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ORIGINAL PAPER

Explaining Intention and Return Behaviour in Deposit-Refund Systems: An Integrated Behavioural Model for Circular Economy Transitions

József Ráti[1] · **Zalán Márk Maró**[2]

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Abstract
Deposit-refund systems (DRS) are increasingly used to reduce packaging waste, yet little is known about the behavioural mechanisms that shape return decisions in newly implemented systems. This study examines the drivers of beverage-container returns in Hungary's national DRS called REPont. It builds on a broad set of behavioural theories, integrating elements from multiple explanatory frameworks to capture the full range of psychological and contextual forces shaping return intention and behaviour. A nationwide online survey (n = 2,661) was conducted to measure behavioural intention and self-reported return frequency, allowing direct assessment of the intention–behaviour relationship. Composite constructs were developed from unidimensional scales, and ordinary least squares regression was used to evaluate the predictive contribution of each construct. Results show that perceived usefulness, financial benefits, and environmental attitudes strongly predict intention, while perceived barriers are not significant predictors of intention but show a positive association with return frequency. Intention was a significant but incomplete predictor of return frequency, indicating the presence of an intention–behaviour gap during the early phase of system adoption. Gender also showed systematic effects. Women reported higher return intentions, whereas, interestingly, men showed higher return frequency. The findings highlight the importance of improving system usability and user experience, addressing context-specific barriers, and providing clear information about DRS in order to strengthen both intention and actual return behaviour. By identifying the most influential psychological and contextual determinants, the study offers implications for policymakers and system operators seeking to increase the efficiency of DRS implementations in emerging circular-economy systems.

Keywords Deposit-refund system · Consumer behaviour · Circular economy · Intention–behaviour gap · Pro-environmental behaviour · Integrated behavioural model

Extended author information available on the last page of the article

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Introduction

Global solid waste has risen heavily with increasing population and consumption. Packaging waste alone accounts for more than 10% of household refuse, a share projected to grow by about 20% by 2030 if no action is taken [1, 2]. The escalating problem of packaging waste has made circular economy solutions like deposit-refund systems (or deposit-return systems) (DRS) increasingly crucial. DRS offer a proven way to boost recycling by attaching refundable deposits to beverage containers, thereby incentivizing returns [3, 4]. Governments worldwide have begun adopting DRS as a policy tool to reduce litter and meet recycling targets [5, 6]. In the European Union, for example, a new Packaging and Packaging Waste Regulation (2024) obliges all member states to implement DRS to achieve high collection rates. Many Member States already operate DRS (with others in preparation), and these programs routinely achieve container return rates above 85%, alongside 40–60% reductions in litter after implementation [7], their effectiveness hinges on regular and widespread consumer participation [6]. Similar schemes are expanding globally under sustainability mandates, highlighting the international and policy relevance of understanding consumer behaviour in DRS [8–10].

Research on pro-environmental consumer behaviour provides important evidence for DRS participation but remains fragmented across multiple theoretical frameworks. The (extended) Theory of Planned Behaviour (TPB) posits that people's intentions to recycle are the primary driver of their recycling actions [11, 12]. In addition, stronger recycling intentions generally lead to more recycling activity [13]. However, intentions often do not fully translate into behaviour, a well-documented intention–behaviour gap in sustainable practices [14, 15]. By contrast, Technology Acceptance Models [16–18] emphasize ease of use, usefulness, and user experience with recycling technologies (e.g., reverse vending machines) as key determinants of participation. At the same time, value-based models [19], including the Value-Belief-Norm (VBN) framework, emphasize the centrality of environmental concern and moral obligation, which can also improve recycling intentions and habits. Structural perspectives add yet another lens, highlighting practical barriers (time, space, convenience) and financial incentives as critical factors shaping recycling behaviour [20].

Despite this rich theoretical background, several notable gaps persist. First, to date, these approaches have largely been applied in isolation, each explaining certain aspects of DRS engagement while overlooking others. No integrated model has emerged, and prior studies often report inconsistent findings. For example, environmental concern predicts willingness but may be overridden by convenience factors, or perceived usefulness of a system boosts intention but does not guarantee actual return behaviour. Thus, there is a need to combine motivational, technological, and structural predictors in one framework and to examine where and why consumers' intentions fail to become actions in a DRS context. Second, the well-documented intention–behaviour gap in sustainable consumption [see e.g., 21, 22] has received limited attention (measuring both individuals' intentions and their actual recycling behaviour) within the same setting in DRS contexts, where system design, habitual routines, and financial incentives may weaken or strengthen the predictive power of intentions. Third, general recycling beliefs and perceived barriers have been extensively studied in household recycling [23–26], yet little is known about how these constructs operate within structured, machine-based return systems.

The present study addresses these gaps by proposing and testing an integrated model of consumer engagement in a national DRS. The study draws jointly on TPB, TAM, and VBN theories to capture a comprehensive set of determinants – from individual attitudes and intentions to user experience with the return system and external constraints. This integrative approach is motivated by the limitations of these frameworks when applied in isolation. TPB focuses on intention formation but may underpredict behaviour in constrained contexts, TAM captures system-related perceptions but lacks a strong motivational component, while VBN explains value-based drivers but has limited predictive power under situational conditions. By combining these perspectives, the model aims to provide a more comprehensive explanation of DRS participation. Unlike most existing work, this study measures both behavioural intention (willingness to return bottles) and actual return behaviour (self-reported return frequency), thereby allowing the intention–behaviour relationship to be assessed directly. The empirical analysis uses a large-scale sample of DRS users from Hungary's recently implemented deposit-refund program, one of the first modern DRS in Central and Eastern Europe. This real-world context and robust sample provide a unique opportunity to evaluate how classic behavioural predictors perform in a fully operational circular economy scheme.

