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Integrating gamification into ecological waste management systems: A narrative review for sustainable energy and environmental transition

Khaira Sakiah Jufri[1], Darhamsyah[1], Miswar Tumpu[2*]

[1] Environmental Management Study Program, The Graduate School, Hasanuddin University, Makassar 90245, Indonesia
[2] Disaster Management Study Program, The Graduate School, Hasanuddin University, Makassar 90245, Indonesia
* Corresponding author's e-mail: miswartumpu@unhas.ac.id

ABSTRACT

Gamification has emerged as an innovative tool within ecological waste management systems, functioning as a behavioural engineering approach to enhance public participation in sustainable waste sorting and recycling practices. This narrative review explores how gamified interventions contribute to ecological sustainability and the broader transition toward energy-efficient waste management systems. Drawing upon behavioural frameworks such as the Theory of Planned Behaviour (TPB), Self-Determination Theory (SDT), and habit formation models, this study synthesizes recent evidence from both developed and developing countries between 2015 and 2024. The analysis identifies five dominant gamification elements – points, rewards, leaderboards, challenges, and feedback – that effectively influence user motivation and participation. Findings indicate that gamification is most successful when integrated within ecological system designs that link household sorting behaviours to waste-to-energy (WTE) conversion and circular economy processes. Case studies from Sweden and South Korea demonstrate strong outcomes when ecological engineering systems are supported by digital platforms and regulatory incentives, whereas cases from Indonesia, India, and Brazil reveal barriers associated with socio-cultural dynamics, limited technological access, and weak policy alignment. This study contributes a conceptual framework that connects behavioural gamification design with ecological engineering and sustainable energy management principles. The findings provide practical insights for policymakers, environmental engineers, and urban planners seeking to design inclusive, data-informed, and resilient waste management systems that support the environmental transition toward a circular and low-carbon economy.

Keywords: gamification, household waste sorting, sustainable energy management, behavioural intervention, public policy integration.

INTRODUCTION

Household waste management remains a critical global challenge, particularly in urbanizing regions of developing countries where waste generation continues to outpace management capacity. The insufficient rate of source-separated waste and the limited integration of community participation within ecological waste systems have resulted in increased landfill dependency and reduced recycling efficiency (Tanwi Trushna et al., 2024). Studies reveal that more than 60% of global municipal solid waste originates from developing nations, where budget allocations primarily focus on collection and disposal rather than on prevention and separation at the source (Aparcana, 2017; Ferronato and Torretta, 2019). Consequently, ecological waste management

systems increasingly demand behavioural innovation to improve public engagement, reduce environmental burdens, and facilitate the transition toward circular and energy-efficient systems.

One promising innovation is gamification – the application of game mechanics and dynamics in non-game contexts – to enhance intrinsic motivation and foster sustainable waste behaviours (Douglas and Brauer, 2021; Santos et al., 2025). By introducing interactive and rewarding experiences, gamification supports long-term behaviour change and engagement with waste sorting activities. Empirical studies show that well-designed gamified systems can bridge the gap between environmental knowledge and action, thereby strengthening the socio-technical link between users and ecological infrastructure (Mabalay, 2025; Triantafyllou and Georgiadis, 2022). According to Santos et al. (2025), gamification aligns strongly with the objectives of SDG 11 (sustainable cities and communities) and SDG 12 (responsible consumption and production), reinforcing its relevance within the broader agenda of sustainable urban transition. For example, Sweden's gamified recycling programs—supported by advanced digital infrastructure and regulatory incentives—have achieved a landfill disposal rate below 1%, showcasing the potential synergy between behavioural innovation and ecological engineering (Arifin Sandhi and Rosenlund, 2024).

Despite these achievements, the majority of evidence originates from developed countries, whereas implementation in developing contexts remains fragmented and underexplored (Aguilar-Cruz and Olaya-Marín, 2025; Ulhasanah et al., 2025). Developing countries face additional structural challenges such as limited digital infrastructure, low ecological literacy, socio-cultural resistance, and the dominance of informal waste sectors (Aparcana, 2017; Tundjungsari et al., 2025). These barriers hinder the integration of gamified systems into ecological waste management frameworks and reduce the effectiveness of interventions aimed at behavioural transformation. Furthermore, the absence of long-term evaluations makes it difficult to assess whether gamification fosters durable habit formation or merely short-term engagement (Luo, 2022; Li et al., 2024). Hence, a comprehensive narrative review is required to synthesize existing approaches, identify critical enablers and limitations, and propose design principles suitable for developing country contexts.

This review aims to systematically synthesize recent evidence on gamification interventions within household waste management and their potential integration into ecological and energy-efficient systems. The objectives are threefold: (1) to classify and analyse gamification elements and behavioural frameworks applied across contexts; (2) to examine the environmental and technological factors influencing intervention success; and (3) to propose a conceptual framework linking gamified behavioural design with ecological engineering and sustainable energy transition. Through this synthesis, the study offers theoretical contributions to behavioural-environmental systems design and practical guidance for policymakers, engineers, and local governments seeking to operationalize inclusive and adaptive ecological waste management strategies.

Recent reviews have examined gamification in sustainability education, climate-action applications, and sustainable consumption more broadly, and an increasing number of studies report gamified recycling initiatives in specific cities or platforms. However, fewer reviews explicitly connect gamification design elements with the operational logic of ecological waste-management systems – from household sorting and collection workflows to downstream recycling, circular economy pathways, and waste-to-energy (WtE) performance. This narrative review addresses that gap by synthesizing evidence across developed and developing contexts (2015–2024) and by integrating behavioural frameworks (TPB, SDT, and habit formation) with system-level ecological engineering considerations. In contrast to earlier syntheses that emphasize only behavioural outcomes or digital engagement, our review highlights how intervention design can influence material quality, contamination reduction, and the stability of feedstock for recycling and WtE conversion. We further propose a conceptual framework that links gamification elements, behavioural mechanisms, and environmental/energy outcomes to support decision making by policymakers and engineers. This positioning clarifies the originality of the review and identifies research gaps related to long-term effectiveness, inclusivity, and real-world scalability. Having defined the review objectives and scope, the next section introduces the key concepts and behavioural foundations of gamification that underpin the evidence synthesized in this review.

CONCEPT OF GAMIFICATION BEHAVIOURAL FOUNDATIONS

Gamification refers to the application of game-design elements and dynamics – such as points, rewards, challenges, and leaderboards – within non-game contexts to enhance user motivation, engagement, and behavioural transformation (Triantafyllou and Georgiadis, 2022). In the domain of ecological waste management and sustainable energy planning, gamification functions as a behavioural intervention that bridges the gap between awareness and sustained participation in environmentally responsible practices (Lim et al., 2024). Through structured feedback loops, competition, and goal-setting mechanisms, gamified systems stimulate both intrinsic motivation – driven by personal satisfaction and autonomy – and extrinsic motivation, encouraged by social recognition or tangible rewards (Dah et al., 2023). These mechanisms have shown particular relevance for household waste sorting in developing countries, where conventional top-down regulatory approaches often fail to activate long-term behavioural change and community ownership (Aparcana, 2017; Ulhasanah et al., 2025).

The theoretical foundations of gamification are anchored in well-established behavioural models. The Theory of Planned Behaviour (TPB) posits that behavioural intention is shaped by attitudes, subjective norms, and perceived behavioural control, offering a structured framework for understanding citizens' participation in waste sorting (Tian and Jiang, 2025). Complementing this, self-determination theory (SDT) underscores the psychological needs for autonomy, competence, and relatedness – each of which can be enhanced through gamified design elements that provide meaningful feedback, social connection, and perceived control (Li, Hew and Du, 2024). Furthermore, habit formation models emphasize the importance of repetition and reward in creating enduring behavioural routines, a principle that aligns well with the use of progressive challenges, badges, and reminder systems in waste-sorting applications (Santos, Sevivas and Carvalho, 2025). Integrating these theoretical perspectives allows for the development of contextually grounded gamification strategies that address the sociocultural, infrastructural, and motivational barriers prevalent in developing economies (Lakhouit, 2025). From a systems perspective, gamification can serve as a complementary mechanism to formal regulation and ecological engineering. By embedding behavioural incentives into digital waste management systems, gamified approaches can strengthen citizen participation in sorting, recycling, and waste-to-energy initiatives (Mabalay, 2025; Tundjungsari et al., 2025). This integration supports the broader objectives of the SDGs – particularly SDG 11 (Sustainable Cities and Communities) and SDG 12 (Responsible Consumption and Production) – by promoting active citizen engagement and decentralized participation in resource recovery (Santos et al., 2025; Sunil, MacLennan and Reisch, 2025). Understanding these behavioural foundations enables policymakers and engineers to co-design adaptive, inclusive, and measurable interventions that bridge technological innovation with social transformation, thereby accelerating the transition toward sustainable energy and ecological waste management systems (Constantino et al., 2021; Ghoulam et al., 2024). After clarifying the definitions and behavioural foundations, we now examine how gamification has been applied to promote pro-environmental behaviour, with particular attention to household waste sorting and recycling participation.

Gamification for pro-environmental behaviour

Gamification has emerged as a promising behavioural intervention for encouraging pro-environmental practices and enhancing public participation in sustainable resource management. In the context of household waste management, gamified systems introduce playful and interactive mechanisms – such as points, leaderboards, challenges, and feedback loops – to transform routine waste sorting into an engaging and rewarding activity (Mabalay, 2025; Santos, Sevivas and Carvalho, 2025). These mechanisms stimulate both intrinsic and extrinsic motivation, leveraging psychological principles such as self-efficacy, competition, and social recognition to promote sustained behavioural change (Triantafyllou and Georgiadis, 2022; Dah et al., 2023). By increasing citizen engagement in waste sorting, gamification contributes not only to improved recycling efficiency but also to the optimization of feedstock for waste-to-energy systems, aligning directly with the objectives of sustainable energy and environmental management (Lakhouit, 2025; Lim et al., 2024).

