

Designing Sustainable Solutions: A Gamified Framework for Empowering Autonomous Household Recycling

Kin Meng Cheng¹, Lianna Wijaya², Siew Chien Teo³, Ah Choo Koo⁴,
Mohammad Hajarian⁵

¹Faculty of Creative Industries, Universiti Tunku Abdul Rahman, Bandar Sungai Long, 43000, Kajang, Selangor.

²Management Department, BINUS Online Learning, Bina Nusantara University, 11530 Jakarta, Indonesia.

³Faculty of Business, Multimedia University, 75450 Melaka, Malaysia

⁴Faculty of Creative Multimedia, Multimedia University, 63100, Cyberjaya, Malaysia.

⁵Department of Information Science and Technology, Instituto Universitário de Lisboa (ISCTE-IUL), ISTAR, Avenida das Forças Armadas, Lisboa, Portugal; Computer Science Department, Universidad Carlos III de Madrid, Avda de la Universidad 30, 28911, Leganes, Madrid, Spain.

ackoo@mmu.edu.my

Abstract

This study explores strategies to facilitate autonomous recycling practices within families, which are essential for supporting sustainable development in local communities. A framework grounded in Self-Determination Theory (SDT) and the Theory of Planned Behavior (TPB), is developed to identify the elements influencing the adoption of autonomous recycling behavior in families. This approach combines autonomous support, integrated regulation, intrinsic aspiration, gamified recycling, societal norms, attitude, perceived behavioral control, and recycling intention to provide a comprehensive understanding of household sustainability dynamics. A webinar was conducted with 424 participants, using Quizziz to engage and evaluate knowledge of recycling. Among these participants, 197 completed the questionnaire, offering significant insights. The effectiveness of the proposed framework was evaluated using SmartPLS analysis. The results add to the expanding knowledge on sustainable development by providing practical insights on promoting household recycling. This study outlined the importance of using gamified engagement and autonomous decision-making processes to promote a more environmentally conscious society. Furthermore, sustainable design solutions were proposed by incorporating a gamified framework into recycling or pro-environmental behaviors.

Keywords: Autonomous motivation, Gamified recycling, Self-determination theory, Sustainable design solutions

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Introduction

Recycling is a crucial strategy in combating climate change and reducing carbon emissions (Ciacci et al., 2016; Stallkamp et al., 2023; Schäfer & Schmidt, 2019). It minimizes dependency on fossil fuels and decreases the release of greenhouse gases, by reusing resources such as waste plastics, and metal scraps. To further enhance efficiency and accessibility, the integration of blockchain technology and artificial intelligence (AI) has been crucial in advancing recycling technologies (Khamis et al., 2019).

Background

Recycling is essential in reducing emissions and energy usage associated with producing essential materials (Benz et al., 2022). The incorporation of recycled materials into industries significantly reduces energy consumption and emissions, with innovative approaches such as chemical recycling contributing to climate change mitigation (Austermann et al., 2022). The process is effective, but the overall impact on global warming is not fully understood (Geyer, 2008). While the study shows that recycling significantly reduces greenhouse gas emissions, further studies are needed to fully comprehend the effects (Yu, 2019; Ackerman, 2000).

Recent studies on household recycling show a growing interest in automation and smart processes. For example, Ahamad (2018) and Alcaraz-Londoño (2022) emphasized the increasing trend toward automated recycling methods. Ahamad proposes using a moisture sensor to differentiate recyclable and non-recyclable household waste, while Tiedemann (2021) suggested the adoption of a robotic system to sort recyclable materials from large waste items. Similarly, Chinnathurai (2016) explores a partially automated waste-sorting robot using image processing. Studies have identified the concept of autonomous support, as a significant factor in predicting goals and behavior (Luqman, 2018).

These studies show the potential of self-governing recycling systems at home and emphasize the importance of proper waste sorting. Within this context, the promotion of recycling behaviors to encourage independent sustainability practices among families was examined. The study questions are:

1. How do autonomous support, integrated regulation, and intrinsic aspiration affect recycling intentions in families?
2. What is the influence of gamified recycling on intent to recycle, considering the moderating effects of autonomous support, integrated regulation, and intrinsic aspiration?

The objective is to develop a Gamified Framework that explores the factors influencing recycling intentions among young people, based on the principles of Self-Determination Theory (SDT) and the Theory of Planned Behavior (TPB). The primary goal of this study is to promote household recycling and foster an environmentally aware society by addressing specific objectives using a game-like experience.

Literature Review

Several investigations have explored the domain of autonomous recycling behavior within residential settings. Ahamad (2018) and Alcaraz-Londoño (2022) provided insights into the growing interest in this field, with a particular focus on automation and intelligent processes. Ahamad suggests a method that can differentiate between leftover and recyclable household waste by using a moisture sensor for waste categorization. Building on this concept, Tiedemann (2021) proposes the development of a robotic system to independently separate recyclable coarse materials from bulky waste. Similarly, Chinnathurai (2016) focuses on the creation of a semi-autonomous waste segregation robot that uses image processing techniques to accurately identify and categorize recyclable and non-recyclable materials. These studies collectively outline the potential of autonomous recycling behavior systems in residential settings, with a particular emphasis on waste differentiation and material segregation. A study by Gajanova and Radišić (2021) examines the function of Self-Determination Theory (SDT) as a mediator in the correlation between gamification and consumer purchasing behaviour. The results demonstrate that participants' views on intrinsic motivation markedly affected their purchasing intentions in the

presence of gamification components. This highlights the significance of cultivating integrated regulation, which can enhance individuals' perceptions of control over their behaviours and eventually result in improved engagement and outcomes across many contexts. This corresponds with the extensive literature highlighting the significance of autonomy support in fostering self-determined behaviours and improving general well-being (Deci & Ryan, 2020; Vansteenkiste et al., 2019).

