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Research Article

A Hybrid SEM-ANN Model for Predicting Purchase Intention Toward Recycled PET Products: Evidence from Indonesian Generational Segments

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Abstract: The escalating plastic waste crisis in Indonesia calls for a transition toward a circular economy, particularly through the adoption of recycled Polyethylene Terephthalate (rPET) products. Despite their environmental benefits, consumer acceptance remains limited due to concerns over quality, cost, and insufficient product information. This study employs a hybrid framework that combines partial least squares structural equation modeling (PLS-SEM) and artificial neural networks (ANN), complemented by multi-group analysis (MGA), to identify the behavioral, ethical, and cognitive determinants of purchase intention (PI) toward rPET products. A survey involving 406 respondents from Generations X, Y, and Z provides empirical evidence of both linear and nonlinear behavioral mechanisms. PLS-SEM captures direct and indirect effects among extended Theory of Planned Behavior (TPB) constructs, while ANN uncovers hidden nonlinear relationships and variable importance rankings. The results show that Willingness to Pay (WTP) is the most decisive predictor of PI, followed by Environmental Literacy (EL) and Moral Obligation (MO), which indirectly influence PI through Attitude (ATT). Moreover, MGA reveals generational heterogeneity: Generation Z responds most strongly to WTP and Perceived Behavioral Control (PBC), whereas Generation X emphasizes Subjective Norms (SN). These findings underscore the importance of affordability, ethical framing, and literacy enhancement as critical levers for policymakers and industry stakeholders seeking to accelerate the adoption of sustainable rPET in emerging economies.

Keywords: Artificial neural networks; Circular economy; Multi-generation; PLS-SEM; Purchase intention; rPET

1. Introduction

The rapid growth of plastic consumption in Indonesia has worsened environmental challenges, particularly in post-consumer waste management. Polyethylene terephthalate (PET) remains the most commonly used plastic type for single-use packaging due to its favorable properties, including durability, transparency, and light weight (Farida et al., 2024). Despite its recyclability, a significant portion of PET waste ends up in landfills or the ocean, contributing to pollution and microplastic contamination (Chae and An, 2018; Li et al., 2016).

Evidence shows that compared with virgin PET, the utilization of recycled PET (rPET) reduces greenhouse gas emissions by up to 26% and energy consumption by 84% (Zhang, 2013), and life-cycle assessments further confirm that PET bottle-to-fiber recycling achieves significant reductions in energy use and emissions (Shen et al., 2010). Consumer adoption of rPET products remains limited because of quality dubiety issues (Ruokamo et al., 2022), affordability constraints (Rizkalla, 2020), and a lack of reliable information infrastructure (Filho et al., 2019). The circular economy emphasizes the need for closed-loop systems and efficient resource use to minimize waste and retain material value, positioning rPET as a key enabler of this transition

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(Ghisellini et al., 2016). The transition toward a circular economy requires an understanding of the behavioral drivers of sustainable product adoption in emerging economies (Farida et al., 2024; Nguyen et al., 2017).

Understanding consumer behavior is crucial to bridge the gap between environmental policies and market acceptance (Nguyen et al., 2017). The Theory of Planned Behavior (TPB) (Botetzagias et al., 2015; Ajzen, 1991) posits that Attitude (ATT), Subjective Norms (SN), and Perceived Behavioral Control (PBC) jointly influence behavioral intentions (Botetzagias et al., 2015; Ajzen, 1991). Nevertheless, studies increasingly argue that the classical TPB undermines behavioral variability in green consumption contexts (Rozenkowska, 2023; Paul et al., 2016). Consumer decision-making toward sustainable products is a multidimensional process shaped by cognitive, affective, and contextual factors that extend beyond traditional attitudinal frameworks (Kumar et al., 2017). Recent extensions incorporate Moral Obligation (MO) that captures individual's internal sense of ethical responsibility toward pro-environment actions (Yildirim et al., 2025), Environmental Literacy (EL) that reflects the cognitive understanding and awareness consumers hold regarding recycled materials and sustainability impacts (Sun, 2020), and Willingness to Pay (WTP) that represents consumers' economic readiness and financial commitment to choose environmentally friendly options (Tan et al., 2017). Together, these constructs capture the ethical concerns, cognitive awareness, and economic commitment that shape sustainable purchasing decisions. These additional constructs enhance explanatory power by reflecting moral framing, literacy-driven attitudes, and consumers' financial readiness to adopt eco-friendly products (Vicente et al., 2021; Rana and Paul, 2017).

