaptive capacity despite the proliferation of green policies and urban farming initiatives. By applying a participatory systems approach grounded in SSM, the research moved beyond program-level evaluation to analyze the structural, relational, and symbolic dynamics shaping the system. The root definition clarified that fragmentation across macro, meso, and micro levels constrains coherent food governance, while the CATWOE analysis exposed how uneven authority, marginalized customers, and competing worldviews reproduce exclusion. The causal loop diagram further demonstrated that participation, knowledge coproduction, soil health, and community investment can reinforce resilience, yet these positive dynamics remain vulnerable to land insecurity, market volatility, and technocratic planning biases.

The findings of this study indicate that Jakarta's adaptation challenge is not primarily technical but political. Urban food initiatives are embedded within broader spatial restructuring processes, where the centralization of governance, class-based participation, and green branding limit transformative potential. Without institutionalized participation, secure land access, and cross-sector coordination, urban agriculture risks functioning as symbolic greening rather than structural food system reform.

Therefore, the study argues for a shift from project-based interventions toward justice-oriented urban food governance. Embedding participatory mechanisms, protecting community farming spaces, and integrating food systems into climate adaptation planning are critical leverage points. More broadly, the research demonstrates the value of combining participatory inquiry with systems thinking to reveal how power and feedback dynamics shape urban sustainability transitions. Such an approach is essential for fostering more inclusive and climate-resilient food systems in Jakarta and comparable rapidly urbanizing cities.

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Forecasting Rice Demand in Bandung, Indonesia, Using ARIMA: Implications for the Free Nutritious Meal Program

Mhd Wahyu Riandani^{1,*}, Agus Purnomo², Maniah³

¹ Magister in Logistics Management, University of Logistic and Business International, Bandung, Indonesia

² Magister in Logistics Management, University of Logistic and Business International, Bandung, Indonesia

³ Magister in Logistics Management, University of Logistics and Business International, Bandung, Indonesia

*Corresponding author: wahyuriandani05@gmail.com

Abstract

This study develops a forecasting model using autoregressive integrated moving average (ARIMA) to estimate rice demand in Bandung, Indonesia, by integrating natural market demand with the additional demand generated by the government's Free Nutritious Meal Program (MBG, from its initials in Bahasa Indonesia). Using time-series data from 2020 to 2024, rice demand is reconstructed based on per-capita carbohydrate requirements and projected for 2025. The results indicate that monthly rice demand is expected to range between 23,532.80 tonnes and 24,903.37 tonnes, reflecting a stable pattern with a significant upward shift compared to the baseline of 16,244.44 tonnes in December 2024. The model achieves a mean absolute percentage error of 6.09 percent, demonstrating a satisfactory predictive accuracy. The findings show that MBG contributes approximately 33.3 percent to the total demand, functioning as a structural and persistent demand driver rather than a temporary shock. This study contributes by introducing a hybrid demand framework that integrates market-based consumption with policy-driven demand components. The results highlight the importance of incorporating institutional demand into forecasting models to support more accurate urban food logistics planning and to ensure effective policy implementation for food security.

Keywords: rice; Free Nutritious Meal Program; ARIMA method

Introduction

Food security is a constitutionally guaranteed human right in Indonesia, guaranteed under the 1945 Constitution and Law No. 7/1996 on food. Food security is defined as the sustained availability of food for the state and individuals, meeting the criteria of quantity, access, quality, and affordability (Government of Indonesia 2012). Rice occupies a central position as the primary pillar of Indonesia's food security. Recent data records the national average rice consumption at 92.1 kilograms (kg) per capita per year in 2024 (Pusat Data dan Sistem Informasi Pertanian 2024). This absolute dominance renders rice a highly inelastic carbohydrate source, where substitution is negligible even amid price volatility. Consequently, rice supply management becomes a critical food security indicator: minor supply chain disruptions trigger not only spikes in national food inflation but also macronutrient insecurity via carbohydrate energy deficits. These deficits are directly correlated with stunting risks and faltering growth in vulnerable groups, including school-age children, whose stunting prevalence remains at 18.7 percent in 2024 (Ministry of Health of the Republic of Indonesia 2024).