The current literature on gamification reveals a notable deficiency in its implementation in recycling activities, especially concerning the incorporation of autonomous motivation frameworks. Although gamification has been extensively researched for its capacity to augment motivation and engagement in fields like as education and health, its potential to encourage recycling behaviours is yet insufficiently examined. Ede (2022) emphasises the importance of cultivating intrinsic motivation via autonomous decision-making in gamified settings, illustrating how these factors can augment user engagement. Mekler et al. (2017) underscores the necessity of comprehending the impact of particular gamification aspects on intrinsic motivation and its potential customisation to promote sustainable behaviours like recycling. A meta-analysis conducted by Sailer and Homner (2019) substantiates that gamification enhances motivation, although highlights an ambiguity over the processes underlying these effects in pro-environmental settings. This study examines the design of gamification frameworks to improve autonomous motivation for recycling, so advancing both gamification research and environmental sustainability initiatives.

Autonomous support

Autonomous support, a crucial element of autonomous motivation, is identified as a significant predictor of goals and behavior. Its influence extends beyond social networking and the workplace, including actions such as recycling. Luqman (2018) shows that autonomous motivation is a strong factor in determining individuals' plans to discontinue the use of social networking sites. The study also outlined the mediating role of the TPB. Gillet et al. (2013) established a relationship between supervisor autonomous support, organizational support, job happiness, and plans to leave the job. In this context, the important self-motivation was outlined. Chan et al. (2020) builds on these results through the application to prevent sports injuries. The study showed the effect of autonomous motivation on factors related to the TPB. In addition, Hagger et al. (2002) discussed the effect of independent motivations, regarding physical exercise, which are affected by TPB-related cognitions. The TPB states that beliefs, subjective norms, and perceived behavioral control affect the intention of individuals to recycle. According to this theory, providing self-directed support enhances individuals' sense of control over actions. This fosters a sense of ownership over recycling activities. As a result, equipping individuals with the tools necessary for self-motivation plays a critical role in strengthening the desire to recycle. Self-support facilitates a stronger commitment to recycling activities by improving perceived behavioral control and intrinsic motivation. This integration presents the importance of autonomous support in fostering autonomous motivation, which influences intentions and actions across different situations. The relationships between Autonomous support (AUT), perceived behavioral control (PBC), attitudes (ATT), subjective norms (SNO), and intention to recycle (INT) are reflected in hypothesis H1 to H4. Chatzisarantis et al. (2007). investigated the influence of perceived autonomous support on physical exercise using the TPB, as reported in the *European Journal of Social Psychology*. The study emphasized that autonomous support includes encouraging choice, engaging people in decision-making, providing appropriate answers, reducing stress, as well as acknowledging individual emotions and perspectives. These factors can positively influence the perceived control individuals have over actions. Therefore, the first hypothesis was established:

H1: Autonomous support (AUT) positively influences perceived behavioral control (PBC).

The findings of Spaulding et al. (2021) indicate that user engagement with technology can significantly shape attitudes towards health-related behaviors. However, this reference does not specifically address attitudes towards recycling. Autonomous support, which includes promoting choice and active participation, offering meaningful explanations, and recognizing different viewpoints, has the potential to cultivate favorable attitudes. Therefore, the second hypothesis was formulated:

H2: Autonomous support (AUT) positively influences attitudes (ATT).

Liu et al. (2019) explored how social support influences health behaviors among older adults, suggesting that autonomy-supportive environments can foster positive subjective norms regarding various behaviors. Chatzisarantis et al. (2007) provide insights into the impact of autonomous support on subjective norms within TPD but do not specifically focus on recycling intentions. Autonomous support is characterized by reducing coercion and recognizing individual viewpoints. It also influences the development of subjective norms about different behaviors, potentially including recycling. Therefore, the third hypothesis was formulated:

H3: Autonomous support (AUT) positively influences subjective norms (SNO).

Chatzisarantis et al. (2007) offered insights into the impact of autonomous support on intentions, according to TPB, but did not specifically focus on recycling intentions. The research by Yousaf et al. (2022) emphasizes the role of social influences and perceived usefulness in technology adoption among older adults. While it discusses social influences, it does not directly relate to recycling intentions. Therefore, this citation should be removed as it does not directly support the claim. By integrating the relevant references, particularly (Liu et al., 2019), the study can provide a more comprehensive understanding of how autonomous support interacts with various components of the TPB and influences recycling intentions among users. Providing autonomous support, which includes promoting choice, participation, and recognizing individual perspectives, has a good influence on intentions to engage in recycling behaviors. Therefore, the fourth hypothesis was formulated:

H4: Autonomous support (AUT) positively influences recycling intentions (INT)

Integrated Regulation, TPB, and Recycling Intention

A recent study by Cheng et al. (2022) and Tan et al. (2024) investigates the integration of Self-Determination Theory (SDT) and the Theory of Planned Behavior (TPB) within a gamified learning context to enhance recycling intentions among youth during the COVID-19 period. The findings demonstrate that gamified experiences significantly influence recycling behaviors by fostering autonomous decision-making and enhancing intrinsic motivation. Similarly, Gajanova and Radišić (2021) explore how intrinsic motivation mediates the relationship between gamification and consumer behavior, emphasizing that gamified interventions designed to satisfy psychological needs can effectively promote sustained behavioral engagement. These studies collectively underscore the importance of leveraging gamification frameworks alongside motivational theories to strengthen individuals' perceptions of control and intention, ultimately driving sustained pro-environmental behaviors like recycling.