Based on the above, the study is novel in its integrated approach and dual outcome measurement. By combining multiple theoretical lenses and observing actual behaviour in the field, it offers a unique opportunity to understand the drivers of sustained consumer participation in DRS. In doing so, this paper contributes evidence on which factors most strongly influence not just willingness to participate, but also consistent action in returning containers. This information is vital for both theory development and the design of more effective recycling policies. Finally, better understanding of consumer behaviour in DRS will help validate that these systems achieve their intended goals of high recycling rates, waste reduction, and public buy-in, thereby advancing broader circular economy and sustainability objectives [27]. To do so, the remainder of this article is organized as follows. Section 2 reviews the relevant literature and theoretical foundations of DRS participation, leading to the development of hypotheses. Section 3 then describes the research design, data collection, and analytical methods. In Sect. 4, the results of the empirical analysis are presented. Section 5 discusses the findings considering existing research, policy objectives, and practical implications. Section 6 concludes by highlighting the study's main contributions, limitations, and avenues for future research.

Literature Review

Theoretical Background

Research on recycling behaviour and participation in DRS draws on several theoretical foundations, yet these frameworks do not always offer consistent explanations. TPB has long been the dominant perspective, proposing that behavioural intention is the most proximal determinant of action [11, 12]. Moreover, Bamberg and Möser [13] confirm that intention is a strong predictor of recycling, but the intention–behaviour relationship is frequently weaker than theory would suggest. Several authors indicate that recycling decisions (particularly in routine, low-cost contexts) are heavily constrained by situational factors

such as accessibility, time pressure, and task effort [14, 28]. This discrepancy challenges TPB's assumption that intention reliably translates into action and suggests that behavioural models must account for contextual moderators rather than relying solely on motivational predictors.

A second line of research draws from technology acceptance models, which emphasize perceived usefulness, ease of use, and user experience as key determinants of system engagement [16, 17, 29]. These models offer a valuable perspective for DRS, where interaction with reverse vending machines and digital interfaces forms the core behavioural task. However, TAM research has been criticized for its predominantly cognitive focus and for assuming that perceived usefulness and ease of use operate uniformly across contexts [30]. In recycling specifically, evidence increasingly shows that experiential factors (e.g., frustration, waiting times, or perceived machine reliability) shape intention and behaviour more strongly than abstract usefulness evaluations [31, 32]. This suggests that TAM-derived constructs need to be adapted to context-specific user experiences in recycling systems, particularly in settings such as DRS where interaction quality directly shapes behaviour. Thus, in this paper, user experience and perceived ease of recycling are conceptualized as system-related determinants, drawing primarily on TAM while extending it toward more context-sensitive operationalisations.

A third perspective emphasizes environmental values and attitudes, drawing on the VBN theory [19]. Strong environmental concern has repeatedly been linked to greater recycling intention and participation [33]. But attitudes alone provide limited predictive power when behaviours involve inconvenience or effort; under such conditions, situational constraints may override values [34]. Moreover, general recycling beliefs often fail to predict real-world behaviour when system-specific factors, such as convenience or financial incentives, play a more immediate role [35]. This indicates that value-based constructs primarily influence motivational readiness, while their effect on actual behaviour is contingent on contextual conditions.

Finally, research on barriers and incentives highlights the importance of structural determinants. Perceived barriers (e.g., time constraints, limited storage space, or competing household responsibilities) are widely examined inhibitors of recycling [24]. Centralized return systems may circumvent some of these obstacles, allowing individuals who struggle with household sorting to adopt deposit–refund practices more readily [36]. Furthermore, financial incentives have been found to increase return rates [37, 38], but critics note that monetary mechanisms may encourage compliance without fostering deeper pro-environmental engagement. This highlights that structural factors may directly influence behaviour, independently of underlying attitudes or intentions, particularly in systems where participation is economically incentivised. In this paper, perceived barriers and financial benefits represent structural determinants that capture the situational and economic context of DRS participation.

Taken together, these perspectives suggest that no single theoretical framework fully captures the complexity of DRS participation. While TPB offers a well-established explanation of intention formation, it does not fully account for system-specific interaction effects. TAM captures user experience and perceived ease of use but lacks a strong motivational and value-based component. VBN explains environmental attitudes and normative motivations but has limited predictive power in contexts characterised by effort and situational constraints. Structural approaches, in turn, capture barriers and incentives but often neglect

underlying psychological mechanisms. By combining these perspectives, the present study seeks to address these limitations and provide a more comprehensive explanation of DRS participation. Therefore, elements from TPB, TAM, and VBN are combined and complemented by structural factors to capture these dimensions of DRS behaviour, thereby justifying the use of an integrated empirical model (see Fig. 1 below).

Literature Review and Hypothesis Development

The following hypotheses synthesize the theoretical mechanisms identified above and distinguish between proximal and more distal determinants of DRS-related behaviour. While (extended) TPB provides the classical foundation [11, 12, 39, 40], newer studies show that intention–behaviour consistency in recycling remains moderately strong, especially in structured, low-cost systems such as DRS [15, 41]. Empirical work on DRS or container systems in Europe similarly finds that intention reliably predicts return frequency but is influenced by situational factors such as convenience and access [38, 42]. Within this framework, behavioural intention functions as the proximal antecedent of behaviour, capturing individuals' motivational readiness to act before situational constraints and structural conditions shape actual return patterns [12, 14].

H1. Behavioural intention is a strong and positive predictor of bottle-return frequency.