A growing body of empirical evidence confirms that gamification can improve participation in recycling and waste reduction activities, particularly when mobile systems combine points, reminders, and social comparison features to sustain motivation over time (Lakhouit, 2025; Mabalay, 2025). Mobile applications incorporating gamification features have become one of the most effective strategies for promoting behavioural consistency in waste management. De Wildt and Meijers (2023) found that regular notifications, feedback messages, and progress tracking embedded in waste-sorting apps effectively foster new behavioural routines. These systems not only provide technical support for waste segregation but also influence psychological determinants of behaviour through social nudges and digital rewards, consistent with the theory of planned behaviour (TPB) framework (Tian and Jiang, 2025). Within the scope of sustainable energy transition, these approaches have the dual benefit of reducing landfill dependency and ensuring a more consistent supply of high-quality waste streams for recycling and energy recovery processes (Ulhasanah et al., 2025; Tundjungsari et al., 2025).

Comparative evidence indicates that challenge-based and feedback-oriented gamification strategies yield more sustainable behavioural impacts than one-time incentive models. Continuous interaction through real-time feedback strengthens user commitment, reinforcing long-term engagement rather than short-lived participation (Santos et al., 2025). These mechanisms reflect the principles of the Self-Determination Theory (SDT), where intrinsic motivation grows from autonomy, competence, and relatedness (Li, Hew and Du, 2024). Gamified interventions designed with these principles help cultivate a sense of ownership and community, thereby embedding sustainable behaviour into daily practices (Figures 1 and 2).

Additionally, the habit loop model explains how digital cues such as notifications and badges serve as triggers that reinforce repeated behaviour through cycles of cue–action–reward (Lim et al., 2024). Over time, these mechanisms can institutionalize waste-sorting habits within community routines. However, the success of this behavioural reinforcement is highly contingent on sociocultural context and technological accessibility. Developed countries such as Sweden, South Korea, and Germany have demonstrated strong adoption of gamified waste management due to advanced digital ecosystems, supportive policy frameworks, and high environmental literacy (Sandhi and Rosenlund, 2024; Rosenlund et al., 2025). In contrast, implementation in developing countries faces barriers including digital inequality, inconsistent policy enforcement, and low levels of environmental awareness (Ferronato and Torretta, 2019; Aparcana, 2017).

These differences raise a critical question about how gamification principles can be adapted and scaled for regions with limited infrastructure yet pressing environmental challenges. Developing context-sensitive frameworks that integrate behavioural science, digital inclusivity, and sustainable energy planning is therefore essential for achieving a just and effective transition toward

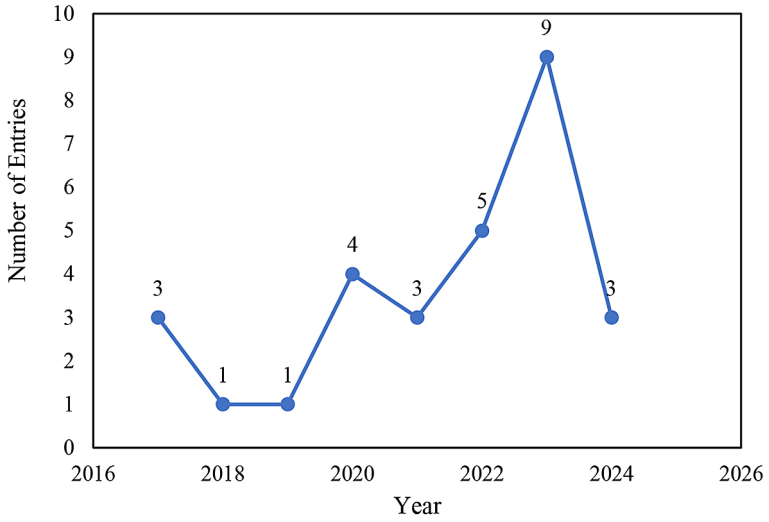

Figure 1. Trend in the number of studies on gamification for waste sorting per year

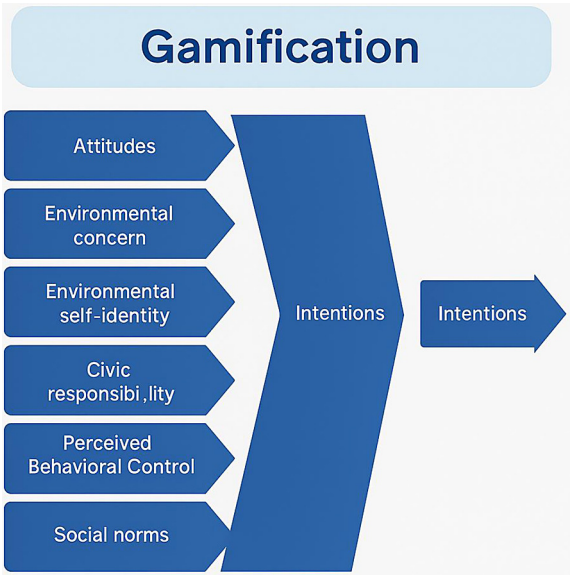

Figure 2. Psychosocial factors in gamification for environmental behaviour

circular economy systems (Sunil, MacLennan and Reisch, 2025; Constantino et al., 2021).

To interpret why specific game elements work and to align intervention design with behavioural mechanisms, the following section synthesizes the dominant behaviour-change theories used in the gamification literature.

Theoretical framework of behaviour change

Gamification as a behavioural intervention is grounded in well-established social and behavioural psychology theories that explain how motivation, intention, and habitual processes drive individual actions. Analyses of previous research reveal that the theory of planned behaviour (TPB) and self-determination theory (SDT) are the two dominant theoretical foundations in gamified environmental interventions (Ahmadov et al., 2024; Li, Hew and Du, 2024). The TPB, developed by Ajzen (1991), posits that an individual's behaviour is guided by intention, which is shaped by three key determinants: attitude toward the behaviour, subjective norms, and perceived behavioural control. In the context of household waste separation, TPB provides a robust explanatory framework for understanding how personal beliefs and social influences shape citizens' intentions to engage in waste sorting (Tian and Jiang, 2025; Cheng et al., 2022).

Alongside TPB, SDT plays a central role in explaining how gamification fosters sustained motivation by satisfying basic psychological needs for autonomy, competence, and relatedness (Li, Hew and Du, 2024). Unlike TPB, which focuses primarily on intention formation, SDT explains how intrinsic motivation can sustain behaviour even in the absence of external rewards. Gamification elements such as voluntary participation (autonomy), tiered challenges (competence), and social leaderboards (relatedness) have been found to significantly strengthen user engagement in waste management systems (Triantafyllou and Georgiadis, 2022; Dah et al., 2023). Empirical evidence from hybrid designs that integrate TPB and SDT demonstrates superior behavioural outcomes, as this combination captures both cognitive intention and motivational persistence (Ahmadov et al., 2024; Lakhouit, 2025).

Figure 3 presents a gamification motivation model that integrates constructs from TPB and SDT. The model illustrates how autonomous motivation (linked to SDT's intrinsic needs) interacts

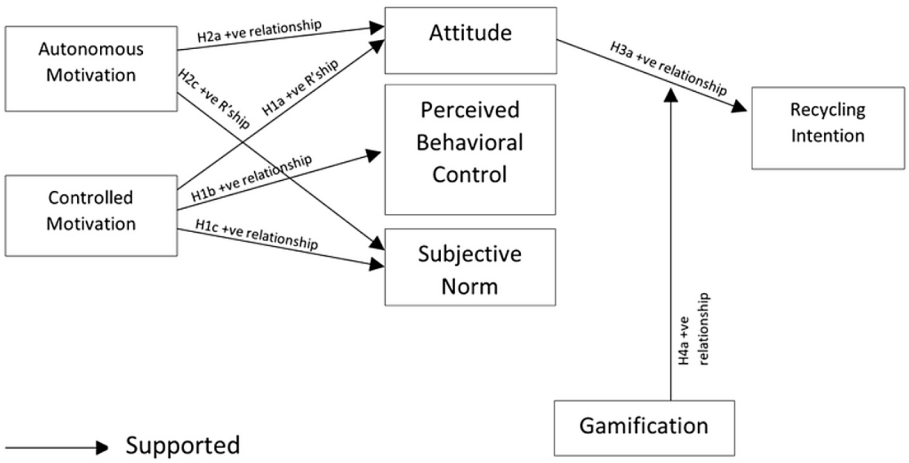

Figure 3. A conceptual model of recycling motivation and intention in gamification

with controlled motivation (influenced by TPB's social and normative pressures) to shape recycling intentions. Gamified interventions that incorporate features such as choice flexibility, progressive feedback, and social interaction are thus more effective in maintaining long-term behavioural change (Mabalay, 2025; Santos, Sevivas and Carvalho, 2025). This theoretical synthesis highlights that effective gamification is not merely about adding points and rewards but about aligning game design with the psychological mechanisms that underpin sustainable behaviour.

Another critical framework in behavioural design is the habit loop model, which conceptualizes behaviour formation through three key components: cue, routine, and reward (Gardner and Lally, 2022). Within gamified waste management systems, daily notifications or reminders act as cues, the act of sorting waste becomes the routine, and virtual points or visual feedback serve as rewards. When this cycle is consistently reinforced, pro-environmental habits become automatic, reducing dependence on continuous external motivation (De Wildt and Meijers, 2023). This mechanism is particularly relevant in developing countries, where sustaining long-term engagement often requires low-cost, self-reinforcing interventions.

In addition to TPB, SDT, and habit theory, recent research has emphasized the importance of the nudge approach, which promotes subtle changes in the decision-making environment to steer behaviour in desired directions (Luo, 2022). For instance, digital avatars or visual progress bars that respond positively to environmentally friendly actions function as visual nudges, providing immediate feedback that encourages repetition without coercion. Nudging complements gamification by reinforcing pro-environmental actions through positive reinforcement and subconscious cues rather than explicit regulation (Sunil, MacLennan and Reisch, 2025) (Table 1).