Integrated regulation (IRE) positively influences perceived behavioral control (PBC) concerning recycling behaviors. The understanding of the significance of recycling and the incorporation into personal identity gives a stronger sense of control and responsibility. The heightened sense of control arises from the congruence between individuals' inherent desires and the capacity to engage in recycling actions. Therefore, the following hypothesis is formulated:

H5: Integrated regulation (IRE) positively influences perceived behavioral control (PBC)

The study conducted by Williams et al. (2004) offers valuable insights into the impact of perceived autonomous support on autonomous motivation, which can be associated with attitudes. It did not directly examine the integrated regulation but showed the relationship between autonomous support and autonomous motivation. The results showed that confidence in self-support correlates with changes in motivation, potentially leading to more positive views toward behaviors. Based on the H6 hypothesis, using IRE enhanced a positive attitude toward recycling (ATT). People who want to help protect the environment due to personal reasons are mostly positive about recycling methods. These attitudes are affected by the happiness and satisfaction derived from engaging in pro-environmental activities. Therefore, the following hypothesis was proposed:

H6: Integrated regulation (IRE) positively influences attitudes (ATT).

Williams et al. (2004) offered valuable insights into the impact of perceived autonomous support on autonomous motivation, which can be associated with attitudes. This study did not directly explore integrated regulation but identified a relationship between the variables. The results showed that the perception of autonomous support is positively related to changes in motivation and leads to more positive views about behaviors. The study conducted by H6 shows that using IRE gives a positive attitude toward recycling (ATT). Individuals who feel a duty to protect the environment tend to develop positive views towards recycling methods. These attitudes are influenced by the contentment and gratification obtained from participating in environmentally mindful behaviors. Therefore, the following hypothesis was proposed:

H7: Integrated regulation (IRE) positively influences subjective norms (SNO)

Williams et al. (2004) did not directly focus on integrated regulation but established a foundation for comprehending the role of perceived autonomous support on autonomous motivation, which might affect intentions. The provision of autonomous support through choice and active engagement positively shapes intentions toward behaviors. Individuals who have a natural inclination to prioritize the preservation of the environment have a high chance of participating in recycling activities. They are more predisposed due to the gratification and sense of responsibility related to active engagement in environmental preservation. Therefore, the following hypothesis was formulated:

H8: Integrated regulation (IRE) positively influences intentions (INT)

The hypotheses emphasize the crucial impact of integrated regulation on individuals' perceptions, attitudes, norms, and intentions toward recycling, outlining the importance of internal motivations in promoting sustainable environmental behaviors.

Intrinsic Aspirations and TPB

Intrinsic ambitions (IAS) have a favorable impact on PBC, and this hypothesis is supported by Kasser & Ryan, (1996). The study presented that individuals with strong intrinsic aspirations toward environmental conservation tend to perceive recycling as within control. This is because the variable was in line with personal values and beliefs, leading to a greater sense of control. The innate inclination of individuals towards engaging in environmentally friendly tasks contributes to an increased sense of agency over recycling behaviors. The increased sense of control is attributed to the congruence between internal motivations and the capacity to engage in recycling. Therefore, the following hypothesis was formulated:

H9: Intrinsic aspiration (IAS) positively influences perceived behavioral control (PBC)

Inherent ambitions (IAS) promote favorable attitudes (ATT) towards recycling. Bamberg and Möser (2007) and Steg and Vlek (2009) provided evidence to support this hypothesis, suggesting that strong intrinsic aspirations towards sustainability lead to more positive attitudes towards recycling. This is because the variable is closely linked to personal values, which shape attitudes towards environmentally friendly behaviors. Individuals who are motivated by internal impulses to help protect the environment naturally develop positive attitudes toward recycling. These attitudes are influenced by the contentment and gratification obtained from participating in environmentally aware actions. Therefore, the following hypothesis was formulated:

H10: Intrinsic aspiration (IAS) positively influences attitudes (ATT)

IAS has a favorable influence on subjective norms (SNO) towards recycling. Thøgersen (2006) and Harland et al. (2007) provided evidence to support this hypothesis, suggesting that individuals with strong intrinsic aspirations are more inclined to perceive social norms favoring recycling. This is because intrinsic aspirations are often rooted in social and environmental values. When self-motive is adapted to recycling, it impacts how other social circles perceive and follow the practices. Engaging in environmentally conscientious behaviors motivates others to adopt these practices and strengthens the subjective norms that promote recycling. Therefore, the following hypothesis was formulated:

H11: Intrinsic aspiration (IAS) positively influences subjective norms (SNO)

IAS has a beneficial influence on recycling intention (INT), and Klöckner (2013) and Bamberg et al. (2003) provided evidence to support this hypothesis, suggesting that strong intrinsic aspirations towards sustainability tend to form intentions to recycle. This is because the variable motivates individuals to act in line with values and beliefs, leading to a greater intention to engage in recycling behavior. Those with a natural inclination to protect the environment are inherently predisposed to engage in recycling behaviors. The motivation to recycle was attributed to the satisfaction and duty that comes with actively participating in the preservation of the environment. Therefore, the following hypothesis was formulated:

H12: Intrinsic aspiration (IAS) positively influences recycling intentions (INT)

These hypotheses emphasize the crucial influence of inherent aspirations on individuals' perceptions, attitudes, norms, and intentions toward recycling, outlining the importance of internal motives in supporting sustainable environmental behaviors.