Consequently, effective food logistics management requires demand forecasting that transcends conventional physical units of quintals or tonnes. The forecasting approach must therefore be converted into per-capita carbohydrate requirement units (grams/capita/day) as the fundamental basis for nutritional planning. This conversion is critical because carbohydrate energy is an absolute prerequisite for the absorption of proteins and other micronutrients. Without adequate carbohydrate availability, for example from rice, specific nutritional interventions (protein, vitamin, mineral supplementation) become biologically ineffective as the body burns protein for energy instead (i.e., protein-sparing failure) (Ratnayani et al. 2024). Without high-accuracy, carbohydrate-based forecasting, Indonesia's complex archipelagic distribution network becomes vulnerable to stock mismatches, in





which rice stocks may appear 'sufficient' in tonnage but fail to meet daily per capita energy requirements during sudden demand shocks. This could result in complete failure of stunting prevention efforts at the food-availability stage, before specific nutritional interventions can even be delivered to toddlers or school-aged children (Azis et al. 2026).

As a preventive response to the chronic nutrition crisis, the government launched the Free Nutritious Meal Program (MBG, from its initials in Bahasa Indonesia) targeting 25.7 million people (Badan Gizi Nasional 2025). MBG does not only target students from elementary to high school, but also preschool children, pregnant women, breastfeeding mothers, and boarding-school students, all of whom have high energy and protein requirements for growth, pregnancy, and lactation. At the time of the study, during the 2024 pilot implementation, MBG was still in a phased pilot stage and had not yet been implemented nationwide. The program was applied in selected cities and districts, with a national target to expand coverage to 82.9 million beneficiaries by 2025, requiring stronger oversight and policy adjustments (CIPS 2025; Satriawan and Nugroho 2025).

Conceptually, MBG has the potential to become a new structural demand driver or shock; it is not merely a supply-side nutritional intervention. The program, supplying 69 million meals annually (assuming 250 school days for 25.7 million students), requires direct rice supplies of approximately 381,800 tonnes/year, which can trigger expected inflation which may increase inflation as kitchen managers secure rice stocks several months in advance to avoid shortages (Damayanti 2025; Robi 2026).

Bandung City in West Java, Indonesia, was selected as the case study due to its large population of approximately 2.5 million people (BPS of Bandung City 2025) and its status as a dense urban center with high dependence on rice, which makes it representative for urban demand-planning analysis (Food Security and Agriculture Agency of Bandung City 2021). Local nutrition data indicate that Bandung bears a high burden of stunting and undernutrition among toddlers. According to August 2024 toddler weighing data, stunting among toddlers was seen in about 8,172 children, an increase from 6,142 children in 2023, and undernutrition (underweight) in several community health clinics, indicating a mismatch between energy intake and growth (Health Agency of Bandung City 2024). Beyond toddlers, nutrition issues also occur among school-aged children (pre-school, elementary, and junior and senior high school) in Bandung. A study on nutrition behavior among school-aged children shows unbalanced food intake and fruit and vegetable consumption below the recommended standards, which raises the risk of undernutrition, latent stunting, and cognitive and academic performance decline (Zafira and Farapti 2020).

From the perspective of supply chain and food logistics management, an increase in rice demand triggered by policy interventions such as the MBG program has the potential to exert substantial pressure on distribution, inventory, and procurement at the city level (Pujawan and Mahendrawati 2017; Setiadi et al. 2022). Without accurate demand forecasting, cities risk experiencing stockouts in certain areas while simultaneously facing overstocks in others, causing rice availability to shift from a pillar of food security to a source of demand and supply mismatch. Consequently, demand planning at the urban level should become a key mechanism of urban food security, especially in densely populated cities like Bandung (Mohammed et al. 2025).