Generational theory posits that individuals born within the same historical period share sociocultural experiences that shape their values, attitudes, and behavioral orientations, including their responses to sustainability and technological adoption. These cohort-based experiences create stable psychological patterns across generations, influencing how they interpret risks, evaluate information, and make ethical or economic trade-offs (Singh and Prakash, 2020; Dimock, 2019; Kupperschmidt, 2000). Generational theory provides a conceptual lens for understanding why environmental motivations, price sensitivity, and moral considerations vary systematically across age cohorts in the context of sustainable consumption. This theoretical foundation is essential for explaining heterogeneous responses to circular economy products, particularly rPET, in emerging markets where socioeconomic transitions differ across generations.

Consistent with widely used cohort definitions, this study classified Generation X as individuals born between 1965 and 1980, Generation Y as individuals born between 1981 and 1996, and Generation Z as individuals born between 1997 and 2012 (Singh and Prakash, 2020; Dimock, 2019). Evidence shows that Generation X is commonly characterized as pragmatic and price-oriented (Kupperschmidt, 2000), whereas Generation Y values convenience-driven and digital information (Ma et al., 2025). Indonesian empirical research further shows that Generations X and Y exhibit behavioral patterns in decision-making contexts (Ardi, Angel, and Afif, 2024; Ardi, Widjaya, et al., 2024). Generation Z is widely recognized as the most environmentally aware cohort (Singh and Prakash, 2020; Dimock, 2019).

Indonesian evidence demonstrates that these generational distinctions translate into meaningful differences in sustainable consumption preferences, particularly for recycled-content products such as rPET. Empirical studies show that younger cohorts benefit from higher environmental literacy and greater exposure to sustainability-oriented education and public campaigns, which increase their responsiveness to recycled materials (Idaa et al., 2025; Nisa et al., 2025; Farida et al., 2024). Meanwhile, older cohorts tend to exhibit greater price sensitivity and more substantial doubts about recycled materials' durability and safety, which lowers their likelihood of choosing recycled plastic-based goods (Handayani et al., 2025). These cohort-specific variations are directly relevant to rPET consumption because the acceptance of recycled materials heavily depends on consumers' trust, values, and willingness to adopt sustainable alternatives.

However, existing studies rarely integrate these demographic nuances with hybrid modeling approaches that combine structural equation modeling (SEM) for explanatory analysis and

artificial neural networks (ANN) for predictive accuracy (Bhatt et al., 2022; Shmueli et al., 2016), leaving a critical gap in understanding both linear and nonlinear behavioral mechanisms driving rPET adoption across diverse generational segments in developing countries.

Most behavioral studies rely on linear mechanisms, which assume proportional and sequential causal relationships between antecedent variables and behavioral outcomes, as reflected in the general linear model in psychology and input-output frameworks in neuroscience, illustrating how extraordinary events disrupt behavior in habitual domains (Yu and Chen, 2012; Yu and Chen, 2010). However, real human behavior often emerges from nonlinear mechanisms within socioeconomic systems involving dynamic interactions, feedback loops, and interdependencies, which can produce emergent or unpredictable behavioral patterns (Jordanov and Nikolova, 2019; Helbing, 2009). Clarifying this distinction is essential because recognizing nonlinearity enables behavioral models to capture complex, context-dependent decision-making processes more accurately.

To address this gap, this study applies a hybrid Partial Least Squares-Structural Equation Modeling (PLS-SEM) and ANN approach, complemented by MGA, to examine the behavioral, cognitive, and ethical determinants of purchase intention toward rPET products across Generations X, Y, and Z in Indonesia. By integrating extended TPB constructs with nonlinear predictive modeling, this study contributes to theory by uncovering generational heterogeneity in sustainable consumption behavior. It provides practical insights for policymakers and industry stakeholders seeking to accelerate the transition toward circular economy practices in developing countries (Farida et al., 2024; Queiroz et al., 2021; Wang et al., 2021).