Recent hybrid models have also begun integrating multiple theoretical perspectives to enhance both cognitive and emotional engagement. Lakhouit (2025) and Ahmadov et al. (2024), for example, suggest that combining TPB and SDT within gamified applications can strengthen users' perceived efficacy and behavioural consistency compared to single-theory frameworks. This integration enables designers to address both rational

Table 1. Summary of behavioural theories and strategies in environmental gamification interventions

Author (Year)	Behavioural approach
Soma et al. (2020)	Theory of Planned Behaviour (TPB), awareness and behaviour change through educational engagement
Sinclair et al. (2021)	Emotional engagement, reflective learning through provocative design
He et al. (2021)	Fogg Behaviour Model (FBM) encompassing motivation, ability, and trigger mechanisms
Nkwo et al. (2021)	Persuasive system design (PSD) framework
Haas et al. (2022)	Hedonic-utilitarian hybrid approach, gamification theory, behaviour change theory
Seiler et al. (2022)	Technology Acceptance Model (TAM), focusing on perceived ease of use (PEOU), perceived usefulness (PU), and intention to use (ITU)
Sato and Mizuyama (2022)	Experiential learning, awareness-raising through interactive simulations
Tian and Zheng (2022)	Normative illusion, evolutionary game theory
Tuah et al. (2022)	User engagement through gamification, agile UX methodology
Miller et al. (2023)	Food systems approach, experiential learning, game-based learning
Jespersen et al. (2023)	Memory retention, behaviour change through regular interaction and emotional attachment
Jung (2023)	Behaviour changes through emotional engagement
Löchtefeld et al. (2023)	Learning through play, memory retention, behaviour change via gamified education
Perera et al. (2023)	Practice-oriented view, social norms, and behavioural change theories
Pajpach et al. (2023)	Persuasive technology, behaviour change through feedback and reminders
Rodrigues et al. (2023)	Game-based learning strategy
Vasconcelos et al. (2023)	Gamification for behaviour change, educational engagement
Yu et al. (2023)	Persuasive technology, self-tracking, gamification for behaviour change
Elnakib et al. (2024)	Theory of Planned Behaviour (TPB) encompassing knowledge, attitudes, self-efficacy, subjective norms, and perceived behavioural control
Hamada et al. (2024)	Cognitive load associated with food
Santa Cruz et al. (2024)	Behavioural change through gamification and educational engagement

decision-making and affective-motivational needs that support sustainable pro-environmental habits (Lim et al., 2024; Venturi et al., 2025).

However, as noted by Santos, Sevivas and Carvalho (2025) in their bibliometric review, most gamification-based behavioural frameworks are still concentrated in Europe and North America, where strong digital infrastructure and environmental education systems prevail. In contrast, empirical applications in developing countries remain scarce (Aparcana, 2017; Ferronato and Torretta, 2019). This geographical imbalance underscores the urgent need to test and adapt behavioural frameworks in diverse sociocultural contexts where community engagement, informal waste sectors, and infrastructural limitations pose unique challenges. Future research should therefore focus on developing context-sensitive behavioural models that integrate gamification with ecological engineering and sustainable energy planning to promote systemic, equitable, and long-lasting environmental transitions (Tundjungsari et al., 2025; Ulhasanah et al., 2025).

Building on these theoretical foundations, we next classify the main types of gamification interventions used in waste management to provide a structured basis for comparing designs and outcomes across contexts.

TYPOLOGY OF GAMIFICATION INTERVENTIONS

The typology of gamification interventions represents a structured classification of design strategies that employ game elements in non-game contexts to modify user behaviour, sustain motivation, and enhance engagement in pro-environmental actions. In the context of household waste management, these interventions are increasingly viewed as part of broader ecological behaviour systems that link individual participation with community-based resource efficiency and sustainable energy transitions (Santos, Sevivas and Carvalho, 2025; Ahmadov et al., 2024). Gamification mechanisms typically include points, badges, leaderboards, narrative challenges, avatars, and instant feedback loops, which collectively function as extrinsic and intrinsic motivators within behavioural change frameworks (Triantafyllou and Georgiadis, 2022; Lim et al., 2024).

Recent reviews classify gamification interventions into three primary categories: reward-based systems, feedback and progress-based systems, and social or collaborative systems (Mabalay, 2025; Aguilar-Cruz and Olaya-Marín, 2025).

1. Reward-based systems utilize tangible or symbolic incentives such as virtual points, tokens, or vouchers that reinforce immediate user actions.
2. Feedback and progress-based systems rely on visual progress bars, performance dashboards, or tiered challenges to promote competence and mastery.
3. Social and collaborative systems integrate features like leaderboards, peer competition, or team missions that foster a sense of relatedness and shared responsibility for environmental outcomes (Dah et al., 2023; Venturi et al., 2025).

These classifications align closely with the SDT framework, in which autonomy, competence, and relatedness are the psychological pillars sustaining long-term motivation (Li, Hew and Du, 2024). At the same time, by embedding social comparison and normative influence, these interventions also correspond to constructs of the TPB, specifically perceived behavioural control and subjective norms (Tian and Jiang, 2025; Cheng et al., 2022). Therefore, understanding the typology of gamification is essential not only for designing effective interventions but also for aligning game elements with the cognitive and emotional mechanisms that drive environmental decision-making.

The literature also identifies several context-specific adaptations of gamification typologies across different socioeconomic and cultural environments. In developed countries such as Sweden and South Korea, gamification has been integrated into digital waste collection infrastructures and smart recycling stations, enabling real-time tracking and behavioural analytics (Rosenlund et al., 2025; Sandhi and Rosenlund, 2024). In contrast, developing countries such as Indonesia and India have implemented hybrid or low-tech gamification systems that emphasize social engagement through community waste banks and mobile-based reward schemes (Tundjungsari et al., 2025; Ulhasanah et al., 2025). These context-specific adaptations reveal that the effectiveness of gamified interventions is strongly dependent on technological accessibility, cultural values, and governance support, reaffirming that gamification cannot be universally applied without contextual calibration (Aparcana, 2017;

Ferronato and Torretta, 2019). Accordingly, the typology of gamification interventions serves a dual function: (1) as a design framework, guiding practitioners in selecting and combining appropriate game elements according to target populations and desired behavioural outcomes; and (2) as an evaluation framework, enabling systematic assessment of motivation types, engagement levels, and long-term behavioural impacts (Santos, Sevivas and Carvalho, 2025; Mabalay, 2025). By synthesizing insights from psychology, human–computer interaction, and environmental management, this typology provides a multidimensional understanding of how gamified interventions can contribute to ecological waste management and the transition toward circular, energy-efficient systems.

Within this typology, the next subsection differentiates interventions by media and format, highlighting how technology choices shape feasibility, inclusivity, and measurement of waste-sorting behaviours.

Classification by media and format

Gamification interventions for household waste sorting exhibit significant diversity in their media, format, and technological design, reflecting the adaptability of this behavioural approach across varying socio-economic and geographic contexts. The distinction between game-based and gamification-based interventions (see Table 2) underscores that mobile applications remain the dominant medium, owing to their scalability,

Table 2. Research classification based on type of game approach (games, serious games, and gamification)

Author (Year)	Game	Serious Games	Gamification
Altarriba et al. (2017)		X	
Fadhil (2017)			X
Joyner et al. (2017)		X	
Sato et al. (2018)		X	
Anderson and Reid (2019)			X
Dolnicar et al. (2020)			X
Gaggi et al. (2020)			X
Jacobsen et al. (2020)			X
Soma et al. (2020)			X
Sinclair et al. (2021)		X	
He et al. (2021)			X
Miller et al. (2021)		X	
Nkwo et al. (2021)			X
Haas et al. (2022)			X
Seiler et al. (2022)		X	
Sato and Mizuyama (2022)		X	
Tian and Zheng (2022)		X	
Tuah et al. (2022)			X
Miller et al. (2023)		X	
Jespersen et al. (2023)		X	
Jung (2023)			X
Löchtefeld et al. (2023)		X	
Perera et al. (2023)			X
Pajpach et al. (2023)			X
Rodrigues et al. (2023)		X	
Vasconcelos et al. (2023)		X	
Yu et al. (2023)			X
Elnakib et al. (2024)		X	
Hamada et al. (2024)			X
Santa Cruz et al. (2024)			X

accessibility, and capacity to integrate real-time data analytics (Mabalay, 2025; Lakhouit, 2025). However, in developing regions, community-based and low-tech systems often demonstrate higher adaptability, particularly where digital infrastructure and internet connectivity remain limited (Aparcana, 2017; Ferronato and Torretta, 2019). In general, gamification interventions can be classified into five primary media categories: (1) mobile applications, (2) community-based systems, (3) sensor- or IoT-based technologies, (4) physical boards and public displays, and (5) social media-based approaches (Santos, Sevivas and Carvalho, 2025; Ahmadov et al., 2024).

Among these, mobile applications have become the most prevalent due to their ability to monitor user behaviour, provide immediate feedback, and deliver personalized incentives. Several studies report that such apps can raise participation and sustain engagement when they integrate point systems, progress tracking, and social comparison features (Lakhouit, 2025; Mabalay, 2025). Similarly, GreenApes in Europe has promoted environmentally responsible behaviours by combining digital feedback, peer comparison, and reward systems (Mabalay, 2025).

Each media format presents distinct advantages and limitations depending on contextual factors such as digital literacy, social cohesion, and governance support. Mobile platforms are optimal for individual-level monitoring and real-time analytics, while community-based systems – often involving gamified neighbourhood challenges or waste bank initiatives – excel in cultivating shared responsibility and collective identity (Waititu, 2021; Ulhasanah et al., 2025). In contrast, social media campaigns leverage viral content, digital challenges, and hashtags to mobilize large-scale participation within short timeframes, though sustaining behavioural consistency remains a challenge (Cheng et al., 2022).