Several prior studies have developed models using autoregressive integrated moving average (ARIMA) at national and district levels, including to forecast rice prices (Naya et al. 2024) and rice production or consumption (Bria 2025; Zamahzari and Puryantoro 2023). However, these studies generally portray rice demand or supply based on internal market factors, including price, production, and seasonal patterns, and neglect structural demand surges arising from intervention programs such as the MBG program. In contrast, existing MBG-related research tends to focus on nutritional and health impacts, menu quality evaluations, and socioeconomic aspects of beneficiaries, rather than on rice supply logistics or ARIMA-based rice demand modeling (Fathurilham and Maulana 2026).

No study has integrated natural rice demand with additional demand from MBG into an ARIMA-based demand-forecasting model at the city level, including for Bandung. Previous works also do not explicitly convert per-capita carbohydrate requirements, as a baseline unit for nutrition planning, into rice demand. In light of this gap,

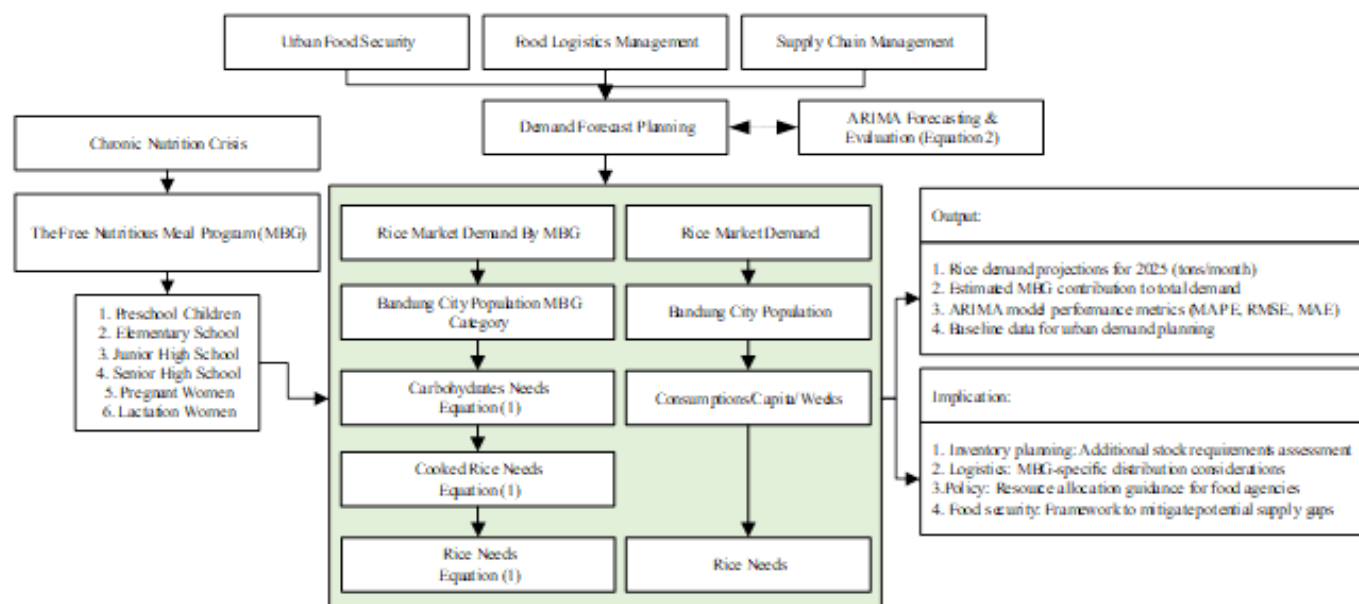


this study aims to develop an ARIMA-based forecasting model for the total rice demand in Bandung City combines natural market demand with the additional demand generated by the MBG Program as a **new** structural demand driver. The resulting model is expected to provide a more precise basis for urban demand planning, supporting inventory and distribution management of rice in the city so that rice supply patterns in Bandung can be planned more effectively, thereby contributing to the success of nutrition interventions and stunting prevention among both toddlers and school-aged children.