Ease of interaction, clarity of instructions, and enjoyment influence how individuals evaluate sustainability-related technologies [18]. In recycling systems, positive interaction experiences increase willingness to participate and reduce cognitive efforts. Furthermore,

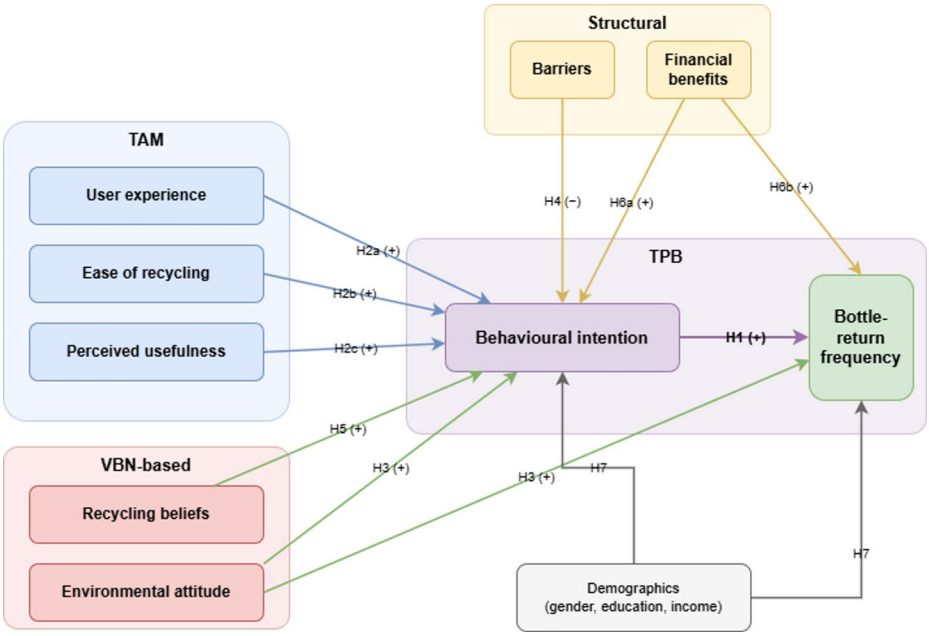

Fig. 1 The proposed integrated behavioural model

convenience is among the strongest predictors of recycling participation across countries and recycling modalities [43, 44]. When the return process is simple, fast, and requires minimal effort, intention and behaviour increase substantially. In deposit systems, convenience often outweighs environmental beliefs [20]. TAM research shows perceived usefulness as a major driver of intention but a weaker predictor of actual behaviour [17]. Taken together, user experience, perceived ease of recycling, and perceived usefulness can be understood as system-specific perceptions that capture how individuals evaluate the REpont platform as a concrete return technology rather than recycling in general. Consistent with TPB, these system-specific evaluations are expected to influence actual bottle-return behaviour primarily through their impact on behavioural intention, while any direct effects on behaviour are expected to be comparatively weaker.

H2a. User experience positively predicts behavioural intention.
H2b. Perceived ease of recycling positively predicts behavioural intention.
H2c. Perceived usefulness positively predicts behavioural intention.

Environmental attitudes are crucial determinants of pro-environmental behaviour. Individuals who place stronger moral importance on environmental protection tend to have greater commitment to ecological actions [19, 45, 46]. Environmental concern and value orientations predict higher levels of recycling motivation and participation across behavioural domains [33, 34]. Recent studies further confirm that environmental attitudes influence both the willingness to adopt circular-economy practices and actual engagement in waste-return schemes, even when structural constraints are present [47, 48]. Although situational constraints may weaken the attitude–behaviour link in some contexts, positive environmental attitudes reliably strengthen individuals' willingness to engage in sustainability-related practices. Therefore, within DRS systems, stronger environmental attitudes are expected to improve both behavioural intention and actual bottle-return behaviour.

H3. Environmental attitude positively predicts behavioural intention and is expected to show a positive association with bottle-return frequency.

Perceived barriers represent a core element of behavioural constraint models and are consistently associated with lower participation in recycling programs. Limited time, space, information, or access reduce individuals' motivation to engage in recycling, even when environmental attitudes are favourable [24, 48, 49]. Barriers increase the cognitive and physical effort associated with recycling tasks, thereby weakening willingness to participate. Similar patterns have been observed in other ecological behaviours that require effort or planning [28]. However, in certain institutional contexts (e.g., DRS), the role of perceived barriers may be more complex. While barriers can discourage participation at the intention stage, they may also coexist with habitual or externally incentivised behaviour once the system is in place. This suggests that perceived barriers may have a dual effect, influencing intention and actual behaviour in different ways [50, 51]. Consistent with the dominant theoretical expectation, but acknowledging this potential complexity, perceived barriers in a DRS context are hypothesised to attenuate intention to participate.

H4. Perceived barriers negatively predict behavioural intention.

Recycling beliefs reflect individuals' cognitive evaluations of recycling outcomes, such as reducing landfill waste, lowering environmental impact, and contributing to sustainable resource use. These beliefs are associated with stronger attitudinal support for recycling and other environmentally significant behaviours [23, 52]. Studies show that individuals who perceive recycling as socially beneficial are more likely to develop favourable attitudes and corresponding behavioural intentions [53, 54]. Although recycling beliefs are more general and less system-specific than experiential perceptions, they remain important antecedents of environmentally responsible decision-making.

H5. Recycling beliefs positively predict behavioural intention, although this effect is expected to be weaker than system-specific perceptions.

Financial incentives are central to DRS and have been shown to increase participation by providing clear and immediate economic benefit. Monetary rewards complement, rather than substitute for, intrinsic environmental motivations, and they reliably enhance both willingness and engagement across recycling contexts [37]. Research on container-deposit systems suggests that perceived financial returns strengthen intention to return containers and support higher return rates [20]. Economic rewards significantly increase the frequency of return behaviour in circular-economy schemes [6], boost participation in reverse vending systems [55], and strengthen compliance in bottle-deposit programs through heightened perceived value [56]. Thus, perceived financial benefits should play a meaningful motivational role in shaping DRS participation.

H6a. Perceived financial benefits positively predict behavioural intention and actual bottle-return frequency.
H6b. Perceived financial benefits positively predict actual bottle-return frequency.

Regarding the sociodemographic characteristics, women tend to report stronger environmental concern, greater ecological responsibility, and higher endorsement of sustainability-related norms compared with men [34]. These differences translate into stronger motivation and willingness to engage in environmentally friendly actions across multiple behavioural domains, including recycling, waste sorting, and circular consumption practices [57–59]. Therefore, stronger pro-environmental motivation among women is expected to manifest in greater behavioural intention to participate in DRS programs [51, 60, 61].