2. Methods

2.1 Conceptual Model and Hypotheses

The conceptual model draws on the TPB (Ajzen, 1991) and is enriched with extended constructs such as Moral Obligation (MO), Willingness to Pay (WTP), and Environmental Literacy (EL). The model hypothesizes that these factors influence Purchase Intention (PI) both directly and indirectly through mediating constructs. Figure 1 illustrates the hypothesized relationship between the TPB variables and extensions. The constructs include Attitude (ATT), Subjective Norm (SN), Perceived Behavioral Control (PBC) (Vicente et al., 2021; Sun, 2020; Tan et al., 2017; Ajzen, 1991), Environmental Literacy (EL) (Yildirim et al., 2025), Moral Obligation (MO), and Purchase Intention (PI) (Rozenkowska, 2023).

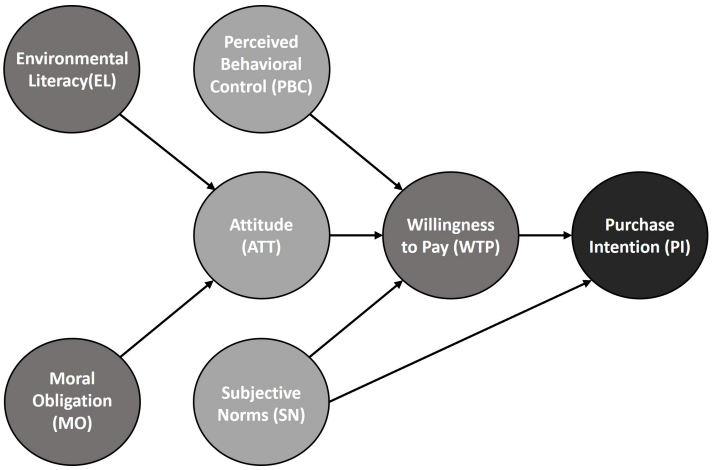

Figure 1 Conceptual Framework and Hypothesized Model (TPB-Based) for rPET Purchase Intention

Based on prior empirical findings that highlight the roles of attitudinal, normative, and perceived control variables in sustainable consumption contexts (Farida et al., 2024; Nguyen et al., 2017), this study formulates a set of hypotheses linking ATT, SN, PBC, EL, MO, and

WTP to PI, incorporating both direct and mediated effects. The color differentiation in Figure 1 visually distinguishes the construct types within the extended TPB framework. The lighter gray circles represent the core TPB constructs (ATT, SN, and PBC), which together constitute the original TPB's theoretical explanatory capacity. The medium-gray circles denote the extended constructs (TPB, MO, and WTP), which capture ethical, cognitive, and economic dimensions added to improve the model's explanatory power. The darkest circle represents the dependent variable (PI), which summarizes consumers' final behavioral intention toward rPET products. This graded color separation clarifies the theoretical extension of traditional TPB components to account for multidimensional drivers of sustainable purchase behavior.

2.2 Integrated Methodological Framework of the Study

This study adopts an integrative approach that combines theoretical, analytical, and comparative procedures to summarize the methodological progression. The extended TPB framework establishes the conceptual foundation, followed by sequential analysis using PLS-SEM for linear causality and ANN for nonlinear prediction. The final MICOM-MGA stage verifies model invariance and captures generational variation across cohorts, ensuring analytical robustness and contextual relevance.

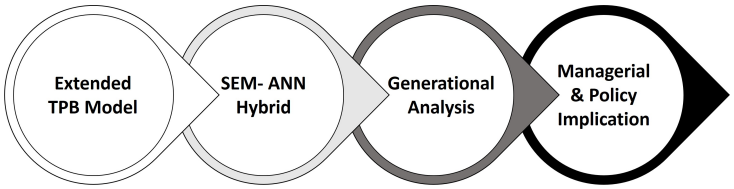

Figure 2 Integrated Methodological Framework of the Study

The figure illustrates the study's overall methodological architecture, showing how the theoretical foundation, hybrid analytical stages, and generational comparison are interconnected. Each component contributes to continuous flow—from model construction and validation to predictive and comparative assessment—culminating in insights that inform generationally responsive strategies for sustainable rPET adoption.