TPB and Recycling Intention

Peterson (2023) stated that individuals' perceptions of self-capacity to regulate behaviors had a significant influence on recycling intention. The study, titled "Extending the TPB in the Context of Recycling: The Role of Moral Norms and Demographic Predictors" published in *Resources Conservation and Recycling*, offers valuable insights into the impact of perceived behavioral control. It explores how an individual's moral beliefs, demographic traits, and the usual predictors of the TPB (Attitude, Subjective Norms, and Perceived Behavioural Control) interact to explain the intention to recycle. Therefore, the following hypothesis was proposed:

H13: Perceived behavioral control (PBC) positively influences recycling intentions (INT)

Attitudes toward recycling play a vital role in shaping the willingness to engage in recycling activities. Chan and Bishop (2013) stated that individuals with favorable

views toward recycling had a stronger inclination to participate in recycling activities. This prevents the need to encourage positive attitudes towards recycling behaviors. The study titled "Understanding Consumer Recycling Behaviour: Combining the Theory of Planned Behaviour and the Norm Activation Model" published in the *Family and Consumer Sciences Research Journal*, stated that attitudes indirectly impact recycling intentions through subjective norms, personal norms, and perceived behavioral control. This evidence shows the crucial influence of attitudes on the formation of recycling intentions. Therefore, the following hypothesis was proposed:

H14: Attitudes (ATT) positively influence recycling intentions (INT)

Subjective norms exert a substantial influence on individuals' intentions to engage in recycling, complementing personal views and attitudes. In a study published in *Group Processes & Intergroup Relations*, White et al. (2009) investigated the origins of normative impact on pro-environmental behaviors, emphasizing the influence of descriptive norms. These norms significantly influence pro-environmental behaviors and have been identified as strong predictors of intentions to recycle, both directly and through the effect of perceived behavioral control. Therefore, the following hypothesis was proposed:

H15: Subjective norms (SNO) positively influence recycling intentions (INT).

The TPB provides valuable insights into the determinants of recycling intentions by analyzing the complex interplay between perceived behavioral control, attitudes, and subjective norms. This understanding can guide targeted efforts and strategies aimed at promoting sustainable waste management practices. To encourage recycling and meet environmental sustainability objectives, organizations and policymakers should enhance the effectiveness of initiatives by considering factors such as individuals' perceived autonomy, attitudes towards recycling, and prevailing social norms within communities.

Gamified Learning and Autonomous Motivation

Studies have shown that incorporating gamification elements in recycling initiatives can increase individuals' autonomous motivation. According to Botetzagias et al. (2015), gamified recycling enhances the tendency to recycle even when receiving help from others. For example, Park and Ha (2014) stated that adding game-like elements to recycling enhances motivation and commitment, specifically through integrated control. The results outlined the effect of gamified recycling on engagement in recycling activities. Cheng & Cao (2024) also discovered that gamification stimulates intrinsic motivation, specifically in terms of recycling intentions. The results showed the intricate relationship between gamified recycling and intentions to recycle. The importance of incorporating motivating elements when creating gamified recycling programs that promote sustainable waste management was also outlined. Besides, Aguiar-Castillo et al. (2019) examined the use of a game-like app called WasteApp to encourage recycling among tourists in European towns. The study shows how gamification positively influences intention. It supported the idea that gamified recycling can effectively enhance self-driven efforts.

Therefore, the final hypothesis is as follows:

H16: Gamified recycling (GAM) moderates autonomous support (AUT) positively on recycling intention (INT)

A study showed that gamified recycling had a favorable effect when combined with integrated regulation. Cheng et al. (2022) investigated the relationship between motivation, intention, and recycling behavior among young people using an online Edcraft gamified learning platform. The results showed that gamification has a

positive effect on the connection between attitude and recycling intention. This supports the hypothesis that gamified recycling can enhance the positive influence of integrated regulation on recycling intention. Therefore, the following hypothesis was proposed:

H17: Gamified recycling (GAM) moderates integrated regulation (IRE) positively on recycling intention (INT)

The use of gamification in recycling significantly influences intrinsic aspirations, subsequently increasing the intention to recycle. It is important to acknowledge that there is no explicit reference to how gamified recycling affects the moderation of intrinsic aspiration on recycling intention. The idea of the influence of gamification on motivation and intention towards recycling helps enhance the understanding of the benefit of gamified approaches. Therefore, the following hypothesis was proposed:

H18: Gamified recycling (GAM) moderates intrinsic aspiration (IAS) positively on recycling intention (INT)

Framework

This study framework combines SDT with the TPB to investigate the factors that impact recycling intentions as shown in Figure 1. According to the hypothesis, autonomous support (AUT) increases perceived behavioral control (PBC), attitudes (ATT), and subjective norms (SNO), which subsequently have a beneficial impact on recycling intentions (INT). Similarly, the concept of integrated regulation (IRE) aims to improve perceived behavioral control (PBC), attitude (ATT), subjective norm (SNO), and intention (INT). Intrinsic aspirations (IAS) are also believed to have a favorable impact on perceived behavioral control (PBC), attitude (ATT), subjective norm (SNO), and intention (INT). Additionally, the study investigated the influence of gamified recycling (GAM) on the relationship between AUT, IRE, IAS, and INT. The results showed that autonomous assistance and integrated regulation promote intrinsic motivation, leading to increased perceived control, favorable attitudes, and supportive norms toward recycling.

The incorporation of gamification features such as incentives, ranking systems, and monitoring of progress is expected to enhance these connections, fostering a stronger commitment to recycling. Further studies should investigate gender disparities, specific components of gamification, and diverse platforms to gain a deeper understanding and improve recycling behaviors within local communities.