H7. Women are expected to report higher behavioural intention to participate and bottle-return frequency in DRS than men.

The proposed research model is presented in Fig. 1. It integrates constructs from TAM, VBN-based frameworks, and structural perspectives as exogenous predictors of behavioural intention, which in turn serves as the proximal determinant of bottle-return frequency, consistent with the TPB framework. Sociodemographic characteristics (gender, education, income) are included as control variables in both models. The hypothesised relationships are represented by directional paths, labelled H1 through H7.

Materials and Methods

Presentation of the Sample

The study draws on data collected through a comprehensive, 45-item questionnaire that was designed using the conceptual foundations of multiple theoretical models widely applied in environmental behaviour and technology-adoption research. In line with TAM, extended TPB, and attitude-based frameworks (Ajzen, 2020; Breckler, 1984; Fraj & Martinez, 2007; Nameghi & Shadi, 2013; Widodo & Wahid, 2018), the survey included items measuring perceived usefulness, ease of use, attitudinal components, behavioural intentions, and value-driven motivations. Further items addressed emotional evaluations, habitual and intentional recycling behaviours, as well as demographic characteristics relevant to understanding uptake of the REpont DRS.

Data collection took place between 24 September and 24 December 2024. The questionnaire was distributed through large social media groups, each with at least 1,000 members, selected to cover a wide range of settlements and regions across Hungary. This convenience-sampling strategy was adopted because recruiting a probabilistic sample through face-to-face methods has become increasingly difficult, particularly in the post-COVID research environment [62, 63]. Furthermore, convenience sampling is widely used in international online research and allows access to large, diverse populations under real-world data-collection constraints [64]. To mitigate the well-known limitations of voluntary online sampling, particular attention was paid to reaching demographically diverse groups in terms of age, gender, and place of residence. However, achieving statistical representativeness was not an objective of the study, as the OLS-based analytical approach (see below) does not require it. To illustrate how the sample compares to the Hungarian population, Table 1 presents the distribution of respondents and national proportions by gender, age, education, and region, based on data of the Hungarian Central Statistical Office [65].

A total of 3,088 individuals completed the questionnaire. To ensure data quality, a four-step screening procedure was applied before conducting the statistical analysis. First, incomplete submissions were eliminated. Second, straight-lining responses, where participants selected the same option across all Likert-scale items, were removed. Third, entries containing intentionally nonsensical demographic answers (e.g., random character strings or unrealistic ages) were excluded. Finally, respondents who completed the survey in an unrealistically short time, below the predefined minimum threshold, were removed on the assumption of insufficient engagement. After applying these exclusion criteria, 2,661 valid cases remained for analysis.

Because the dataset was obtained through non-probability sampling, the study relied on Ordinary Least Squares (OLS) regression to examine the relationships between the key theoretical constructs and behavioural outcomes. Bias-reduction was achieved by careful sample-recruitment design, rigorous data-cleaning protocols, and the inclusion of demographic control variables in all regression models. This approach is consistent with established recommendations for improving the analytical validity of convenience-based online samples [66, 67].

To further assess the extent of sampling bias, chi-square goodness-of-fit tests were conducted comparing the sample distribution with the known Hungarian population proportions [65] across all four demographic dimensions (see in Table A.1. in the Appendix).

Table 1 Distribution of the sample

Variable	Sample distribution (n=2,661)	Sample distribution (%)	Hungarian population (%)
Gender			
Male	1,648	61.94%	47.57%
Female	1,013	38.06%	52.43%
Age category			
18–29	775	29.11%	16.04%
30–39	342	12.87%	15.68%
40–59	1,145	43.02%	36.29%
60+	399	15.00%	31.98%
Place of residence (region)			
Central Hungary	893	33.57%	31.50%
Central Transdanubia	367	13.80%	11.03%
Western Transdanubia	124	4.65%	10.24%
Southern Transdanubia	136	5.10%	8.89%
Northern Hungary	585	21.98%	11.30%
Northern Great Plain	145	5.44%	14.59%
Southern Great Plain	411	15.45%	12.44%
Highest level of education			
Primary	187	7.01%	17.07%
Secondary	1,463	54.99%	56.68%
Tertiary	1,011	38.00%	26.25%

Note: Own data collection and data published by the Hungarian Central Statistical Office [65]

Statistically significant differences were observed for gender, and education. However, it should be noted that chi-square tests are highly sensitive to large sample sizes, and statistically significant deviations are expected even when the practical magnitude of the difference is modest. To assess the practical magnitude of the observed deviations, Cramér's V was calculated for each variable. All values fell below 0.30 (range: 0.192–0.288), indicating moderate or weak deviations.

To evaluate whether the observed sample deviations influence the substantive findings, a sensitivity analysis was conducted by re-estimating the main behavioural regression model across demographic subgroups defined by gender (male vs. female) and age (18–39 vs. 40+). As shown in Table A.2. in the Appendix, the direction and approximate magnitude of the key regression coefficients remain consistent across all subgroups. User experience, perceived ease of recycling, environmental attitude, and financial motivation are positive and stable predictors across subgroups, while recycling beliefs show a consistently negative association. These results indicate that the principal findings are not driven by the overrepresentation of any demographic group, and that the sampling bias does not materially affect the validity of the conclusions.