Each method contributes a layer of behavioral insight to clarify how cohort-responsive strategies emerge from the analytical design. The SEM reveals the principal linear determinants of intention, ANN exposes nonlinear reinforcement patterns within these relationships, and MICOM-MGA reveals how their relative influence varies across Generations X, Y, and Z. Together, these complementary outputs generate a differentiated understanding of each cohort's most salient psychological levers, forming the empirical basis for generation-specific strategic recommendations.

2.3 Size of the dataset

We developed a structured questionnaire using validated items from prior TPB-based studies, which were measured on a 5-point Likert scale (Tommasetti et al., 2018; Tan et al., 2017). A pilot test with 30 respondents confirmed the reliability and clarity of the results. The final survey was distributed online and offline across multiple Indonesian regions between September and December 2024. Most respondents resided on Java Island (83.33%), while the remaining 16.67% originated from regions outside Java, reflecting Indonesia's demographic reality, as Java is the most populous and serves as the country's primary economic center. All participants provided informed consent, and data confidentiality was maintained in accordance with ethics guidelines.

A total of 406 valid responses were obtained from 47.6% male and 52.4% female participants. The generational distribution was as follows: 23.5%, 41.7%, and 34.8% for Generation X, Y, and Z, respectively. Educational attainment was relatively high, with 62.1% holding at least a bachelor's degree, 28.1% holding a diploma-level qualification, and 16.1% having secondary

education. Occupations included 48.6% professionals, 32.7% students, and 18.7% entrepreneurs. The monthly income reflected Indonesia's middle-class profile: 46.2% of the population earned below IDR 5 million, 37.4% earned between IDR 5 and 10 million, and 16.4% earned above IDR 10 million. This demographic diversity supports robust multi-group and predictive analyses (Tan et al., 2017).

2.4 Measurement model assessment

The measurement model was evaluated using SmartPLS 4.0 following established guidelines (Hair et al., 2021). Internal consistency reliability was confirmed as all constructs reported Cronbach's alpha and CR values above the 0.7 threshold (Lin et al., 2017). Convergent validity was ensured with Average Variance Extracted (AVE) values that surpassed 0.5, indicating that each latent construct explained at least half of the variance in its indicators (Hair et al., 2021). Discriminant validity was assessed using three multiple criteria, including cross-loadings, the Fornell-Lacker criterion, and the Heterotrait-Monotrait (HTMT) ratio, with all HTMT values remaining below a conservative cutoff of 0.85 (Henseler et al., 2015). This study examined the variance inflation factor (VIF) scores and confirmed that all values remained within acceptable limits to rule out multicollinearity. Collectively, these results demonstrate that the measurement model met all reliability and validity requirements, permitting further structural analysis.

Following measurement validation, the structural model was tested using PLS-SEM to estimate direct and indirect relationships among constructs. This study used bootstrapping with 5,000 resamples to assess the statistical significance of each hypothesized path (Hair et al., 2021). This study used the coefficient of determination (R2) for endogenous variables to evaluate model explanatory power, effect sizes (f2) to classify the substantive impact of each path according to Cohen's criteria, and predictive relevance (Q2) to reinforce the model's robustness.

2.5 Artificial Neural Network (ANN) Analysis

Previous computational and behavioral research has highlighted that linear causation assumptions often fail to represent feedback-driven or emergent behavioral responses (Jordanov and Nikolova, 2019; Helbing, 2009). Indonesian empirical work further demonstrates the importance of nonlinear predictors in ANN applications for recycled PET purchase intention, where perception-related variables, environmental literacy, and behavioral control show irregular sensitivity patterns not reflected in SEM coefficients (Bhatt et al., 2022; Shmueli et al., 2016). Therefore, ANN complements PLS-SEM by uncovering complex, nonlinear behavioral dynamics that are theoretically expected in sustainability-related decision-making and necessary to improve predictive accuracy.

Predictive modeling was applied using the SPSS Neural Network Module. To prevent overfitting, three feed-forward backpropagation ANN models were constructed using a-70-30 training-testing split. Models varied in depth: Model A serves as a shallow baseline with one hidden layer and tanh activation, followed by a linear output; this configuration establishes the baseline for predictive accuracy. Model B increases the depth to two hidden layers with nonlinear activation, allowing the network to learn more complex interactions. Model C further increases the depth/width and applies stronger regularization (e.g., tighter epoch limits and weight penalties) to the stress-test capacity. Predictive accuracy was assessed using the RMSE and predictive R2. Global sensitivity analysis further ranked the relative importance of predictors, enabling comparison with PLS-SEM findings and identification of nonlinear relationships influencing purchase intention.