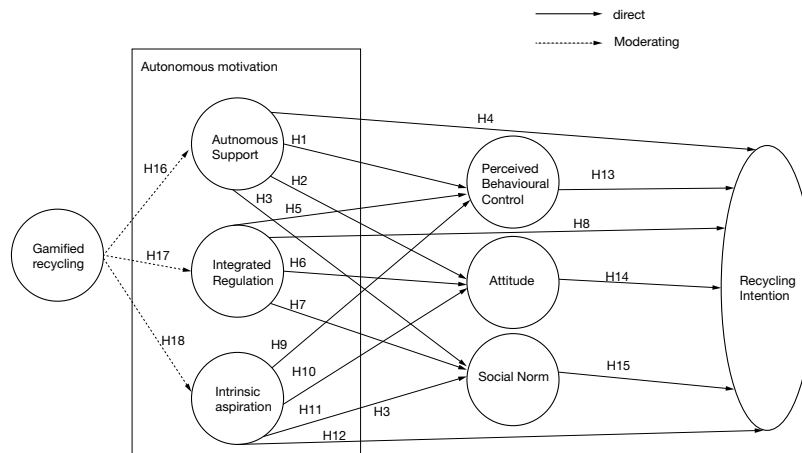


Figure 1: Conceptual Framework

Methodology

Data was collected after a two-hour online webinar on self-directed game-based activities. The webinar was organized by two private universities, in Indonesia and Malaysia. The participants were 24 full-time and part-time students from different backgrounds who actively engaged in online activities, including a 15-minute quiz designed to be fun using Quizizz. After the webinar, a Google Forms survey was distributed to attendees to gather feedback. Among the 424 students who attended, 197 completed and returned the questionnaires, totalling a response rate of 46%.

The questionnaire comprised nine parts, each aimed at assessing different aspects of participants' perceptions and behaviors regarding sustainable actions. A Likert scale ranging from 1 (strong disagreement) to 5 (strong agreement) was adopted to express the level of agreement and support for various statements. The survey contained 51 items, organized into distinct categories. These include items related to demographic information, IRE, IAS, gamified recycling, SNO, ATT, PBC, and INT respectively. The questionnaire items were adapted from established studies to ensure validity in assessing each construct related to sustainability behaviour. Questions on Autonomy Support were derived from the works of Hagger et al. (2002) and Williams et al. (2006), exploring the role of autonomy in fostering motivation. Integrated Regulation (IRE) items followed the framework by De Jorge-Huertas and De Jorge-Moreno (2021), which links recycling behaviors with individual identity and values. Intrinsic Aspiration (IAS) questions drew on concepts from Shahzad et al. (2023), focusing on enjoyment and aspirational aspects of recycling. Gamified Recycling was inspired by Cheng et al. (2022), examining how game-like elements motivate behavior. Social Norms (SNO) were adapted based on Bonan et al. (2020), Kavvouris et al. (2020), which consider peer influence on recycling. Attitude (ATT) items reflect research by Klein et al. (2022), Siegel et al. (2014). Perceived Behavioral Control (PBC) reflects TPB studies, while Recycling Intention (INT) questions align with the approach of Ozturk (2015), emphasizing willingness and planning in recycling activities.

Demographic analysis

Among the 197 people who filled out the survey, a balanced gender distribution of 95 males (48.2%) and 102 females (51.8%) was observed. The majority were in the age of 18-25 years old, (60.4%), while 70.6% were degree holders, followed by high school leavers (27.9%). Most participants were private employees (49.2%) and students (41.6%), as shown in Table 1.

Table 1: Demographic Data of the Participants

Demographic	Item	Frequency	Percentage
Gender	Male	95	48.2
	Female	102	51.8
Age	18–25 years old	119	60.4
	26–30 years old	40	20.3
	31–40 years old	31	15.7
	41–50 years old	6	3.0
	Below 18 years old	1	0.5
Education	Bachelor's degree	139	70.6
	High School	22	27.9
	Graduate degree	3	1.5

Demographic	Item	Frequency	Percentage
Career	Civil Servant	7	3.5
	Housewife	3	1.5
	Private Employee	96	49.2
	Student	82	41.6
	Entrepreneur	8	4.1
Do you recycle often?	No	91	46.2
	Yes	106	53.8
How often you do recycle?	Once a week	36	18.3
	Once a month	28	14.2
	Never	133	67.5
What do you recycle?	Never do recycle for these items	15	7.6
	Iron Item	1	0.5
	Plastic Items	86	43.7
	Paper Items	44	22.3
	Food-waste	49	24.9
	Cloth Items	2	1.0
Do you think the Webinar participation approach helps in recycling packaging without external rewards?	Yes	177	89.8%
	No	20	10.2%

Note. N=197 participants

Questionnaires were administered to gather information on recycling frequency. A total of 106 out of 197 participants, were reported to engage in recycling activities regularly. The results showed a positive attitude towards caring for the earth and long-term sustainability practices. However, 133 participants reported an infrequent participation in recycling habits. A total number of 36 responses showed once-a-week recycling, while 28 engaged in the activity once a month. The results suggested an opportunity for encouraging more consistent recycling behavior. Based on types of materials, 86 (43.7%), 49 (24.9%), 44 (22.3%), 2 (1%), and 1 (0.5%) recycled plastic, food trash, paper, cloth, and iron. The last question assessed whether the self-directed game-based approach helps recycle packaging without outside rewards. A significant majority of 177 participants (89.8%), agreed with the autonomous gamified approach, while only 20 (10.2%) disagreed, signifying a very low percentage.