Emerging innovations also include sensor- and IoT-integrated gamification systems, such as smart bins equipped with RFID or weight sensors that automatically record disposal data and reward users based on participation frequency (Tundjungsari et al., 2025). These systems exemplify the convergence of gamification and ecological engineering, as they integrate behavioural psychology with environmental monitoring technologies to support waste-to-energy optimization and circular economy objectives (Lakhouit, 2025; Rosenlund et al., 2025). Similarly, physical notice boards and eco-kiosks—commonly deployed in low-income or rural areas—serve as tangible, low-cost gamification tools that provide visible feedback on household or community waste performance, reinforcing pro-environmental norms through social comparison.

Comparative analyses across regions indicate that mobile-based systems tend to outperform other formats in maintaining behavioural consistency and providing measurable outcomes, while community-based and physical systems are more effective at fostering sustained social norms and inclusion (Sandhi and Rosenlund, 2024; Venturi et al., 2025). Social media-based interventions, despite their ephemeral nature, remain powerful catalysts for awareness and short-term mobilization among younger demographics. Therefore, the selection of gamification media should be context-sensitive, balancing technological feasibility with sociocultural compatibility.

In conclusion, the classification of gamification media and format is not merely a technical taxonomy but a strategic behavioural mapping that connects technology design with psychological and social dimensions of environmental participation. Future research should explore hybrid intervention models that integrate mobile, community, and IoT-based components to achieve synergistic impacts, particularly in developing countries undergoing ecological and energy transitions (Tundjungsari et al., 2025; Lim et al., 2024). Such hybrid systems could represent a next-generation pathway for embedding behavioural intelligence within ecological waste management infrastructures.

After reviewing the main media formats, we then focus on the most common game elements themselves and summarize the motivational functions each element serves in waste-sorting contexts

Common game elements and their functions

Gamification in household waste sorting systems operates through the deliberate adaptation of game-design elements to influence user motivation, engagement, and long-term behavioural transformation. In sustainable waste management contexts, these elements are not superficial "game-like" features, but structured behavioural tools that transform waste sorting from a routine task into a motivating, socially valued, and goal-oriented experience (Santos, Sevivas and Carvalho, 2025). As illustrated in Figure 4, the design

of gamified recycling stations incorporates interactive, feedback-driven, and socially engaging components that merge technological functionality with behavioural psychology (Rosenlund et al., 2025). A synthesis of the reviewed literature identifies five dominant game elements widely employed across gamified waste management systems – points, rewards, leaderboards, challenges, and feedback – each serving a distinct psychological function in reinforcing pro-environmental behaviour (Mabalay, 2025; Triantafyllou and Georgiadis, 2022).

Points act as quantitative representations of user engagement, translating correct waste-sorting actions into measurable achievements. They provide immediate, tangible feedback, stimulating short-term extrinsic motivation and helping users perceive their contribution as meaningful. Lakhouit (2025) notes that points form the foundational mechanism for other elements such as rewards and leaderboards, serving as the behavioural "currency" that sustains initial engagement phases. However, studies emphasize that points must be contextually meaningful – for instance, reflecting environmental impact metrics such as kilograms of waste sorted or CO_2 saved – to prevent them from becoming abstract and demotivating (Douglas and Brauer, 2021; Santos et al., 2025).

Rewards operate primarily as extrinsic reinforcers, providing recognition in tangible (e.g., vouchers, discounts) or symbolic forms (e.g., badges, certificates). Empirical studies generally report that incentives can increase short-term participation in waste sorting, especially when paired with feedback and community-based challenges; however, sustained engagement requires designs that also support intrinsic motivation and habit formation (Santos, Sevivas and Carvalho, 2025; Li, Hew and Du, 2024).

Leaderboards introduce social comparison and transparency, transforming waste sorting into a shared social activity. By allowing individuals or households to compare achievements within specific communities – such as neighbourhoods, schools, or residential clusters – leaderboards foster a sense of collective accountability. Wang, Wei and Xiong (2025) observe that localized leaderboards, implemented at small social scales (e.g., RT/RW in Indonesia or housing blocks), generate stronger emotional resonance and sustained participation than city-wide systems, as they reinforce belonging and friendly competition. However, inclusive design remains critical; without careful calibration, leaderboards may unintentionally exclude low-performing participants or those with limited access to digital tools (Aguilar-Cruz and Olaya-Marín, 2025).

Challenges and feedback systems complement the above mechanisms by maintaining user interest and reinforcing awareness of environmental outcomes. Periodic challenges (e.g., weekly or thematic missions) prevent habituation and introduce variety into repetitive sorting tasks (de Wildt and Meijers, 2023). Meanwhile, real-time and visual feedback, such as showing CO_2 reduction or cumulative waste diverted from landfills, strengthens users' sense of efficacy and social contribution (Santos, Sevivas and Carvalho, 2025; Venturi et al., 2025). These feedback mechanisms are directly linked to habit formation loops, where cues (notifications), routines (sorting), and rewards (visual acknowledgment) interact to form sustainable behavioural cycles (Gardner and Lally, 2022).

Figure 5 summarizes these elements and their psychological functions in the context of waste sorting gamification. It also outlines measurable indicators such as frequency of participation, duration of engagement, and sustainability of

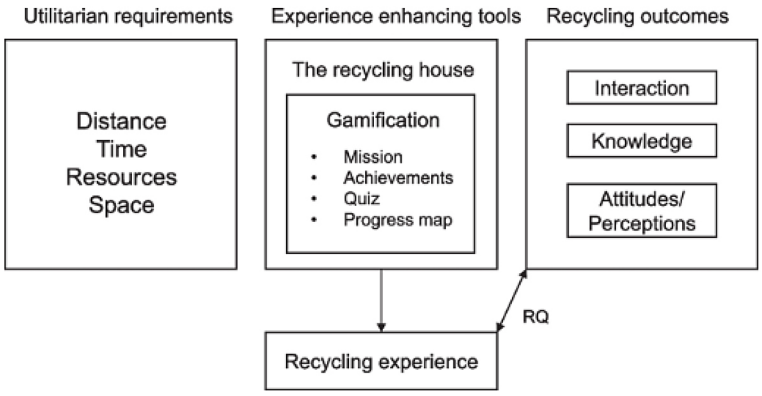

Figure 4. Conceptual framework of example of gamification implementation at recycling stations

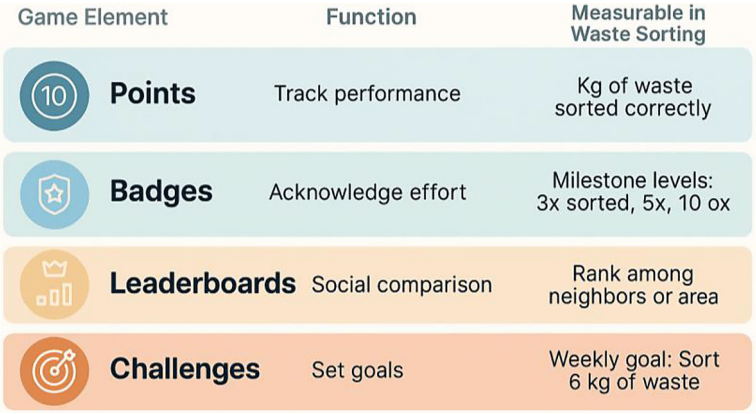

Figure 5. Common game elements and their measurable functions in waste sorting gamification

behaviour change. The synthesis reveals that the effectiveness of gamification elements is highly context-dependent: in economically driven communities, tangible rewards often outperform symbolic recognition, while in socially cohesive groups, competitive elements like leaderboards foster enduring behavioural norms (Waititu, 2021; Ulhasanah et al., 2025).

Ultimately, combining multiple elements—rather than relying on a single mechanism—produces the most sustainable outcomes. Integrated gamification systems that merge points, leaderboards, and real-time feedback within supportive community frameworks have been found to generate higher participation rates, greater behavioural persistence, and stronger alignment with sustainable energy and waste-to-resource objectives (Tundjungsari et al., 2025; Lakhouit, 2025). Such hybrid approaches exemplify how gamification can evolve beyond awareness-raising into a form of ecological behavioural engineering, directly contributing to circular economy transitions in developing regions.

Because gamification is ultimately intended to improve ecological outcomes, the next section explains why household waste sorting is environmentally critical and how behavioural participation translates into system-level benefits.

ENVIRONMENTAL SIGNIFICANCE OF HOUSEHOLD WASTE SORTING

Household waste sorting represents one of the most fundamental yet impactful components of sustainable waste management and ecological engineering. Proper segregation of recyclable, organic, and hazardous waste at the source is critical not only for minimizing landfill dependency but also for enhancing the efficiency of recycling and energy recovery systems (Trushna et al., 2024; Ferronato and Torretta, 2019). By separating materials before collection, households enable more effective downstream processing, reducing contamination in recycling streams and improving the economic viability of secondary material markets (Aparcana, 2017). This process directly contributes to the conservation of natural resources and the mitigation of greenhouse gas emissions arising from waste decomposition, transport, and virgin material production (Maria and Sisani, 2017; UNEP, 2022).

From a socio-technical systems perspective, household waste sorting functions as a critical entry point in the transition toward circular economy models and sustainable urban energy systems. When integrated with energy recovery technologies such as waste-to-energy (WtE) conversion or biogas production, segregated waste streams significantly enhance the efficiency of energy generation and reduce environmental externalities (Lakhouit, 2025; Sunil, MacLennan and Reisch, 2025). Furthermore, effective source separation supports urban resilience by reducing the volume of waste transported to landfills, thereby decreasing methane emissions and leachate generation that contaminate groundwater and local ecosystems (Gollapalli and Kota, 2018; Grant et al., 2013).

The environmental impact of household waste sorting extends beyond landfill reduction; it contributes to better resource recovery, reduced pollution, and more reliable feedstock for recycling and energy recovery. Studies emphasize that consistent waste sorting practices at the household level can lower municipal management costs and reduce local air and water pollution by decreasing

open dumping and burning (Trushna et al., 2024; Santos, Sevivas and Carvalho, 2025).