2.6 Multi-group analysis

To explore behavioral differences across generational cohorts, a multi-group analysis (MGA) was conducted by categorizing respondents into Generation X, Y, and Z based on standard birth-year definitions (Singh and Prakash, 2020; Dimock, 2019). Before performing MGA,

the Measurement Invariance of Composite Models (MICOM) procedure was applied, which confirmed both configural and compositional invariance across groups. This validation ensured that the path comparisons across generational segments were statistically meaningful (Sarstedt et al., 2021).

3. Results and Discussion

3.1 Structural Model Assessment (PLS-SEM)

Bootstrapping confirmed that all hypothesized paths were significant ($p < 0.05$). The core TPB constructs — ATT, SN, and PBC—positively influence PI. Extended constructs (EL, MO, and WTP) significantly predict ATT, whereas MO and EL indirectly enhance PI through ATT and WTP.

The structural model also demonstrates internal coherence, with each path estimate remaining stable under repeated bootstrapping resampling. This stability indicates that the relationships specified in the extended TPB framework are consistently supported across the observed dataset. In addition, no issues of multicollinearity or model misspecification were detected, confirming that the constructs operate independently as intended within the structural framework. These conditions provide a sound empirical basis for examining the magnitude and direction of the hypothesized relationships, as summarized in Table 1.

Table 1 PLS-SEM Hypothesis Testing Results

Hypothesis	Path	β	t-value	p-value	f^2 (Effect Size)
H1	ATT → WTP	0.201	4.739	0.000	0.052 (Small)
H2	EL → ATT	0.315	9.986	0.000	0.225 (Medium)
H3	MO → ATT	0.352	10.955	0.000	0.306 (Medium)
H4	SN → WTP	0.183	4.957	0.000	0.084 (Small)
H5	PBC → WTP	0.176	4.953	0.000	0.069 (Small)
H6	PBC → PI	0.132	5.048	0.000	0.009 (Small)
H7	WTP → PI	0.484	22.988	0.000	0.994 (Large)
H8	EL → WTP	0.156	3.925	0.000	0.065 (Small)
H9	MO → WTP	0.165	4.690	0.000	0.071 (Small)
H10	ATT → PI	0.141	4.621	0.000	0.052 (Small)
H11	SN → PI	0.126	4.452	0.000	0.084 (Small)

As shown in Table 1, the path from WTP to PI ($t = 22.988$) emerges as the most potent effect, thereby underscoring consumer financial commitment as the most decisive driver of purchase intention, supporting prior studies in Brazil and Italy emphasizing consumers' price sensitivity toward eco-friendly products (Queiroz et al., 2021; Testa et al., 2013). However, in developing economies, affordability constraints may exacerbate the gap between intention and action, consistent with evidence from China and India, where willingness does not always translate into actual purchase due to income limitations (Wang et al., 2021; Rana and Paul, 2017; Yadav and Pathak, 2017).

PBC demonstrated a weak direct influence on PI but contributed indirectly through WTP, partially supporting TPB's original assumption that PBC reflects perceived behavioral ease (Paul et al., 2016; Ajzen, 1991). Earlier research also found that PBC effects vary by context, stronger where infrastructural barriers dominate (Yadav and Pathak, 2017) but weaker in contexts where financial willingness is more decisive (Queiroz et al., 2021; Vicente et al., 2021). EL and MO significantly influenced ATT, which enhanced both WTP and PI. This proves that literacy and moral framing enhance positive attitudes toward sustainable choices (Yildirim et al., 2025; Sun, 2020; Tan et al., 2017). However, some studies have argued that literacy and moral concern alone are insufficient without enabling systems or supportive campaigns (Lin et al.,

2017). The relatively minor role of SN aligns with research suggesting a weaker normative effect in individual decision-making regarding green products (Rozenkowska, 2023; Paul et al., 2016), although stronger influences are reported in collectivist contexts (Lin et al., 2017; Nguyen et al., 2017).