Methods and Models

OLS regression was selected as the primary analytical method. Because the constructs were measured using reliable, unidimensional scales and aggregated into composite indices, OLS is considered to provide a transparent and robust means of assessing the incremental explanatory power of each construct and of comparing nested models. The primary aim of the

analysis is to examine direct relationships between variables and test theoretically derived hypotheses in a parsimonious and interpretable way. While structural equation modelling (SEM) could also be applied in principle, the present study focuses on observed composite variables and direct effects rather than on modelling complex latent structures or indirect relationships. Therefore, OLS is considered appropriate for the research objectives, as the analysis models the composite constructs as observed predictors. Furthermore, OLS enables straightforward model comparison, hierarchical regression, and the assessment of incremental explanatory power, which are central to the analytical strategy applied in this study [68, 69]. The large sample size in this study ($n = 2{,}666$) further strengthens the appropriateness of OLS, ensuring stable parameter estimates, minimal sampling error, and reliable detection of both psychological and demographic effects, consistent with classical statistical guidance regarding large-sample regression [68].

The constructs in this study were measured using validated, internally consistent scales (see Table 2) that were aggregated prior to model estimation. Once the questionnaire items had been examined through exploratory factor analysis, the resulting composite scores provided stable and theoretically coherent representations of the underlying constructs. In such cases, where the measurement structure is well established and the scales themselves serve as reliable indicators, OLS offers a transparent and statistically robust approach for estimating relationships between constructs without the need for latent variable scoring. Recent psychometric research demonstrates that aggregated sum or mean scores can be statistically equivalent or even superior to model-based factor scores when scales are unidimensional and exhibit high reliability [70, 71]. These considerations make OLS regression a theoretically well-justified, empirically stable, and methodologically transparent choice for the present analysis.

Exploratory Factor Analysis and Item Reduction

The aim of the factor analysis was to identify the latent dimensions reflected in the questionnaire and to determine whether the items could be meaningfully grouped into theoretically coherent constructs (Table 2). After confirming sampling adequacy with the KMO statistic and Bartlett's test, an Exploratory Factor Analysis (EFA) was conducted using principal axis factoring with oblique rotation. Factor retention was guided by the Kaiser criterion (eigenvalue > 1), visual inspection of Cattell's scree plot, and the underlying theoretical framework of the study [72–74]. The extracted factor solution is in line with the hypothesized multidimensional structure of recycling-related behaviour, motivation, and attitudes.

Each item was assigned to the factor on which it exhibited the highest loading, applying a minimum threshold of 0.40, consistent with conventional recommendations for large samples [76]. To assess the robustness of the factor retention decision, a sensitivity analysis was conducted by re-estimating both regression models using alternative composite scores constructed with a more conservative threshold of 0.50. The direction and statistical significance of all key coefficients remained unchanged across both the behavioural intention model ($R^2 = 0.659$ vs. 0.660) and the bottle-return frequency model ($R^2 = 0.238$ vs. 0.244). These results confirm that the application of the 0.40 threshold does not materially influence the substantive findings, and that the retained items do not introduce bias into the regression estimates.

Table 2 Exploratory Factor Analysis results

Construct (Theory)	Item	Source	Factor loading
User Experience (TAM)	I enjoy using the REpont system.	[11, 12]	0.6139
	I find the REpont system user-friendly.	[11, 12, 75]	0.6643
	It is easy to learn how to use the REpont system.	[11, 12]	0.4978
	I am satisfied with the REpont system.	[11, 12]	0.7477
	Using the REpont system was simple and convenient.	[11, 12, 75]	0.7717
Perceived Convenience/Ease of Recycling (TAM)	Using the REpont system helps me manage plastic and glass waste more effectively.	[11, 12, 53]	0.7368
	Using the REpont system contributes to making me more environmentally conscious.	[11, 12]	0.7762
	Using the REpont system makes recycling easier for me.	[11, 12, 53, 75]	0.7348
Perceived Usefulness (TAM)	I believe that using the REpont system is beneficial for the environment.	[11, 12]	0.7058
	I consider the REpont system useful.	[11, 12, 54]	0.6924
	Using the REpont system is a good solution for managing bottle returns.	[53, 54]	0.6397
	I support the REpont system because I believe it is an effective solution to waste-related problems.	[11, 12, 53]	0.5448
Environmental Attitude (VBN)	How important do you consider recycling?	[12, 23]	0.6786
	How often do you collect waste selectively?	[12, 53]	0.5445
	Recycling is an important value for me.	[23, 54]	0.8079
	I am proud to contribute to recycling.	[23, 54]	0.8237
	I feel good about participating in recycling.	[12, 54]	0.8266
	I consider it important to participate in selective waste collection to protect the environment.	[12, 53]	0.7362
Barriers (Structural factor)	I find selective waste collection difficult.	[12, 53]	0.6472
	I do not have enough information about recycling.	[12, 23]	0.6557
	There are no suitable recycling facilities near me.	[12, 23]	0.6463
	I do not have enough time for selective waste collection.	[12, 53]	0.652
	I do not have enough space at home to collect waste selectively.	[12, 53]	0.5882
Behavioural Intention (TPB)	I will recommend the REpont system to others.	[12]	0.5526
	I am willing to change my daily habits to use the REpont system.	[53, 54, 75]	0.6108
	I will download and use the REpont application.	[53, 54, 75]	0.5283
	I will regularly use the REpont system.	[12, 53, 54]	0.6051
Recycling Beliefs (VBN)	Recycling significantly reduces the amount of waste that ends up in landfills.	[12, 23]	0.4332
	Recycling helps combat climate change.	[12, 23]	0.5663
	Recycling is essential for a sustainable lifestyle.	[12, 23]	0.5045
Financial Benefits (Structural factor)	The 50 HUF refund motivates me to use the REpont system.	[12]	0.5615
	The REpont system provides financial benefits for me.	[12]	0.4581

The resulting structure revealed eight distinct and interpretable factors, each corresponding to a theoretically expected construct. Items forming User Experience (UX) clustered together to create a coherent experiential dimension. The Perceived Convenience/Ease of Recycling (PCON/PEOR) items formed a strong, unidimensional factor, while the Perceived Usefulness (PU) items also grouped consistently on a single latent dimension. The Environ-

mental Attitude (EA) factor showed particularly clear psychometric structure, with all items loading strongly on the same latent dimension and reflecting the theoretical expectations surrounding attitudinal evaluation. The Barriers construct formed a moderately heterogeneous but conceptually consistent factor. Behavioural Intention (BI) items grouped reliably, reflecting a stable motivational component related to future recycling actions. Recycling Beliefs (RB) items loaded acceptably on their factor, with all items meeting the established threshold. The Financial Benefits (FB) factor emerged as a distinct two-indicator construct; both indicators exceeded the minimum loading threshold, supporting its retention despite its smaller size. No problematic cross-loadings were observed, and all items loaded primarily on a single factor, indicating clear construct separation and supporting discriminant validity at the exploratory stage.