In this context, gamification-based interventions play an increasingly strategic role. By embedding motivational elements – such as rewards, feedback, and challenges – into waste sorting programs, gamification enhances both participation rates and behavioural consistency over time (Mabalay, 2025; Venturi et al., 2025). This behavioural innovation bridges individual action and collective environmental outcomes, creating a visible linkage between household choices and measurable sustainability indicators such as waste reduction, resource recovery, and carbon footprint reduction. In addition, gamification aligns with ecological engineering principles, transforming waste management systems into participatory, feedback-oriented ecosystems that engage communities as active agents of change.

Therefore, understanding the environmental significance of household waste sorting – particularly when enhanced through gamified behavioural interventions – is crucial for advancing integrated policy and engineering frameworks. For policymakers and urban planners, this understanding provides an empirical and behavioural foundation for designing context-sensitive, inclusive, and technologically adaptive waste systems that support the broader transition toward sustainable energy and environmental management (Rosenlund et al., 2025; Tundjungsari et al., 2025). With the baseline importance of household sorting established, we first detail the environmental consequences of poor segregation to clarify the specific problems that gamification aims to mitigate.

Environmental impact of poor household waste segeregation

Inadequate household waste segregation generates significant and multi-layered environmental consequences that extend from local ecological degradation to global climate impacts. As illustrated in Figure 6, poor waste sorting disrupts material recovery chains and triggers cascading effects, including contamination of recyclable materials, increased landfill dependency, and inefficient incineration without energy recovery (Ferronato and Torretta, 2019). When organic, plastic, metallic, and hazardous wastes are mixed, recycling processes become both technically and economically infeasible, undermining the principles of circular economy and ecological engineering. This inefficiency leads to resource depletion and higher energy demands in material reproduction cycles (Maria and Sisani, 2017). Unsorted waste that ends up in landfills exerts substantial pressure on surrounding ecosystems through groundwater contamination, soil acidification, and emissions of greenhouse gases such as methane and carbon dioxide (Trushna et al., 2024; UNEP, 2022). One of the most critical outcomes of poor waste segregation is the intensification of methane emissions from the anaerobic decomposition of organic matter. Methane is known to be over 25 times more potent than carbon dioxide in contributing to global warming. Gollapalli and Kota (2018) demonstrated that in developing cities with insufficient segregation infrastructure, more than 40% of municipal solid waste significantly contributes

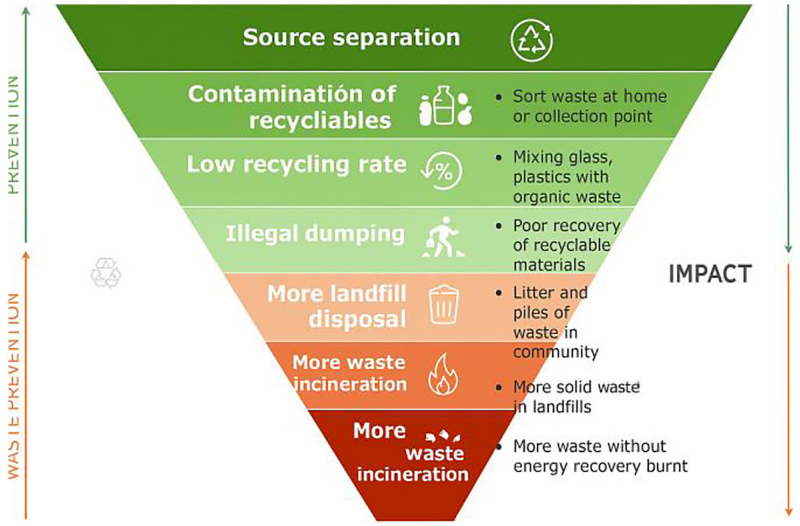

Figure 6. Environmental impacts of poor household waste segregation practices

to methane generation, exacerbating both local air quality degradation and global climate change.

The ecological implications extend beyond greenhouse gas emissions. The co-disposal of electronic waste with general household waste results in leaching of toxic heavy metals such as mercury, cadmium, and lead into groundwater and surface water systems (Grant et al., 2013). These contaminants enter food chains, leading to bioaccumulation and increased health risks, including neurological, respiratory, and reproductive disorders among communities residing near poorly managed landfills. Such findings highlight the intersection between inadequate waste management and environmental health inequities, particularly in rapidly urbanizing regions where informal waste systems dominate (Aparcana, 2017).

Poor household waste sorting also plays a direct role in exacerbating marine plastic pollution. Mismanaged waste, especially lightweight plastics, is transported through urban drainage and river systems into oceans. In Southeast Asia, including Indonesia, low household-level segregation has been identified as a primary driver of microplastic accumulation in marine ecosystems (UNEP, 2022). It is estimated that up to 80% of marine debris originates from land-based sources, with household waste contributing the largest share due to inadequate source separation practices. This not only threatens marine biodiversity but also undermines coastal livelihoods and food security.

From an operational standpoint, poor segregation increases the burden on recycling, composting, and waste-to-energy facilities. Mixed waste streams reduce the efficiency of recovery technologies and increase treatment costs, while recyclable materials contaminated by organic waste are often diverted back to landfills or incineration (Sandhi and Rosenlund, 2024). This inefficiency represents a structural barrier to achieving circular material flows, leading to higher emissions and energy losses across the system. Cities that neglect source-level sorting frequently exhibit stagnant recycling rates despite substantial investments in waste infrastructure and technology (Lakhouit, 2025).

Therefore, inadequate household waste segregation must be recognized not merely as a technical deficiency but as a systemic socio-environmental challenge that undermines ecological resilience and public health. Addressing this issue requires integrating behavioural science with technological innovation. Behaviour-based interventions such as gamification offer promising pathways for transforming citizen participation, reinforcing pro-environmental norms, and linking individual household actions to collective ecological outcomes (Mabalay, 2025; Venturi et al., 2025). By embedding motivational elements into ecological waste management systems, gamified interventions can mitigate the root causes of poor segregation, ultimately contributing to sustainable energy transitions and the realization of low-carbon urban environments.

Having described the harms of inadequate segregation, we then summarize the ecological benefits that can be achieved when behaviour-based interventions successfully improve source separation.

Ecological benefits of behaviour-based interventions

Behavioural interventions, particularly those based on gamification strategies, have emerged as powerful tools to improve ecological performance in household waste management systems. Encouraging waste sorting at the source significantly reduces the volume of mixed waste entering landfills, thereby increasing recycling efficiency and minimizing the generation of greenhouse gases such as methane from the anaerobic decomposition of organic matter (Maria and Sisani, 2017). Effective source separation extends the lifespan of landfill facilities and reduces operational burdens on municipal solid waste systems, which are often overstressed in developing countries with limited infrastructure (Ferronato and Torretta, 2019). From an ecological engineering perspective, such interventions enable more efficient resource loops and contribute to the design of sustainable material cycles within urban environments.

Increased separation at source can also reduce the leakage of pollutants into coastal and marine ecosystems. UNEP (2022), for example, highlights that improvements in household waste segregation can substantially reduce marine plastic leakage when scaled across urban populations. Furthermore, recycling materials such as aluminium, paper, and glass consumes considerably less energy than producing them from virgin resources, supporting broader energy efficiency and emissions-reduction goals (Trushna et al., 2024).

Technological integration amplifies these ecological outcomes by enabling precise data-driven monitoring. Gamified mobile applications

and IoT-based systems allow real-time tracking of household participation, providing valuable feedback loops that inform policy design and local-level optimization (Tundjungsari et al., 2025). Such digitalized behavioural monitoring not only enhances transparency and accountability but also provides a quantifiable means of evaluating ecological impacts, such as reductions in waste-to-landfill volumes or cumulative decreases in greenhouse gas emissions. These mechanisms demonstrate how behaviour-based interventions bridge the gap between individual actions and measurable sustainability indicators within ecological engineering systems.

Beyond immediate waste reduction outcomes, gamification interventions contribute to long-term ecological resilience by fostering environmental literacy and social co-responsibility. Mabalay (2025) notes that sustained engagement through interactive challenges and reward systems cultivates intrinsic motivation, transforming temporary behaviours into enduring pro-environmental habits. This behavioural shift enhances the capacity of communities to participate in decentralized waste management and renewable energy initiatives, including composting and waste-to-energy programs (Sandhi and Rosenlund, 2024). As such, the behavioural transformation initiated through gamification supports the integration of ecological and energy systems by aligning human behaviour with material and energy efficiency objectives.

At a broader level, these interventions align closely with the SDGs, particularly SDG 11 and SDG 12 (Responsible Consumption and Production). By strengthening community participation and fostering intergenerational awareness, gamification promotes a culture of environmental stewardship and collective ecological responsibility (Santos et al., 2025). The resulting socio-ecological transformation contributes not only to urban environmental quality but also to climate resilience and sustainable energy transitions. Consequently, integrating gamified behavioural frameworks into ecological waste management systems offers a holistic strategy to achieve long-term environmental sustainability and adaptive capacity in the face of global environmental change.

These ecological benefits motivate the question of what works in practice; therefore, the next section evaluates the effectiveness of gamification interventions in developing-country settings and the contextual factors that shape outcomes.

EFFECTIVENESS OF INTERVENTIONS IN DEVELOPING COUNTRIES

The effectiveness of behavioural interventions, including gamification-based approaches, in household waste management within developing countries is profoundly shaped by socio-economic, cultural, and infrastructural conditions. Limited access to digital technology, inconsistent policy implementation, and low public awareness often constrain the scalability of such interventions. Nevertheless, evidence indicates that contextually adapted gamification programs can significantly improve household participation in waste sorting and recycling practices, thereby reducing landfill dependency and enhancing overall material recovery rates (Lakhouit, 2025; Santos et al., 2025). These improvements contribute directly to ecological outcomes such as reduced greenhouse gas emissions, better resource efficiency, and decreased contamination in waste streams – key components of sustainable environmental management systems.