Analysis and Results

The analysis was conducted using SmartPLS, adopting structural equation modeling (SEM) to examine the relationships between identified variables. Data collected through post-webinar surveys were processed to assess the validity and reliability of the constructs. This was performed using measures such as factor loadings, composite reliability (CR), and average variance extracted (AVE). The analysis focused on exploring the structural relationships between integrated regulation, intrinsic aspiration, social norms, attitudes, perceived behavioral control, and recycling intentions. The results provided insights into the factors influencing sustainable behaviors among the participants.

Measurement Model Assessment

Convergent validity

This study assessed the factor loadings to evaluate the strength of the association between the different assessment items and the respective constructs. As shown in Table 2, there is a strong connection between owned items and the structures when loading factors are high. At 0.8, factors such as AUT6, IRE3, GAM2, and INT5 show strong connection. Those with smaller loading factors suggest weaker connections or potential concerns about measurement accuracy. For example, PBC2, having a loading factor of 0.434, may require further examination to determine its fit with the construct. Cronbach's alpha coefficients provide insights about how consistent thoughts are with each other and a higher number signifies greater reliability. When the score is greater than 0.9, as observed in the IRE and INT models, it shows a high level of internal consistency. However, the idea of AUT has a Cronbach's alpha score of 0.909, suggesting slight inconsistencies among the components. This warrants a more detailed examination of some specific elements within the construct to better understand the impact on overall reliability. Composite reliability scores offer a comprehensive assessment of construct reliability, considering both internal consistency and the number of indicators. The constructs of IRE and INT show strong reliability, with scores exceeding 0.9. However, categories such as ATT and PBC had slightly lower composite reliability scores, signifying potential areas for enhancing the consistency of these structures. The Average Variance Extracted (AVE) values reflect the extent to which measurement items capture the variance of the respective constructs. Its higher values show that the items explain a greater proportion of the difference. Constructs such as IRE and INT have AVE values exceeding 0.8. This signified effectiveness in capturing a substantial portion of the variance. In contrast, PBC and AUT have lower values, suggesting the ability to explain a smaller portion of the variance within the respective models. To assess potential multicollinearity among the measurement items within a construct, the VIF was adopted as a statistical measure. Multicollinearity concerns arise when VIF is greater than 3 or 5. In this study, several variables show values greater than 3, suggesting the presence of multicollinearity issues. For instance, the factors protected by IRE and INT structures have VIF values higher than 3. This signifies potential concerns that warrant further investigation to ensure the construct's validity.

Table 2: Measurement Model

Constructs/ Items	Loading Factors	Cronbach Alpha	Composite Reliability	Average Variance Extracted	Variance Inflation Factor
Autonomous support (AUT)		0.909	0.927	0.613	
AUT1	0.742				2.136
AUT2	0.664				1.971
AUT3	0.802				2.410
AUT4	0.771				2.580
AUT5	0.788				2.323
AUT6	0.840				3.504
AUT7	0.813				2.514
AUT8	0.830				2.674
Integrated Regulation (IRE)		0.926	0.947	0.818	
IRE1	0.902				3.234
IRE2	0.914				4.144
IRE3	0.929				4.422
IRE4	0.872				2.498

Constructs/ Items	Loading Factors	Cronbach Alpha	Composite Reliability	Average Variance Extracted	Variance Inflation Factor
Intrinsic Aspiration (IAS)		0.921	0.937	0.680	
IAS1	0.801				2.987
IAS2	0.818				3.185
IAS3	0.786				2.267
IAS4	0.853				3.665
IAS5	0.880				4.320
IAS6	0.810				3.056
IAS7	0.820				2.777
Gamified Recycling (GAM)		0.925	0.944	0.771	
GAM1	0.853				2.882
GAM2	0.921				4.319
GAM3	0.895				3.263
GAM4	0.865				2.698
GAM5	0.854				2.611
Perceived Behavioral Control (PBC)		0.709	0.792	0.509	
PBC1	0.534				2.037
PBC2	0.434				1.937
PBC3	0.875				2.009
PBC4	0.892				2.045
Attitude (ATT)		0.914	0.936	0.747	
ATT1	0.908				4.580
ATT2	0.744				1.706
ATT3	0.880				4.249
ATT4	0.879				2.723
ATT5	0.900				4.304
Social Norms (SNO)		0.924	0.946	0.813	
SNO1	0.897				3.569
SNO2	0.926				4.215
SNO3	0.900				3.124
SNO4	0.883				2.524
Recycling Intention (INT)		0.950	0.960	0.801	
INT1	0.880				3.191
INT2	0.841				2.900
INT3	0.892				3.688
INT4	0.935				6.082
INT5	0.942				6.502
INT6	0.876				3.560

Discriminant Validity

The Fornell-Larcker criterion (Fornell & Larcker, 1981) is a widely accepted method for assessing discriminant validity in structural equation modeling. This criterion includes comparing the square root of the AVE for each construct against the correlations with others in the model. In this study, the square roots of the AVE values for each construct consistently exceeded the correlations with others, signifying strong discriminant validity. For example, Attitude has a square root of 0.864, which surpasses its correlations with other constructs, as shown in Table 3.

The results were the same across other constructs such as Autonomous Support, Gamified Recycling, Integrated Regulation, Intrinsic Aspiration, Perceived Behavioural Control, Recycling Intention, and Social norms. The square root of AVE values ranged from 0.498 to 0.902, confirming that each construct captures distinct variance and represents unique theoretical concepts, establishing clear differentiation within the model.