Reliability Indicators and OLS Suitability Checks

To assess the robustness of the measurement instrument, reliability indices and multicollinearity diagnostics were computed for all constructs. These evaluations confirm whether the aggregated scales meet the assumptions required for valid and unbiased OLS regression estimates (Table 3). The internal consistency indicators demonstrate that most of the constructs used in the study exhibit strong reliability, meeting or exceeding conventional psychometric thresholds. Cronbach's α and composite reliability (rhoC) values generally fall well above the accepted benchmark of 0.70, confirming that the items within each construct measure a coherent underlying concept. UX, PEOR, PU, and EA all show particularly high reliability coefficients, suggesting that the item sets for these constructs function consistently and provide a stable basis for creating composite variables.

RB and Barriers show reliability levels that, while slightly lower, remain within ranges commonly accepted for complex behavioural constructs. These two domains inherently capture more heterogeneous psychological evaluations, i.e., belief structures and perceived obstacles, thus, somewhat lower internal consistency is theoretically expected. The FB construct has the weakest psychometric profile, driven largely by its two-item structure. Nonetheless, its reliability measures remain interpretable, and its retention is supported by its substantive relevance in consumer reward and recycling-motivation research. Furthermore, the construct was retained due to its strong theoretical and practical importance in the context of DRS, where financial incentives represent a key driver of behaviour. The relatively

Table 3 Reliability and multicollinearity diagnostics for all constructs

Construct	Cronbach's α	rhoC	rhoA	VIF	1/VIF
User Experience (UX)	0.913	0.914	0.917	3.41	0.293
Ease of Recycling (PEOR)	0.925	0.925	0.927	3.07	0.326
Perceived Usefulness (PU)	0.925	0.924	0.929	4.24	0.236
Environmental Attitude (EA)	0.897	0.894	0.931	1.99	0.503
Barriers	0.796	0.790	0.801	1.15	0.870
Recycling Beliefs (RB)	0.786	0.784	0.787	2.00	0.500
Financial Benefits (FB)	0.562	0.596	0.649	1.39	0.719

low reliability may also reflect the multifaceted nature of perceived financial benefits rather than measurement error alone.

The multicollinearity diagnostics further strengthen the suitability of these constructs for OLS regression. All VIF values fall below the threshold of 5, with most values far below 3, indicating that no predictor exhibits problematic overlap with other variables. The highest VIF value (PU = 4.24) remains well within acceptable limits and is expected in behavioural intention models where perceived usefulness frequently co-varies with experiential or attitudinal beliefs. Mean VIF values around 2.6 indicate a healthy degree of shared variance. This level of shared variance is sufficient to be theoretically meaningful, but not large enough to destabilize coefficient estimates or inflate standard errors. The 1/VIF values (tolerance statistics) complement these findings by confirming that each construct retains a sufficient proportion of unique variance to be included as an independent predictor in regression modelling. Constructs such as Barriers (1/VIF = 0.870) and FB (1/VIF = 0.719) show exceptionally low collinearity, while stronger conceptual domains such as UX, PCON/PEOR, and PU still demonstrate tolerances well above acceptable cutoffs.

Two complementary regression models were specified to examine the determinants of recycling behaviour and to quantify the gap between behavioural intention and actual system use. All models were estimated using OLS with heteroskedasticity-robust standard errors (HC3). Residual diagnostics indicated no violations of the OLS assumptions. The residuals were approximately normally distributed, as confirmed by Q-Q plots and distributional checks. The first model focuses on actual bottle-return frequency (BRF), measured as a behavioural outcome on a scale ranging from "never return bottles" to "always return every bottle". This outcome variable was regressed on all theoretically grounded psychological constructs alongside key demographic predictors including gender, education level, household income, type of settlement (the region). Formally, the behavioural model can be written as Eq. 1:

$$\begin{aligned} BRF_i = {} & \beta_0 + \beta_1 UX_i + \beta_2 PEOR_i + \beta_3 PU_i + \beta_4 EA_i \\ & + \beta_5 Barriers_i + \beta_6 RB_i + \beta_7 FB_i + \beta_8 Gender_i \\ & + \beta_9 Education_i + \beta_{10} Income_i + \beta_{11} Settlement_i + \epsilon_i \end{aligned} \tag{1}$$

where the ε is the error term. This specification allows for the simultaneous evaluation of psychological and socio-demographic influences on actual recycling behaviour, enabling the identification of which factors most strongly predict whether individuals routinely use the REpont system in practice.

The second model mirrors the structure of the behavioural model but uses Behavioural Intention (BI) as the dependent variable (Eq. 2):

$$\begin{aligned} B_i = {} & \beta_0 + \beta_1 UX_i + \beta_2 PEOR_i + \beta_3 PU_i + \beta_4 EA_i \\ & + \beta_5 Barriers_i + \beta_6 RB_i + \beta_7 FB_i + \beta_8 Gender_i \\ & + \beta_9 Education_i + \beta_{10} Income_i + \beta_{11} Settlement_i + \epsilon_i \end{aligned} \tag{2}$$

By estimating both models, the analysis allows a direct comparison between intention and action, providing insight into the well-documented intention–behaviour gap in sustainable consumption research [see e.g., 77]. Furthermore, incorporating demographic predictors makes it possible to determine whether intention and action are influenced by similar

or divergent socio-demographic patterns, and whether disparities in recycling behaviour are attributable to psychological drivers, structural constraints (or both). This dual-model approach thus offers a comprehensive understanding of the motivational and contextual factors shaping REpont system usage.