Technological innovation plays a central role in addressing the structural barriers that commonly hinder behavioural programs in low- and middle-income regions. Studies conducted by Tundjungsari et al. (2025) and Sandhi and Rosenlund (2024) show that integrating Internet of Things (IoT) and mobile-based applications with gamified features – such as progress tracking, digital leaderboards, and real-time feedback – can enhance participation even in regions with limited formal waste management infrastructure. These tools provide adaptive feedback loops that align with local behavioural patterns, allowing for incremental habit formation among users while generating valuable datasets for municipal authorities. The digital layer of gamification thus acts as both an educational and a governance mechanism, connecting individual behaviour with system-level environmental performance indicators.

However, the success of these interventions is not solely determined by technological design but also by their alignment with social and cultural dynamics. As highlighted by Waititu (2021), community-based gamification models that incorporate collective incentives – such as social recognition or neighbourhood competitions – tend to achieve higher participation rates in regions where collectivist values prevail. Similarly, Khalid et al. (2024) found that the combination of gamification and informal education initiatives

can bridge digital literacy gaps and promote sustained behavioural change in rural and peri-urban areas. These findings underscore the importance of integrating socio-cultural dimensions into gamification frameworks rather than relying on technological determinism alone. Economic incentives and social norms also play crucial roles in shaping the adoption of gamification interventions. In low-income communities, reward-based mechanisms – such as redeemable points, micro-vouchers, or community-level benefits – have proven effective in maintaining engagement and overcoming motivational barriers (Trushna et al., 2024). Nevertheless, sustained success depends on transitioning from extrinsic to intrinsic motivation, which can be facilitated through feedback mechanisms emphasizing environmental impact, local pride, and social responsibility. As Dah et al. (2023) argue, a balanced design that maintains "gamification equilibrium" between external rewards and internalized motivation is essential for long-term behavioural sustainability.

Overall, the effectiveness of gamification interventions in developing countries relies on the strategic combination of social innovation, digital infrastructure, and behavioural insight. When appropriately contextualized, such interventions can transform individual waste-sorting actions into collective ecological outcomes, enhancing community resilience and supporting transitions toward circular economies and sustainable urban energy systems (Santos et al., 2025; Venturi et al., 2025). The findings from recent empirical and narrative reviews suggest that future research should focus on longitudinal evaluations of behavioural persistence and cross-sectoral policy integration to scale these benefits across diverse socio-environmental contexts.

To ground the discussion in evidence, we begin with success stories and lessons on transferability from contexts where gamified waste-management systems have been implemented and evaluated.

Success stories and transferability challenges

Several countries have achieved remarkable progress in implementing gamification within household waste management systems, demonstrating how behavioural innovation can accelerate ecological transition. Sweden, for example, has reached a landfill diversion rate of nearly 99% by integrating digital incentive systems with advanced monitoring technologies (Sandhi and Rosenlund, 2024). Through the combination of mobile applications, reward-based mechanisms, and transparent feedback platforms, citizens are encouraged to separate waste according to standardized categories. This success is supported by robust institutional frameworks, widespread digital access, and a deeply ingrained environmental culture that emphasizes collective responsibility. Similarly, European initiatives such as GreenApes and the Circular Recycling Station in Gothenburg illustrate how gamified design can transform waste sorting from a routine task into a socially rewarding and educational experience (Rosenlund et al., 2025).

South Korea's Pay-As-You-Throw (PAYT) model represents another globally recognized success. The system combines RFID-enabled waste bags with mobile applications that track individual disposal behaviour, charging households based on unsorted waste volumes while rewarding consistent recyclers (Lee, n.d.). This integration of gamified feedback and fiscal accountability has proven effective in fostering behavioural discipline, reducing waste generation, and cultivating a community-based innovation ecosystem. The PAYT model has since inspired similar pilot programs in Japan, Singapore, and parts of China, showcasing the potential of technology-mediated behavioural interventions for sustainable urban waste management (Lakhouit, 2025; Santos et al., 2025).

However, replicating such success in developing countries remains challenging due to vast differences in infrastructure, socio-economic capacity, and cultural norms. Many low- and middle-income countries face digital literacy gaps, limited internet connectivity, and fragmented waste management systems, which undermine the scalability of gamified solutions (Aparcana, 2017). For instance, reward-based mechanisms that rely on mobile applications may be less effective in areas where smartphone penetration is low or where communities have limited trust in digital platforms. Furthermore, research by Aguilar-Cruz and Olaya-Marín (2025) indicates that interventions designed in high-income contexts often fail to account for local behavioural drivers, resulting in short-lived participation and limited environmental impact.

Another major challenge lies in the overreliance on extrinsic motivators – such as points, vouchers, or rankings – without adequately integrating intrinsic motivational factors. The

assumption that reward systems are universally effective overlooks the influence of cultural and social values on behaviour. In many developing countries, waste sorting is still perceived as a government duty rather than a shared civic responsibility (Ferronato and Torretta, 2019). Consequently, gamification programs that neglect participatory and educational components often struggle to generate sustained engagement. A study by Khalid et al. (2024) on digital gamification for learning highlights that effective interventions in resource-constrained contexts must first build awareness and environmental literacy before introducing complex reward systems.

To overcome these transferability barriers, adaptive strategies that combine gamification principles with localized knowledge and participatory design are essential. Rather than directly replicating models from high-income nations, interventions should be co-created with communities to align with local behaviours, socio-economic realities, and infrastructural capacities (Waititu, 2021; Tundjungsari et al., 2025). Hybrid approaches that integrate low-tech solutions – such as community-based competitions, social recognition systems, or analog leaderboards – with gradual digital integration can enhance inclusivity and long-term adoption. Ultimately, the sustainability of behavioural change depends not merely on technological sophistication but on building enduring community ownership and trust in collective ecological goals (Santos et al., 2025; Venturi et al., 2025).

These experiences also reveal constraints; accordingly, the following subsection synthesizes the key barriers that limit adoption, equity, and long-term engagement—especially in resource-constrained settings.

Barriers to implementing gamification for waste sorting

Implementing gamification in household waste management faces multiple structural, socio-cultural, and technological barriers, particularly within developing country contexts. One of the most persistent obstacles is the digital infrastructure gap, which limits the scalability of technology-based behavioural interventions. Many communities in low- and middle-income countries still experience unstable internet connectivity, low smartphone penetration, and limited access to digital literacy programs (Aparcana, 2017; Khalid et al., 2024). These conditions constrain participation in mobile-based gamification systems and create unequal access to engagement opportunities. As a result, interventions that rely heavily on digital platforms risk reinforcing existing inequalities, especially among lower-income households and rural populations.

Beyond technical constraints, socio-cultural factors present another significant challenge. In many regions, waste sorting has not yet evolved into an established social norm and is often perceived as a governmental or sanitation worker responsibility rather than a collective civic duty (Ferronato and Torretta, 2019). This perception weakens intrinsic motivation and reduces the sense of ownership required for sustained behavioural change. Research by Waititu (2021) in Kenya and Tundjungsari et al. (2025) in Indonesia shows that the absence of community-based facilitation and localized environmental education leads to short-lived participation in gamified programs. Without culturally embedded narratives and social reinforcement mechanisms, gamification risks being perceived as an external or temporary initiative rather than a transformative behavioural tool.

Institutional and governance-related barriers further hinder implementation. Limited coordination among waste management agencies, weak policy support for digital incentive systems, and the absence of cross-sectoral collaboration between environmental and information technology departments often result in fragmented program design (Santos et al., 2025; Aguilar-Cruz and Olaya-Marín, 2025). Many municipalities lack standardized frameworks for integrating behavioural interventions into waste management systems, resulting in pilot projects that operate in isolation and fail to achieve long-term institutionalization. Moreover, systematic monitoring and evaluation mechanisms are frequently absent, preventing policymakers from assessing the real-world impact of gamified interventions on waste reduction, recycling rates, and community engagement.

Financial and resource-related challenges also remain substantial. Developing gamified applications, maintaining user engagement systems, and providing tangible or symbolic rewards require consistent funding and technical capacity. In many developing countries, public budgets for waste management are already constrained, with most resources allocated to collection and disposal rather than behavioural innovation (Tanwi et al., 2024). As highlighted by Mabalay (2025),

sustained gamification efforts depend on regular updates, technical maintenance, and responsive user feedback loops—elements that demand long-term investment. Without continuous support, initial enthusiasm for gamified systems often declines, leading to low retention rates and limited ecological impact.

Finally, data privacy and inclusivity issues are emerging as critical concerns in the digitalization of environmental programs. Studies by Lakhouit (2025) and Rosenlund et al. (2025) caution that poorly regulated data management systems may deter users from participating in tracking-based gamification platforms. Additionally, designs that fail to account for gender, age, and literacy diversity risk excluding key population groups from engagement. Addressing these barriers requires context-sensitive design strategies that balance technological sophistication with local accessibility, institutional capacity, and community empowerment. In this way, gamification can evolve from a novelty tool into a sustainable behavioural innovation that strengthens ecological waste management and energy transition objectives.

Given these barriers, we then discuss the Indonesian context as a focused case to illustrate how socio-technical conditions, governance, and digital access influence the design of feasible and inclusive gamification models.

Relevance of gamification in the indonesian context

Indonesia, similar to other rapidly urbanizing developing countries, continues to face persistent challenges in promoting effective household waste segregation. According to the Ministry of Environment and Forestry (KLHK, 2023), the proportion of source-separated waste in Indonesia remains below 15%, far from the national target of a 30% reduction by 2025. This shortfall highlights the need for innovative behavioural approaches that go beyond regulatory enforcement or infrastructural investment. In this context, gamification offers an alternative pathway to enhance citizen participation and reshape social norms related to waste management, aligning with the country's broader objectives for sustainable energy transition and circular economy development (Tundjungsari et al., 2025; Ulhasanah et al., 2025).