Table 3: Fornell-Larcker Criterion

Constructs	Attitude	Autonomous support	Gamified Recycling	Integrated Regulation	Intrinsic Aspiration	Perceived Behavioral Control	Recycling Intention	Social Norm
ATT	0.864							
AUT	0.623	0.783						
GAM	0.812	0.712	0.878					
IRE	0.611	0.705	0.625	0.904				
IAS	0.801	0.709	0.839	0.717	0.824			
PBC	0.716	0.630	0.759	0.571	0.725	0.713		
INT	0.757	0.650	0.846	0.640	0.805	0.822	0.895	
SNO	0.498	0.712	0.653	0.548	0.580	0.565	0.617	0.902

Assessment of Structural Model

The results of the hypothesis testing, presented in Table 4, explain the relationships between GAM, AUT, IRE, IAS, and various behavioral and attitudinal outcomes. The strong associations observed between AUT and PBC, ATT, as well as SNO suggest that individuals who experience higher levels of autonomous support tend to perceive greater control over actions, hold more positive attitudes, and are more influenced by societal norms. These results were in line with SDT, which emphasizes the role of autonomy in shaping behavior and motivation. However, the weaker relationship between AUT and intention (INT) signifies the complexity of cognitive processes and suggests the need for further investigation.

Based on the significant connections between IRE and INT, individuals who are intrinsically motivated and have integrated a behavior into an identity are more inclined to show strong intentions of engagement. This emphasizes the importance of internalization and personal identification in shaping behavioral intentions. Similarly, the robust relationships between IAS and PBC, ATT, and SNO suggest that those with intrinsic aspirations are more likely to feel empowered, show positive attitudes, and be influenced by social norms. The results outline the crucial role of intrinsic motivation in guiding behavior and social influence.

Table 4: Hypothesis Testing

No	Hypothesis	β	T statistics	P values	Result
1	AUT > PBC	0.229	2.974	0.003	Supported
2	AUT > ATT	0.097	1.404	0.161	No
3	AUT > SNO	0.593	6.136	0.000	Supported
4	AUT > INT	-0.064	0.959	0.337	No
5	IRE > PBC	0.013	0.139	0.890	No
6	IRE > ATT	0.036	0.529	0.597	No
7	IRE > SNO	0.032	0.266	0.790	No
8	IRE > INT	0.123	1.970	0.049	Supported
9	IAS > PBC	0.554	6.128	0.000	Supported
10	IAS > ATT	0.706	10.886	0.000	Supported
11	IAS > SNO	0.137	1.344	0.179	No
12	IAS > INT	0.214	2.669	0.008	Supported
13	PBC > INT	0.348	5.192	0.000	Supported
14	ATT > INT	0.038	0.634	0.526	No
15	SNO > INT	0.076	1.285	0.199	No
16	GAM x AUT > INT	0.035	0.512	0.609	No
17	GAM x IRE > INT	-0.192	2.682	0.007	Supported
18	GAM x IAS > INT	0.146	2.196	0.028	Supported

Table 5: R-Square and Q-Square Evaluation

Constructs	R-square	R-square adjusted	Q-Square
Attitude	0.648	0.642	0.636
Perceived Behavioral Control	0.552	0.545	0.528
Recycling Intention	0.824	0.814	0.735
Social Norm	0.519	0.511	0.488

Moderation analysis

In this study, certain relationships such as the influence of GAM and AUT on INT, as well as the impact of GAM and IRE on INT, show strong support for the association between gamified learning activities and recycling intentions. This was in line with the results from studies evaluating the effectiveness of gamified learning in encouraging recycling behavior (Cheng et al., 2022). Additionally, the TPB has been crucial in explaining the determinants of recycling intentions, particularly the roles of attitudes, subjective norms, and perceived behavioral control (Park & Ha, 2014). This suggests that making recycling more like a game or providing more personal support might not have a direct impact.

The TPB is instrumental in understanding these determinants of recycling intentions, presenting the roles of attitudes, subjective norms, and perceived behavioral control. It states that the desire to recycle is influenced by attitude, social pressures (subjective norms), and perception of the ease or difficulty of the activity (perceived behavioral control). However, gamification and personal support may not have a direct impact on recycling plans. This shows that the interventions can increase engagement but may not independently translate into behavioral intentions without addressing other motivational factors.

The literature discusses the relationship between intrinsic aspirations and factors like perceived behavioral control, mood, and subjective norm. Deci and Ryan (2020) emphasized the role of intrinsic motivation in influencing behavior and psychological functioning, including perceived behavioral control. Similarly, studies by Sheldon and Elliot (1999) and Vansteenkiste et al. (2019) examined how intrinsic aspirations affect mood and subjective norms. This signified the need for a deeper understanding of the impact of the variable on behavior.

The study shows the complex interactions between motivational factors, environmental interventions, and behavioral outcomes. It presents the complexity of human behavior in recycling and environmental protection, suggesting the need for further investigations to enhance understanding. These insights will be instrumental in developing effective policies and interventions to promote sustainable behavior.

In terms of the structural equation model, the R-square values show the extent of variance in endogenous constructs explained by exogenous factors (Hair et al., 2019; Rachmawati & Suyatno, 2021). According to Table 5, constructs such as "Recycling Intention" and "Attitude" have high R-square values, suggesting better explanatory power (Hair et al., 2019; Fernandes et al., 2019). Adjusted R-square values provide a more refined assessment, considering the number of predictors (Hair et al., 2019; Fernandes et al., 2019). Additionally, Q-square values evaluate predictive accuracy, with higher values representing better prediction (Shmueli et al., 2019). Therefore, evaluating R-square, adjusted R-square, and Q-square values is crucial for understanding the explanatory and predictive capabilities of structural equation models (Hair et al., 2019; Rachmawati & Suyatno, 2021; Fernandes et al., 2019; Shmueli et al., 2019).