Table 2 Endogenous Construct Fit (R^2, adjusted R^2, and Q^2_{predict})

Endogenous	R^2	R^2_{adj}	Q^2_{predict}	Interpretation
WTP	0.380	0.377	0.342	small to moderate predictive power
PI	0.598	0.596	0.331	moderate predictive power
ATT	0.438	0.436	0.432	moderate predictive power

As presented in Table 2, the model explained 59.8% of the PI variance (R2 = 0.598), which is consistent with previous TPB-based studies in emerging markets reporting R2 values between 0.50 and 0.86 (Rozenkowska, 2023; Paul et al., 2016), thereby confirming that extending TPB with EL, MO, and WTP significantly improves the explanatory power over classical TPB models.

3.2 Predictive Modeling with Artificial Neural Network (ANN)

ANN complements the PLS-SEM by capturing potential nonlinear interactions that SEM cannot detect and by improving predictive accuracy. Following best practices in hybrid SEM-ANN applications, the ANN was applied to the three endogenous constructs (ATT, WTP, and PI) identified in the structural model. Model A predicts ATT from EL and MO (both significant antecedents in H2 and H3). Model B predicts WTP from SN, PBC, and ATT (H1, H4, and H5). Model C predicts PI from WTP and PBC (H6 and H7). Only three models were estimated because the ANN was applied to deepen the predictive interpretation of SEM-identified endogenous variables rather than to re-estimate exogenous constructs. This design allows ANN to isolate nonlinear effects specifically within the structural paths supported by SEM.

Table 3 Artificial Neural Network (ANN) – Sensitivity Analysis

Model	Target	Inputs	RMSE (Train)	RMSE (Predictive/Test)	Predictive R^2
Model A	ATT	EL, MO	0.0795	0.0777	0.456
Model B	WTP	SN, PBC, ATT	0.1094	0.1061	0.394
Model C	PI	WTP, PBC	0.0786	0.0756	0.595

As reported in Table 3, Model C, which forecasts PI from WTP and PBC, achieved the highest predictive accuracy among the three ANN models, achieving a test RMSE of 0.0756 and a predictive R2 of 0.595. Model A performs moderately well in predicting ATT from MO and EL, confirming that ethical and literacy cues provide a substantial signal in shaping ATT. Model B estimates WTP from SN, PBC, and ATT, which is less accurate, demonstrating that WTP is more volatile and may be influenced by additional drivers not yet included. The minimal RMSE gaps across all models indicate good generalization with no material overfitting. These results confirm the SEM findings, particularly by capturing nonlinear interactions that SEM could not detect. Model C achieved the highest predictive accuracy for PI, whereas Models A and B showed moderate performance in predicting ATT and WTP, respectively (Bhatt et al., 2022; Shmueli et al., 2016).

Whereas SEM assumes a linear and additive causal relationship, ANN does not impose linearity and allows interactions among variables to operate through hidden-layer transformations. The stronger predictive power of Model C relative to its linear counterpart indicates that WTP and PBC interact multiplicatively rather than additively. This explains why a construct with a small direct SEM effect (PBC → PI) can still exert a substantial nonlinear influence when combined with WTP in ANN.

3.3 Multi-Group Analysis on Generation Differences

MGA examined generational differences in the strength of relationships between constructs, building on the SEM and ANN results. Although the overall intention did not differ significantly among Generations X, Y, and Z, the relative influence of individual predictors varied.

Table 4 Multi-Group Analysis (MGA) Output

Predictor	Generation X	Generation Y	Generation Z
ATT	Moderate	Strong	Moderate
SN	Strong	Moderate	Low
PBC	Moderate	Moderate	Strong
WTP	Moderate	Strong	Very Strong

The effect sizes were classified as low (f2 = 0.02), moderate (f2 = 0.15), or strong (f2 = 0.35) (Hair et al., 2021). As shown in Table 4, Generation Z prioritized empowerment and ethical value alignment, as evidenced by their strong responsiveness to PBC and WTP. Generation X emphasized social approval, with a stronger role for the SN. Generation Y accentuated the effects of ATT and WTP on PI. This pattern aligns with evidence on generational segmentation in sustainable consumption (Ma et al., 2025; Singh and Prakash, 2020; Dimock, 2019; Kupperschmidt, 2000), although other studies also highlight the strong attitudinal commitment of Generation Z (Dewi et al., 2020).