Results

Results of the Regression Models

The first regression model examines the determinants of Behavioural Intention, and the corresponding results are presented in Table 4. It explains a substantial proportion of the variance ($R^2 = 0.6595$), indicating that the psychological constructs and demographic variables jointly provide strong explanatory power. User Experience has a clear positive association with intention ($\beta = 0.193$, $p < 0.001$), indicating that individuals who enjoy the system and find it easy to use are more likely to continue using it. A pleasant and satisfying interaction with the system therefore translates directly into stronger motivation for future engagement. Perceived Convenience or Ease of Recycling emerges as one of the most influential predictors ($\beta = 0.261$, $p < 0.001$). When respondents feel that the REpont system simplifies the bottle return process and reduces the effort required for recycling, their intention to use it increases substantially. Convenience plays a central role in sustainable behaviour, and these results confirm that making recycling easier is strongly connected to higher willingness to adopt and maintain such practices.

Perceived Usefulness also contributes positively to intention ($\beta = 0.146$, $p < 0.001$). Individuals who believe the system provides meaningful environmental or practical benefits express stronger commitment to using it. Although this effect is somewhat smaller than

Table 4 Comparison of regression results for Behavioural Intention (BI) and actual Bottle-return Frequency (BRF)

Variable	BI (Model 1)	BRF (Model 2)
User experience (UX)	0.193 (0.023) ***	0.157 (0.027) ***
Ease of Recycling (PEOR)	0.261 (0.021) ***	0.167 (0.023) ***
Perceived Usefulness (PU)	0.146 (0.027) ***	−0.035 (0.030)
Environmental Attitude (EA)	0.361 (0.024) ***	0.164 (0.029) ***
Barriers	0.013 (0.012)	0.046 (0.017) **
Recycling Beliefs (RB)	−0.017 (0.021)	−0.070 (0.026) **
Financial Benefits (FB)	0.043 (0.012) ***	0.123 (0.016) ***
Gender (ref: female)	−0.064 (0.029) **	0.130 (0.036) ***
Education: Medium	0.143 (0.047) **	0.152 (0.069) **
Education: High	0.150 (0.051) **	0.110 (0.073)
Income: Medium	0.065 (0.028) **	−0.013 (0.036)
Income: High	0.093 (0.042) **	−0.074 (0.052)
Settlement: Town	0.002 (0.027)	0.016 (0.035)
Settlement: Capital	0.039 (0.044)	−0.085 (0.051) *
Constant	−0.330 (0.095) ***	1.114 (0.143) ***
N	2661	2661
R^2	0.660	0.244

Note: Robust standard errors were used in all models to account for potential heteroskedasticity

experiential and convenience factors, it still highlights the importance of conveying the system's value to users. Environmental Attitude is the strongest predictor in the model ($\beta = 0.361$, $p < 0.001$). Respondents with more positive environmental values and a stronger sense of environmental responsibility are significantly more inclined to use the system. This confirms that pro-environmental dispositions are central drivers of behavioural intention in recycling contexts, even when convenience and usefulness are accounted for.

In contrast, Barriers ($\beta = 0.013$) and Recycling Beliefs ($\beta = -0.017$) do not show meaningful relationships with intention in this model. Before interpreting this finding, multicollinearity was considered as a potential explanation; however, the variance inflation factors reported in Table 3 fall well below the conventional threshold of 5 (range: 1.15–4.24), confirming that multicollinearity does not account for the absence of significant effects. The non-significance of these constructs is therefore a substantive finding. Once system-specific perceptions and environmental attitudes are included in the model, they account for the variance that would otherwise be attributed to general barriers and recycling beliefs. This suggests that intention formation in a DRS context is primarily governed by direct evaluations of the system and pro-environmental values, rather than by abstract recycling cognitions or perceived situational obstacles. This does not imply that Barriers and Recycling Beliefs are irrelevant to DRS participation altogether. As demonstrated in the robustness analysis presented in Tables 5 and 6 (see below), both constructs exert direct effects on actual bottle-return behaviour, confirming that they operate through pathways that bypass intention rather than through motivational processes.

A particularly noteworthy finding concerns gender. Men report lower behavioural intention compared to women ($\beta = -0.064$, $p < 0.01$), even after controlling for all psychologi-

Table 5 Comparison of three regression models predicting actual Bottle-Return Frequency (BFR)

Variable	Model 1	Model 2	Model 3
BI	0.405*** (0.016)	0.419*** (0.017)	0.255*** (0.025)
UX			0.107*** (0.027)
PEOR			0.100*** (0.024)
PU			−0.072* (0.029)
EA			0.073** (0.030)
FB			0.112*** (0.016)
Barriers		0.037** (0.017)	0.043** (0.017)
RB		−0.005 (0.022)	−0.065** (0.026)
Gender		0.121*** (0.037)	0.146*** (0.036)
Education: Medium		0.068 (0.071)	0.115 (0.068)
Education: High		−0.028 (0.073)	0.072 (0.072)
Income: Medium		−0.038 (0.036)	−0.029 (0.036)
Income: High		−0.115** (0.052)	−0.098* (0.050)
Settlement: Town		0.018 (0.036)	0.015 (0.035)
Settlement: Capital		−0.112** (0.051)	−0.095 (0.050)
R^2	0.218	0.231	0.274

Table 6 Comparison of direct effects with and without Behavioural Intention (BI)

Variable	Original BRF Model	BRF Model With BI	Interpretation
UX	0.157***	0.107***	Partially mediated
PEOR	0.167***	0.100***	Partially mediated
EA	0.164***	0.073**	Partially mediated
PU	−0.035	−0.072*	Suppressor effect (BI absorbs the positive component)
RB	−0.070**	−0.065**	Stable direct negative effect
FB	0.123***	0.112***	Stable direct positive effect

cal constructs and demographic characteristics. This pattern is in line with environmental psychology research [57–59, 78], which consistently shows that women tend to express stronger pro-environmental attitudes, higher sustainability motivation, and greater willingness to engage in everyday ecological behaviours than men. This suggests that even when experiential and attitudinal factors toward the REpont system are similar, men remain less inclined to commit to future usage. Such differences may stem from variations in environmental identity, risk perception, moral motivation, or the perceived personal relevance of recycling, and warrant further investigation.