Several pilot initiatives in Indonesia have already experimented with gamified systems to encourage community participation. Digital platforms such as Zerolim and Bank Sampah Digital integrate point-based reward mechanisms, allowing users to exchange accumulated points for vouchers or digital savings. These programs have demonstrated measurable increases in household waste deposits at waste banks, indicating the motivational potential of incentive-based participation (Tundjungsari et al., 2025). However, the majority of these interventions still depend on short-term extrinsic rewards, such as financial incentives or digital tokens, which may not sustain long-term behavioural change without supporting elements like social competition, narrative feedback, or environmental education (Aguilar-Cruz and Olaya-Marín, 2025). To enhance scalability and durability, these systems could integrate neighbourhood-level leaderboards, collective achievement badges, and monthly community challenges, leveraging Indonesia's strong social fabric and localized governance structures (RT/RW).

Despite these promising developments, several context-specific barriers constrain widespread adoption. The first challenge lies in digital access inequality. Internet penetration and smartphone ownership remain concentrated in urban areas, while many rural and peri-urban regions still experience low connectivity and limited digital literacy (Khalid et al., 2024). Second, deeply ingrained collectivist norms in Indonesian society often assign environmental responsibility to the government or sanitation workers rather than to individual citizens, creating resistance to behavioural interventions that emphasize personal accountability (Ferronato and Torretta, 2019; Waititu, 2021). Third, regulatory frameworks governing digital incentives, data management, and cross-sector integration of gamification into national waste policies are still underdeveloped, leading to fragmented pilot projects and weak institutional continuity (Aparcana, 2017; Lakhouit, 2025). Figure 7 illustrates these three major contextual barriers – technological, socio-cultural, and institutional – that commonly limit gamification effectiveness in developing countries, including Indonesia.

Comparative evidence from other developing nations – such as India and Brazil – suggests that localized adaptations of gamification can improve recycling participation when social and cultural dynamics are integrated into design strategies. Studies describe benefits when mobile-based rewards are paired with social-media outreach and community-level challenges (Mabalay, 2025;

Figure 7. Illustration of three main barriers to implementing gamified household waste sorting in developing countries: (a) technical and digital infrastructure barriers; (b) collective social and cultural barriers; (c) institutional barriers and the need for a structured, adaptive approach

Santos et al., 2025). In comparison, Indonesia's initiatives remain at an early experimental stage, characterized by fragmented implementation and limited cross-sectoral support.

To enhance the effectiveness of gamification in Indonesia, design strategies must be tailored to local socio-technical systems. This includes leveraging existing community infrastructures such as waste banks, youth organizations, and neighbourhood governance networks (RT/RW) to integrate gamified mechanisms into familiar social settings. Sustained environmental education and digital literacy programs are equally essential to ensure that gamification transcends short-term engagement and facilitates enduring pro-environmental habits. Furthermore, institutional frameworks should incentivize collaboration between local governments, technology developers, and community leaders to align gamification systems with the national Circular Economy Roadmap and the Waste-to-Energy (WtE) agenda (Ulhasanah et al., 2025).

Ultimately, Indonesia presents a valuable case study for understanding the contextual adaptation of gamification in developing countries. Its combination of high social capital, emerging digital infrastructure, and community-based environmental programs offers fertile ground for developing hybrid gamification models—merging digital, social, and behavioural incentives—to promote sustainable waste management. Future research should focus on evaluating long-term behavioural retention, exploring the psychological mechanisms driving engagement in collective waste programs, and assessing ecological outcomes such as emission reduction and resource recovery efficiency (Table 3). Based on the evidence and the Indonesia-focused discussion, the next section outlines future perspectives and research directions to strengthen scalability, inclusivity, and long-term environmental impact.

FUTURE PERSPECTIVES

Gamification presents significant potential as an innovative behavioural intervention for advancing sustainable household waste management in developing countries. Despite encouraging early results, its adoption remains limited and fragmented, often constrained by the digital divide, socio-cultural heterogeneity, and inadequate regulatory frameworks (Santos et al., 2025; Lakhouit, 2025). The success of future interventions depends on the establishment of structured, evidence-based, and context-sensitive approaches that consider the socio-economic, infrastructural, and cultural specificities of each region. A more integrated research agenda is needed to assess how technological design, behavioural psychology, and policy innovation can collectively shape more sustainable waste management practices (Ahmadov et al., 2024; Lim et al., 2024).

From a technological perspective, the future of gamification lies in the integration of digital applications, Internet of Things (IoT)-enabled smart sensors, and behavioural data analytics to monitor, evaluate, and personalize user participation. These technologies allow policymakers to generate real-time data on household sorting performance, thereby improving the precision of policy responses and enabling adaptive incentive systems (Lakhouit, 2025; Tundjungsari et al., 2025). However, successful implementation will require robust digital infrastructures and user-friendly interfaces tailored to populations with varying levels of technological literacy.

From a policy perspective, gamification should be embedded within broader frameworks of environmental governance and sustainable energy transition. Integrating digital incentive mechanisms into waste management policies – through tax rebates, community rewards, or circular economy credits – can institutionalize

Table 3. A comparative summary of gamification interventions for waste sorting in developing countries

No.	Country /Program	Description / Intervention	Source / DOI / Link
1	Germany – Smart Recycling Initiative	Uses IoT sensors and mobile applications to monitor household waste sorting levels.	https://doi.org/10.1016/j.procs.2021.01.068
2	Sweden – Digital Incentive System	Achieved 99% waste diversion through digital incentive systems and smart monitoring.	https://doi.org/10.3390/su12147918
3	UN-Habitat – Urban Waste Management	Global program to strengthen city capacities in inclusive waste management.	https://unhabitat.org
4	South Korea – PAYT + RFID	"Pay As You Throw" system integrated with RFID and mobile app incentives for residents.	https://doi.org/10.1080/23311983.2023.2247605
5	Bangkok – City Waste Program	City-level waste management policy in Bangkok based on community participation.	https://www.bangkok.go.th
6	Vietnam – GreenHub	Community-based initiative for plastic waste reduction and public education.	https://greenhub.org.vn
7	Philippines – Basura Center	Digital community-based waste bank program with incentives.	https://basuracenter.org
8	UNDP – Global Waste Projects	Waste management projects in developing countries focusing on circularity and community empowerment.	https://www.undp.org
9	End Plastic Waste Alliance	Global collaboration to reduce plastic waste through technology and education.	https://www.endplasticwaste.org
10	India – TechforWaste	Digital platform facilitating community-based waste sorting.	https://doi.org/10.1016/j.jclepro.2023.127123
11	Brazil – Circular App	Digital incentive app integrating informal recycling actors.	https://doi.org/10.1016/j.jclepro.2023.100206
12	Nigeria – Gamify Waste Sorting	Pilot gamification project for household waste sorting.	https://doi.org/10.1016/j.procs.2021.01.127
13	Ukraine – UNDP Waste Program	Strengthening waste sorting systems through community-based approaches.	https://www.undp.org/ukraine
14	Zimbabwe – Community Recycling Network	Raising awareness and enhancing recycling capacity at the local level.	https://doi.org/10.1016/j.jclepro.2021.101146

behavioural change at scale (Aparcana, 2017; Ulhasanah et al., 2025). Moreover, systematic monitoring and evaluation tools are needed to assess not only participation rates but also ecological outcomes, such as reductions in landfill dependency, resource recovery efficiency, and greenhouse gas emissions (Ferronato and Torretta, 2019; Gollapalli and Kota, 2018).

From a socio-cultural perspective, locally informed gamification models must account for collective values, community engagement patterns, and informal waste management networks that dominate in many developing countries. For example, in Indonesia and the Philippines, leveraging community-based institutions such as waste banks and neighbourhood associations (RT/RW) can strengthen social trust and long-term participation (Waititu, 2021; Tundjungsari et al., 2025). Behavioural design should therefore move beyond individual motivation toward community-centred gamification, emphasizing cooperation, collective progress, and localized feedback loops to sustain engagement over time.

Future research should prioritize longitudinal and comparative studies to examine the persistence of behavioural change across diverse demographic and socio-economic contexts. This includes evaluating the balance between intrinsic and extrinsic motivators, as well as investigating the psychological mechanisms—such as autonomy, competence, and relatedness—derived from Self-Determination Theory (Li et al., 2024; Triantafyllou and Georgiadis, 2022). Additionally, interdisciplinary studies linking behavioural science, ecological engineering, and digital technology can advance the theoretical and empirical understanding of gamification's role in sustainability transitions (Constantino et al., 2021; Tian and Jiang, 2025).

Ultimately, the future of gamification for household waste management lies in cross-sector collaboration among academics, policymakers,

local governments, and private technology developers. Building inclusive digital ecosystems that integrate behavioural incentives with environmental data systems will ensure scalability, equity, and sustainability. Such integration not only enhances public participation in waste management but also contributes directly to SDG 11 and 12 – fostering responsible consumption, resilient cities, and sustainable energy transitions (Sunil et al., 2025; United Nations Environment Programme, 2022). By aligning social innovation with ecological engineering principles, gamification can evolve from a digital novelty into a cornerstone of sustainable urban transformation.

Finally, we consolidate the main insights and practical implications of the review in the concluding section.

CONCLUSIONS

Gamification represents a promising and innovative behavioural intervention for advancing sustainable household waste management in developing countries. This review demonstrates that gamification can effectively enhance public participation, environmental awareness, and waste segregation practices when designed with sensitivity to local socio-cultural dynamics. However, its effectiveness remains highly dependent on the interplay between social context, digital infrastructure, policy support, and levels of environmental literacy. In settings where technological access and governance structures are limited, purely digital or reward-based systems often fail to sustain long-term behavioural change.

To achieve transformative outcomes, gamification must be adaptive, community-centred, and institutionally embedded. Integrating gamification frameworks with local governance mechanisms—such as waste banks, neighbourhood associations (RT/RW), and municipal programs – can strengthen collective ownership and ensure continuity of participation. Moreover, establishing coherent public policies that align digital innovation with environmental goals is essential to enhance scalability and policy coherence. When combined with adequate digital literacy initiatives, gamification can act as a bridge between technological innovation and social transformation, empowering communities to become active agents in sustainable waste management.