Table 6: F-Square Evaluation

	Path	F-Value	Effect Size
ATT	INT	0.002	No Effect
AUT	ATT	0.011	No Effect
	PBC	0.049	Small
	INT	0.007	No Effect
	SNO	0.305	Medium
IRE	ATT	0.002	No Effect
	PBC	0.000	No Effect
	INT	0.032	Small
	SNO	0.001	No Effect
IAS	ATT	0.570	Large
	PBC	0.276	Medium
	INT	0.052	Small
	SNO	0.016	No Effect
PBC	INT	0.251	Medium
SNO	INT	0.014	No Effect
GAM x IAS	INT	0.033	Small
GAM x IRE	INT	0.054	Small
GAM x AUT	INT	0.002	No Effect

Notes. f-square is effect size (≥ 0.02 is small; ≥ 0.15 is medium; > 0.35 is large) (Cohen, 1988)

Discussions

This study investigates factors influencing sustainable behavior within families or households, specifically targeting recycling intentions. The results emphasize the significance of autonomous support, integrated regulation, and intrinsic aspiration in shaping recycling attitudes and behavior.

AUT showed a strong connection with PBC, ATT, and SNO. This was in line with SDT, which emphasizes autonomy as a behavioral driver, to enhance control, positive recycling attitudes, and social responsiveness. However, a direct AUT-recycling intention (INT) relationship lacked strong support, prompting further exploration of the complex psychological process (Park & Ha, 2014).

IRE showed a significant positive relationship with recycling intention (INT), featuring the importance of internalizing recycling behaviors for solidifying intentions. Additionally, IAS was strongly correlated with PBC, ATT, and SNO, presenting the role of intrinsic motivation in enhancing perceived control, positive recycling attitudes, and social susceptibility (Nguyen & Lobò, 2017; Cheng et al., 2022).

As hypothesized, perceived behavioral control, attitudes, and subjective norms all influenced recycling intentions. This emphasized the role of these factors in shaping household recycling behavior. Significantly, GAM positively moderated the relationships between AUT, IRE, IAS, and recycling intention, signifying the potential of gamification strategies to enhance sustainable behavior (Cheng et al., 2021). The framework highlights how different types of autonomous motivation—support from others, internalized values, and personal enjoyment—enhance recycling intentions by strengthening attitudes, perceived control, and social norms. Gamified recycling acts as a booster, making recycling more engaging and increasing the likelihood of sustainable behavior. This suggests that combining intrinsic motivation with gamified elements can effectively encourage household recycling.

Sustainable Design Ideas and Solutions

The results offer actionable insights for household sustainability, presenting autonomous decision-making and intrinsic motivation as crucial factors for promoting environmentally responsible household behaviors. Furthermore, sustainable design solutions are proposed by incorporating a gamified framework into promoting sustainable and pro-environmental behaviors. While gamified approaches have received positive and receptive feedback in business settings, applying these strategies to household recycling across various localities, scales, or community groups presents significant potential. Recyclable materials, ranging from metals and clothing to plastic and paper, can be used to regenerate other useful materials or designs. Jalil and Shaari (2023) explored sustainable children's clothing design with multifunctional ability. By integrating key gamification elements, such as tasks, achievements, and leaderboards, into the recycling process, it can be transformed into a more engaging activity. This method leverages individuals' basic psychological instinct to compete and succeed, making recycling a possible fun and interesting endeavor in everyday life.

The combination of intrinsic and extrinsic factors would be more impactful in driving recycling behaviors for sustainable households and communities. It is important to acknowledge that gamified engagement can change the perception of behavioral control and feelings associated with recycling. These in-depth thinking processes related to gamification deserve future investigations.

Conclusions

In conclusion, the results represented a significant contribution to the field of sustainable development. This study adopted the principles of SDT and the TPB to explain the factors that encouraged household members to adopt recycling. The results emphasized the important intrinsic motivation in sustaining autonomous recycling behavior. From the perspective of SDT, individuals who perceived greater autonomous support tended to develop positive attitudes toward sustainable behaviors. This sense of autonomy enhanced the feeling of control over actions and was in line with societal norms. The observations correlated with the SDT principles, which presented relatedness, competence, and autonomy as key factors shaping intrinsic motivation and behavior.

The data support the TPB's assertion that attitudes, subjective norms, and perceived behavioral control significantly influence intentions to act. These factors were applicable in a pro-environmental context and contributed to fostering autonomous recycling behaviors.

Households play a crucial role in promoting a more sustainable society by empowering individuals to make eco-friendly choices. Integrating gamification into different aspects of planning experiences, including educational activities, household routines, and community engagement initiatives, further enhanced this effort.

The questionnaires may not have provided a comprehensive representation of the larger community, potentially limiting the generalizability of the results. Furthermore, the dependence on self-reported data could have introduced biases, such as social desirability bias, affecting the accuracy of the outcomes. The study primarily examined internal motivation and gamification, potentially neglecting other significant elements such as economic incentives and external laws.

This study showed that intrinsic motivation and gamified engagement significantly influenced recycling behavior, contributing to SDG 12 and the broader goals of sustainable development. Environmentalists, policymakers, and educators can leverage these insights to advocate for innovative sustainable design and solutions.

To advance investigations on recycling and sustainable development among local communities, future studies should explore the impact of gender differences, identify specific gamification elements such as rewards, leaderboards, and progress tracking, as well as evaluate the role of various platforms in promoting sustainable practices. These additional directions will enhance the global sustainability plan for SDG 12 and foster a more sustainable future.

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