3.4 Integrated Synthesis and Implications

The integrated analysis presented cross-method synthesis of SEM and ANN, generational mechanisms derived from MGA, and cohort-specific strategic implications to improve structural clarity. To holistically interpret the findings, this study applies hybrid analytics, integrating PLS-SEM and ANN to offer two complementary perspectives on consumer behavior.

Table 5 demonstrates that WTP → PI (H7) consistently emerges as the strongest determinant of purchase intention, as evidenced by both the large SEM effect size and the dominant predictor ranking in ANN Model C. This cross-method consistency indicates that financial readiness is the primary driver of rPET adoption. PBC also shows convergent evidence; although its direct effect on PI is small (H6), ANN results confirm its nonlinear contribution, particularly through its interaction with WTP in predicting PI.

Table 5 Combined Influence of Variables in SEM and ANN Models

Pathways	SEM Evidence	ANN Evidence	MGA Differences
WTP → PI	Large effect ($f^2 = 0.994$)	Dominant predictor (Model C)	Strongest for Generation Z
PBC → PI	Significant, small	Secondary (Model C)	Strongest for Generation Z
ATT → PI	Significant	Moderate predictor	Strongest for Generation Y
SN → PI	Significant	Secondary	Strongest for Generation X
EL → ATT	Medium effect	Strong in Model A	Stronger for Generation Z
MO → ATT	Medium effect	Top-ranked in Model A	Stable
EL → WTP	Small effect	Contributes to WTP	Stronger for Generation Z
MO → WTP	Small effect	Contributes to WTP	Stable
ATT → WTP	Small effect	Important in Model B	Consistent
PBC → WTP	Small effect	Top-ranked in Model B	Strongest for Generation Z
SN → WTP	Small effect	Important in Model B	Strongest for Generation X

The medium effects on EL → ATT (H2) and MO → ATT (H3), reinforced by ANN Model A, illustrate that cognitive and ethical cues shape attitudinal evaluations. The small but significant effects of SN (H4, H11) are consistent with its lower ANN importance, indicating that normative

pressure is not universally decisive but may operate selectively across demographic segments.

This triangulation confirms that SEM and ANN capture distinct but complementary behavioral mechanisms. SEM identifies the directional causal structure, whereas ANN reveals the nonlinear amplification of WTP and PBC under specific conditions.

Generation Z has the highest sensitivity to both WTP and PBC (i.e., "very strong" and "strong"). This pattern aligns with Indonesian empirical studies showing that younger consumers evaluate recycled products through a feasibility-based lens, incorporating both financial accessibility and perceived ease of action (Octavia et al., 2025; Farida et al., 2024). Their purchasing decisions are highly elastic to price and convenience, making WTP and PBC decisive behavioral drivers. Since their decisions shift quickly with changes in cost and effort, interventions should focus on minimizing economic and practical barriers. Targeted price incentives, such as student discounts, eco-point rewards, or cashback programs, together with digital tools that simplify verification of rPET content and convenience-oriented features, such as QR-based recycling guidance or fast-purchase mobile interfaces, are likely to be most effective.

Generation Y shows the most decisive influence of ATT on PI. Prior evidence shows that Generation Y relies more on attitudinal and lifestyle congruence in sustainability choices, in which the translation of attitudes into intentions is enhanced by alignment between product meaning and personal identity (Kumar et al., 2017; Nguyen et al., 2017). This explains why attitude-based evaluations amplify purchase intention more than other cohorts. Strategies should reinforce positive feelings and personal relevance, for example, through lifestyle-oriented branding (eco-fashion esthetics), narrative-based social media content, influencer collaborations that emphasize sustainability identity, and communication that highlights the emotional and self-expressive dimensions of rPET use.

For Generation X, normative cues remain the most influential, consistent with findings that older cohorts rely more on social approval, institutional endorsement, and trust signals when evaluating credence products, such as rPET, whose quality and safety cannot be easily verified (Handayani et al., 2025; Ruokamo et al., 2022). Normative legitimacy functions as a primary filter in decision-making. Interventions must build trust, credibility, and institutional legitimacy. Practical approaches include emphasizing quality certifications such as the Indonesian National Standard (SNI) or the International Organization for Standardization (ISO), showcasing endorsements from government or non-governmental organizations (NGOs), leveraging community-based programs that signal social approval, and using traditional media formats to communicate product reliability and safety.