From a broader perspective, the findings highlight the importance of interdisciplinary collaboration among behavioural scientists, engineers, policymakers, and technology developers in designing effective interventions. By integrating social, technological, and regulatory dimensions, gamification can move beyond short-term motivation to create systemic, measurable impacts on sustainability outcomes. This aligns directly with the objectives of Ecological Engineering & Environmental Technology in promoting practical, scalable, and socially inclusive solutions for sustainable resource and energy management.

Ultimately, gamification has the potential to serve not merely as a digital engagement tool but as a catalyst for ecological citizenship, fostering behavioural shifts that underpin the transition toward circular economies and resilient urban systems. Future efforts should prioritize context-sensitive frameworks, long-term impact assessments, and participatory models that embed gamification within local socio-technical systems – ensuring that behavioural innovation contributes effectively to the realization of SDG 11 and 12 on sustainable cities, responsible consumption, and production.

REFERENCES

1. Aguilar-Cruz, P.J. dan Olaya-Marín, E.J. (2025). Gamification and eco-literacy: A bibliometric analysis of research trends. *International Journal of Serious Games 12*(3), 29–46. https://doi.org/10.17083/8mzab045
2. Ahmadov, T., Karimov, A., Durst, S., Saarela, M., Gerstlberger, W. dan Wahl, M.F. (2024). A two-phase systematic literature review on the use of serious games for sustainable environmental education. *Interactive Learning Environments 33*(3), 1945–1966. https://doi.org/10.1080/10494820.2024.2414429
3. Aparcana, S. (2017). Approaches to formalization of the informal waste sector into municipal solid waste management systems in low- and middle-income countries: Review of barriers and success factors. *Waste Management 61*, 593–607. https://doi.org/10.1016/j.wasman.2016.12.028
4. Cheng, K.M., Koo, A.C., Nasir, J.S.B.M. et al. (2022). An evaluation of online Edcraft gamified learning (EGL) to understand motivation and intention of recycling among youth. *Scientific Reports 12*, 14843. https://doi.org/10.1038/s41598-022-15709-2
5. Dah, J., Hussin, N., Zaini, M.K., Helda, L.I., Ametefe, D.S., Aliu, A.A., Suqi, W. dan Caliskan, A.

(2023). Gamification equilibrium: The fulcrum for balanced intrinsic motivation and extrinsic rewards in electronic learning systems. *International Journal of Serious Games 10*(3), 83–100. https://doi.org/10.17083/ijsg.v10i3.633

6. de Wildt, K.K. dan Meijers, M.H.C. (2023). Time spent on separating waste is never wasted: Fostering people's recycling behavior through the use of a mobile application. *Computers in Human Behavior 139*, 107541. https://doi.org/10.1016/j.chb.2022.107541
7. Douglas, B.D. dan Brauer, M. (2021). Gamification to prevent climate change: A review of games and apps for sustainability. *Current Opinion in Psychology 42*, 89–94. https://doi.org/10.1016/j.copsyc.2021.04.008
8. Ferronato, N. dan Torretta, V. (2019) Waste mismanagement in developing countries: A review of global issues. *International Journal of Environmental Research and Public Health 16*(6), 1060. https://doi.org/10.3390/ijerph16061060
9. Ghoulam, K., Bouikhalene, B., Babori, A. dan Falih, N. (2024). Gamification in e-learning: Bridging educational gaps in developing countries. International *Journal of Advanced Corporate Learning 17*(1), 85–95. https://doi.org/10.3991/ijac.v17i1.47631
10. Gkargkavouzi, A., Halkou, P. dan Halkos, G. (2025). Behavioural and psychological insights in climate policy. *MPRA Paper.* https://mpra.ub.uni-muenchen.de/125312/ Constantino, S.M., Schlüter, M. dan Weber, E.U. et al. (2021) Cognition and behavior in context: A framework and theories to explain natural resource use decisions in social-ecological systems. *Sustainability Science 16*, 1651–1671. https://doi.org/10.1007/s11625-021-00989-w
11. Gollapalli, M. dan Kota, S.H. (2018) Methane emissions from a landfill in north-east India: Performance of various landfill gas emission models. Environmental Pollution *234*, 174–180. https://doi.org/10.1016/j.envpol.2017.11.064
12. Grant, K., Goldizen, F.C., Sly, P.D., Brune, M.N., Neira, M., van den Berg, M. dan Norman, R.E. (2013) Health consequences of exposure to e-waste: A systematic review. *Lancet Global Health 1*, e350–e361. https://doi.org/10.1016/S2214-109X(13)70101-3
13. Lakhouit, A. (2025) Revolutionizing urban solid waste management with AI and IoT: A review of smart solutions for waste collection, sorting, and recycling. *Results in Engineering 25*, 104018. https://doi.org/10.1016/j.rineng.2025.104018
14. Lee, D. (n.d.) *Transforming waste management systems through location tracking and data sharing.* Master's thesis, Massachusetts Institute of Technology. Available at: http://dspace.mit.edu/handle/1721.1/7582
15. Li, L., Hew, K.F. dan Du, J. (2024). Gamification enhances student intrinsic motivation, perceptions of autonomy and relatedness, but minimal impact on competency: A meta-analysis and systematic review. *Educational Technology Research and Development 72*, 765–796. https://doi.org/10.1007/s11423-023-10337-7
16. Lim, W.M., Das, M., Sharma, W., Verma, A. dan Kumra, R. (2024). Gamification for sustainable consumption: A state-of-the-art overview and future agenda. *Business Strategy and the Environment.* https://doi.org/10.1002/bse.4021
17. Luo, Z. (2022). Gamification for educational purposes: What are the factors contributing to varied effectiveness? *Education and Information Technologies 27*, 891–915. https://doi.org/10.1007/s10639-021-10642-9
18. Mabalay, A.A. (2025). Gamification for sustainability: A systematic review of applications, trends, and opportunities. *Computers in Human Behavior 165*, 108529. https://doi.org/10.1016/j.chb.2024.108529
19. Maria, F.D. dan Sisani, F. (2017) Greenhouse gas emissions and environmental impact from recycling the organic fraction of solid waste: Comparison of different treatment schemes from a life cycle perspective. *Recycling 2*(3), 13. https://doi.org/10.3390/recycling2030013
20. Rosenlund, J., Helmefalk, M. dan Stenfelt, S. et al. (2025) Levelling up the recycling experience: Gamification of recycling through an innovative recycling station. *Circular Economy and Sustainability 5*, 1983–2007. https://doi.org/10.1007/s43615-025-00510-w
21. Sandhi, A. dan Rosenlund, J. (2024) Municipal solid waste management in Scandinavia and key factors for improved waste segregation: A review. *Cleaner Waste Systems 8*, 100144. https://doi.org/10.1016/j.clwas.2024.100144
22. Santos, E., Sevivas, C. dan Carvalho, V. (2025) Gamified approaches in environmental behavior: A bibliometric analysis. *Sustainability 17*(5), 10012. https://doi.org/10.3390/su170510012
23. Santos, E., Sevivas, C. dan Carvalho, V. (2025) Managing food waste through gamification and serious games: A systematic literature review. *Information 16*(3), 246. https://doi.org/10.3390/info16030246
24. Sunil, A., MacLennan, M. dan Reisch, L.A. (2025) Advancing sustainable consumption: SDG 12, behavioural science, and the work of the United Nations. *Business 2025* 2–17. https://doi.org/10.4337/9781035325061.00008
25. Tian, X. dan Jiang, Y. (2025) Exploring behavioral determinants of residents' ecological conservation in rural tourism development. *Scientific Reports 15*, 1826. https://doi.org/10.1038/s41598-025-85571-5
26. Triantafyllou, S.A. dan Georgiadis, C.K. (2022) Gamification design patterns for user engagement. *Informatics in Education 21*(4): 655–674. https://doi.org/10.15388/infedu.2022.27

27. Trushna, T., Krishnan, K., Soni, R., Singh, S., Kalyanasundaram, M., Annerstedt, K.S., Pathak, A., Purohit, M., Lundboge, C.S., Sabde, Y., Atkins, S., Sahoo, K.C. dan Rousta, K. (2024) Interventions to promote household waste segregation: A systematic review. *Heliyon 10*(2), e24332. https://doi.org/10.1016/j.heliyon.2024.e24332
28. Tundjungsari, V., Putranto, B.P.D., Ulum, M.B. dan Anwar, N. (2025). An integrated model for circular waste management using the Internet of Things, Semantic Web, and gamification (Circonomy): Case study in Indonesia. *JMIR Serious Games 13*, e66781. https://doi.org/10.2196/66781
29. Ulhasanah, N., Suhardono, S. dan Lee, C.H. et al. (2025) Modelling participation in waste bank initiatives at public transport hubs to advance circular economy development. *Discover Sustainability 6*, 153. https://doi.org/10.1007/s43621-025-00940-4
30. United Nations Environment Programme. (2022). *From pollution to solution: A global assessment of marine litter and plastic pollution.* Nairobi: UNEP. https://www.unep.org/resources/pollution-solution.
31. Venturi, S., Zulauf, K., Cuel, R. dan Wagner, R. (2025) Trash to treasure: Gamification and informed recycling behavior. *Resources, Conservation and Recycling 215*, 108108. https://doi.org/10.1016/j.resconrec.2024.108108
32. Waititu, P. (2021). Creating community-based environmental awareness with social media: A Kenyan perspective. *Southern African Journal of Environmental Education 37*(1). https://doi.org/10.4314/sajee.v37i1.2
33. Wang, Y., Wei, Y.D. dan Xiong, N. (2025). Teleworking, social capital, and subjective well-being: Evidence from US county-level data. *Cities 167*, 106355. https://doi.org/10.1016/j.cities.2025.106355