Methodology

This study employs a quantitative descriptive approach to describe and analyze rice demand patterns in Bandung before and after the introduction of the MBG program (Figure 1). This approach is appropriate because the research aims to measure, map, and forecast rice demand based on numerical historical data rather than to interpret qualitative social phenomena (Creswell and Guetterman 2021; Peren 2025).

Figure 1. Conceptual framework of the study



Source: Author.

The daily rice consumption is calculated by converting per-capita carbohydrate requirements drawn from the recommended dietary allowances in Indonesia (Minister of Health of the Republic of Indonesia 2019) into cooked-rice requirements, and then into raw rice using the relationship between carbohydrate content and water absorption. According to studies, 100 grams (g) of cooked rice contains 27.9–87.9 g of carbohydrates (Rozi et al. 2023; Nurwahidah et al. 2024), and the conversion ratio from cooked rice to raw rice is 1:2.5 (1 kg of cooked rice = 2.5 kg of raw rice) (Sajiman and Nurhamidi 2018).

This conversion is expressed as:

$$Q_{Rice} = \frac{C_{Carbohydrate} \times F_{Cooked\ Rice}}{C_{Cooked\ Rice} \times E_{Rice}} \dots \dots \dots (1)$$

Where:

Q_{Rice} = Period rice requirement

$C_{Carbohydrate}$ = Period carbohydrate requirement (g)

$C_{Cooked\ Rice}$ = Carbohydrate content in cooked rice

$F_{Cooked\ Rice}$ = Cooked rice conversion factor

E_{Rice} = Energy equivalence factor for rice

An ARIMA model is used to forecast 2025 rice demand based on the historical data from 2020 to 2024. The general form of an ARIMA (p,d,q) model is:

$$(1 - \sum_{i=1}^p \phi_i B^i)(1 - B)^d Y_t = (1 + \sum_{j=1}^q \theta_j B^j) \epsilon_t \dots \dots \dots (2)$$

Where:

Y_t = Time series of rice demand

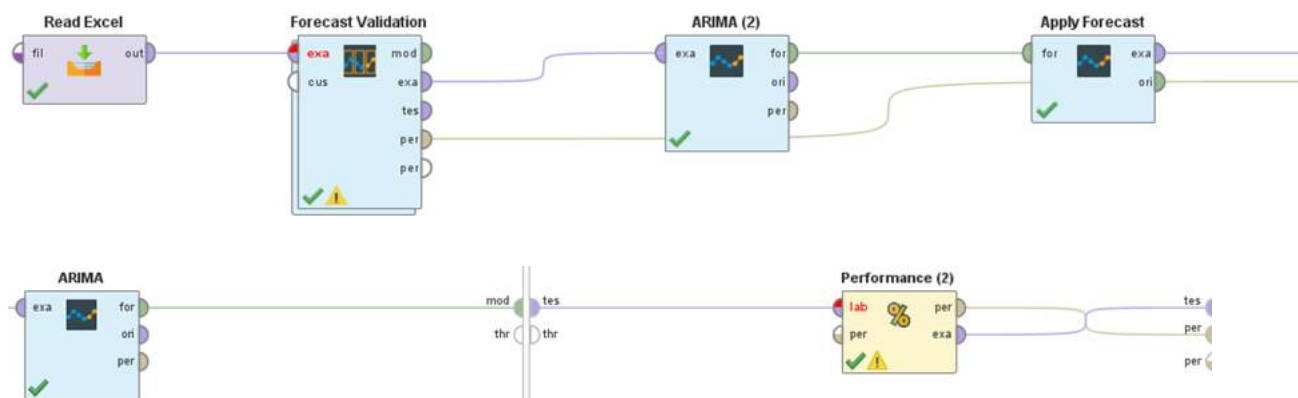
ϕ_i = Autoregressive coefficients

θ_j = Moving averages coefficients

ϵ_t = Random error

Rice consumption data in Indonesia are inherently time-dependent, trending, and seasonal, making ARIMA particularly suitable as it has been empirically validated with a low mean absolute percentage error (MAPE) of below 10 percent across numerous studies on Indonesia's rice demand (Lucassen et al. 2021; Othman et al. 2023; Rosadi et al. 2024). Models were implemented in Altair Studio with accuracy rigorously evaluated using MAPE, root mean square error (RMSE), and mean absolute error (MAE) to ensure results provide a robust, practical foundation for urban rice-demand planning in Bandung (Altair Engineering Inc 2026) (Figure 2).

Figure 2. ARIMA forecasting workflow in Altair Studio



Source: Author.



Results and discussion

The forecasting results indicate that the monthly rice demand in Bandung City for 2025 is projected to remain relatively stable, ranging from 23,532.80 tonnes to 24,903.37 tonnes (Table 1). Compared to the baseline value of 16,244.44 tonnes in December 2024, the model shows a clear upward shift in demand at the beginning of the forecast period, followed by a consistent pattern with limited monthly fluctuations. The highest demand is projected in December 2025, while the lowest occurs in February 2025.

Model validation yields a MAPE of 6.09 percent, with RMSE and absolute error values of 1044.706 (Table 2). These indicators confirm that the ARIMA model achieves satisfactory predictive accuracy and is capable of capturing the underlying demand pattern without significant deviation.

Table 1. Forecast results for rice

Period	Forecast result for rice (tonnes)
Baseline Dec. 2024	16244.44
Forecast Jan. 2025	24442.99
Forecast Feb. 2025	23532.80
Forecast March 2025	23988.84
Forecast April 2025	24444.84
Forecast May 2025	23989.92
Forecast June 2025	23990.39
Forecast July 2025	24901.69
Forecast Aug. 2025	23535.79
Forecast Sep. 2025	24447.02
Forecast Oct. 2025	24447.35
Forecast Nov. 2025	23536.79
Forecast Dec. 2025	24903.37

Arima indicator method:

Time series attribute = Kebutuhan Beras

Indices attribute = Period

Window size = 15; Step Size = 1 ;

Horizon size = 1

$p = 1; d = 0; q = 1$

Forecast horizon = 3



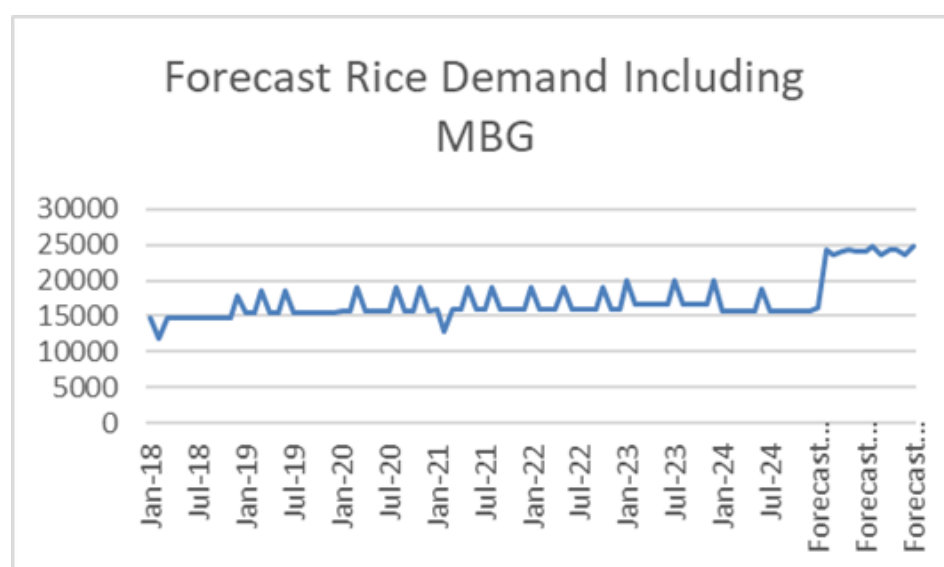
Table 2. Forecasting model validation

Validation	Value
MAPE	6.09%
RMSE	1044.706
Absolute error	1044.706

Source: Authors' analysis.