Collectively, these differentiated strategies ensure that recommendations are not generic but are explicitly grounded in each cohort's dominant psychological mechanism and the quantified SEM-ANN-MGA results, providing a clear operational pathway for what to adjust, why it matters, and how to implement it in practice. They also reinforce the value of the hybrid SEM-ANN Framework as a dual-level analytical approach that captures both causal relationships and NLDs. Consequently, policies and managerial actions for rPET adoption should be segment-specific, combining economic incentives, moral framing, and environmental education tailored to each cohort's decision-making patterns.

3.5 Limitations and Future Research

This study has several limitations, including its cross-sectional design and focus on Indonesian consumers, which constrain causal inference and generalizability across other cultural or economic contexts. The study relied on self-reported measures of ATT, WTP, and PI, which may have been influenced by social desirability bias or gaps between intentions and behavior. Although the hybrid SEM-ANN approach improves explanatory depth and predictive accuracy, it does not incorporate external constructs, such as brand trust, regulatory awareness, or green skepticism, which could further enrich the understanding of consumer behavior. These limitations warrant caution in interpretation and highlight avenues for future research. The hybrid SEM-ANN application remains rare in developing-country contexts, offering opportunities for

comparative cross-country studies.

Future research may extend this work by applying a hybrid SEM-ANN approach to other types of recycled materials beyond PET (e.g., HDPE or bioplastics) to validate cross-material consumer behavior patterns while integrating additional constructs to enhance explanatory power. A longitudinal design would provide valuable insight into how consumer attitudes and purchase intentions evolve in response to environmental campaigns or product innovations, as well as how cultural, regional, and socioeconomic variations influence sustainable behavior on a larger scale.

Furthermore, future work can benefit from integrating behavioral models with environmental impact metrics, such as life cycle assessment (LCA) or carbon savings per product. Such integration could strengthen the link between consumer decision-making and measurable environmental outcomes, enhancing the strategic alignment of marketing, policy, and sustainability goals.

4. Conclusions

This study provides an integrated understanding of sustainable purchasing behavior by integrating explanatory and predictive perspectives within a hybrid PLS-SEM and ANN framework. The findings demonstrate that purchase intention toward rPET products is shaped by the interplay of economic readiness, cognitive awareness, and ethical motivation, with Willingness to Pay (WTP) emerging as the most decisive driver. The hybrid analytical approach allows these mechanisms to be captured in a complementary manner, offering a more complete representation of consumer decision-making in an emerging economy context.

A key contribution or this research lies in its generational perspective, which reveals that the drivers of sustainable consumption are not uniform across age cohorts. Younger consumers are primarily influenced by affordability and perceived ease of action, middle-aged consumers translate positive attitudes more strongly into intention, and older consumers rely more on social legitimacy and institutional assurance. These patterns highlight the importance of moving beyond one-size-fits-all approaches and adopting segmentation strategies that reflect underlying behavioral differences rather than demographic labels alone.

Overall, this study extends behavioral modeling in sustainability research by demonstrating the value of integrating linear and nonlinear analytical techniques to capture complex decision dynamics. From a practical standpoint, the findings provide a clear foundation for designing cohort-responsive interventions that align economic incentives, educational efforts, and trust-building mechanisms with dominant motivational structures. The study contributes to more effective and evidence-based strategies for advancing circular economy adoption in developing countries.

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Author Contributions

RA; conceptualization, supervision, project administration, funding acquisition, methodology, validation, resources, and writing—review and editing, ANAM; conceptualization, methodology, software, validation, formal analysis, investigation, resources, data curation, and writing—original draft preparation, RRA; methodology, validation, resources, and writing—review and editing, TNZ; methodology, validation, resources, and writing—review and editing. All authors have read and agreed to the published version of the manuscript.

Conflict of Interest

The authors declare no conflicts of interest.

Supplementary Materials

No supplementary materials are available for this article. All data supporting the findings are included within the manuscript and can be obtained from the corresponding author upon reasonable request.

Declaration of AI

This paper was developed without the use of generative AI for writing or analysis assistance.

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