Historical consumption data from 2018 to 2024 show that rice demand in Bandung fluctuates between approximately 11,868 tonnes and 20,070 tonnes per month, reflecting moderate variability influenced by seasonal and behavioral factors (Figure 3). The comparison between historical and forecasted values suggests that the increase observed in 2025 represents a systematic shift in demand level rather than random fluctuation.

Figure 3. Forecast rice demand including additional demand from the MBG Program



Source: Authors' analysis.

The observed increase in projected rice demand reflects the integration of additional consumption generated by the MBG Program. Unlike conventional demand drivers such as population growth or price changes, MBG introduces a policy-induced and recurring institutional demand component. This demand does not substitute household consumption but adds a new layer to the overall market demand structure.

Based on the estimated demand composition, baseline rice demand in Bandung is approximately 16,000 tonnes per month, while MBG contributes an additional demand of around 8,000 tonnes. This means MBG accounts for approximately 33.3 percent of the total demand, representing a substantial yet manageable increase. The results suggest that the rice market in Bandung is transitioning toward a new equilibrium, in which institutional demand plays a significant and persistent role alongside household consumption.

From a methodological perspective, the findings demonstrate that the ARIMA model remains effective in capturing demand patterns even in the presence of structural shifts. This finding supports previous studies that highlight the robustness of ARIMA in modeling time-series data with stable trends. However, this study extends prior research by showing that policy-driven demand does not necessarily reduce model reliability, but instead shifts the baseline around which demand fluctuates. This implies that short-term forecasting can remain accurate without modifying the core model structure, as long as the additional demand is consistently incorporated into the dataset.

From a supply chain perspective, the introduction of the MBG Program as a structural demand driver has important operational implications. The increase in demand requires adjustments in inventory planning to ensure sufficient stock levels, particularly during peak periods. Procurement strategies must account for the continuous and predictable nature of program demand, enabling better alignment between supply and consumption. In addition, distribution systems must be optimized to support regular delivery to program service points operating on a daily schedule. Failure to adapt to this structural shift may result in localized supply imbalances, where shortages occur in specific areas despite overall adequacy of supply. Integrating demand forecasting with supply chain planning becomes essential to maintain market stability.

More broadly, the findings indicate that urban food demand is increasingly shaped by policy interventions in addition to traditional market forces. This highlights the need for forecasting frameworks that integrate both market-based and institutional demand components to improve accuracy and support more resilient urban food systems.

Conclusion

This study confirms that the MBG Program functions as a structural demand driver in Bandung's rice market, contributing approximately 33.3 percent, equivalent to around 8,000 tonnes, of total monthly demand. This additional demand introduces a persistent institutional consumption layer, shifting the market toward a new and higher demand equilibrium.

The ARIMA model demonstrates reliable performance in forecasting short-term rice demand, successfully capturing both stable consumption patterns and the upward shift induced by policy intervention. These results indicate that traditional time-series models remain applicable in the presence of structural changes, provided that policy-driven demand is appropriately incorporated into the analysis.

From a theoretical perspective, this study reconceptualizes rice demand as a hybrid construct consisting of both market-based and policy-driven components. Methodologically, it contributes by integrating nutrition-based demand estimation with time-series forecasting.

From a practical standpoint, the findings highlight the need for coordinated adjustments in inventory management, procurement planning, and distribution systems to accommodate the additional demand generated by the MBG Program. Without such adjustments, the risk of supply-demand mismatches may increase, potentially affecting market stability and food security outcomes.

Overall, this study provides a data-driven foundation for improving urban food demand planning and supports the development of more adaptive and resilient food logistics systems in the context of large-scale nutrition intervention programs.



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