Education and income both show positive associations with intention. Respondents with medium educational attainment ($\beta = 0.143$, $p < 0.01$) and higher education ($\beta = 0.150$, $p < 0.01$) both express significantly stronger intention to use the system. The income effect, however, is more complex. Although respondents with higher incomes exhibit stronger behavioural intention ($\beta = 0.093$, $p < 0.05$), this pattern appears somewhat paradoxical, given that individuals with greater financial resources are less economically dependent on the deposit-refund incentive. This suggests that the income effect may not reflect financial motivations directly, but rather broader lifestyle differences, such as stronger alignment with environmentally conscious consumption norms, greater flexibility in daily routines, or higher likelihood of adopting structured sustainability practices. Finally, settlement type does not have a significant effect. Controlling psychological and socioeconomic factors, behavioural intention does not differ between urban, capital, and rural respondents. It highlights that the motivational structure behind intention is relatively stable across geographic contexts, and that differences in access, infrastructure, or exposure do not substantially alter individuals' willingness to use the REpont system.

The second regression model (Model 2) examines the determinants of actual bottle-return frequency. Compared to behavioural intention, the model explains a more modest share of variance ($R^2 = 0.2444$), which is fully expected in intention–behaviour research, where real behaviours tend to be influenced by additional situational constraints. Several predictors show similar directions of association in both models. User Experience, Perceived Convenience, and Environmental Attitude are all positively related to both intention and actual frequency, confirming that enjoying the system, finding it easy to use, and holding pro-environmental values encourage not only willingness but also real engagement. In numerical terms, UX ($\beta = 0.157$, $p < 0.001$), PEOR ($\beta = 0.167$, $p < 0.001$), and EA ($\beta = 0.164$, $p < 0.001$) all remain significant predictors, although their effect sizes are, as expected, smaller than in the intention model (Model 1). It reflects the greater instability, situational dependence, and external constraints that characterize everyday recycling actions compared to intentions.

More interesting results emerge from the predictors that differ across the two models. Perceived Usefulness is a meaningful predictor of intention but does not influence actual return frequency. Consistent with this interpretation, the coefficient for PU is small and statistically not significant ($\beta = -0.035$, p = n.s.), indicating that believing the system is beneficial may help shape positive attitudes and commitment, yet it does not necessarily translate into regular bottle returns when confronted with everyday routines. Recycling Beliefs similarly show a negative effect on actual behaviour, while they have no influence on intention. The negative and statistically significant coefficient ($\beta = -0.070$, $p < 0.01$) implies that general environmental beliefs are weak predictors of concrete return habits once system-specific experiences are considered.

Barriers also behave differently from the other constructs. They do not influence behavioural intention but show a small positive relationship with actual bottle-return frequency ($\beta = 0.046$, $p < 0.01$). To interpret this finding correctly, it is important to note that the Barriers construct does not capture obstacles specific to the REpont system. As shown in Table 2, all five items refer exclusively to difficulties associated with conventional selective waste collection at home, including lack of time, insufficient storage space, absence of nearby recycling facilities, and general difficulty with waste sorting and separation by material type (e.g., glass, caps, packaging, bottles). Individuals who struggle with these aspects of traditional household recycling may find the REpont system a more accessible and manageable alternative, precisely because it does not require domestic sorting or separation. Rather than bringing pre-sorted waste to different collection points, users simply return beverage containers to a reverse vending machine at a nearby store. This substitution mechanism, whereby perceived barriers to conventional recycling redirect behaviour toward a simpler, more structured return channel, provides a theoretically coherent explanation for the observed positive association.

The contrast between gender effects in the two models is particularly striking. Men report lower behavioural intention than women, yet they report more frequent actual bottle returns. Model 2 shows a positive and strongly significant coefficient for men ($\beta = 0.130$, $p < 0.001$). This suggests that men's engagement with the REpont system may be driven less by internal motivations and more by practical household role distribution and situational factors. Although women typically express stronger pro-environmental attitudes and are often responsible for everyday shopping routines, the task of bottle return may be delegated to men. Several contextual factors may contribute to this pattern, including long queues at reverse vending machines, the presence of unhoused individuals around return points, or a generally less comfortable and secure environment at collection sites. As a result, women's higher willingness to engage in sustainable behaviour does not fully translate into return frequency, whereas men, despite reporting weaker environmental motivation, may carry out the practical act of bottle return more regularly. Therefore, it highlights a gender-specific intention–behaviour gap shaped by both motivational and situational mechanisms.

Other sociodemographic variables show mixed patterns. Education positively predicts both intention and behaviour, consistent with extensive evidence linking higher education to stronger environmental responsibility and greater adoption of sustainable practices. Respondents with medium education show a significant positive association with behaviour ($\beta = 0.152$, $p < 0.05$), while those with high education exhibit a positive but statistically non-significant coefficient ($\beta = 0.110$, p = n.s.). Income, however, shows a divergence. Higher-income respondents express stronger intention but do not return bottles more frequently in

practice. In Model 2, the income variables reflect this pattern: medium income is unrelated to BRF ($\beta = -0.013$, p=n.s.), and high income is negatively signed but statistically not significant ($\beta = -0.074$, p=n.s.). This may reflect the reduced motivational relevance of the financial incentive among wealthier individuals, together with lifestyle patterns that weaken the translation of intention into everyday routines. Finally, settlement type shows no significant effect. Neither urban machine congestion nor rural access limitations appear to influence actual usage once psychological and socio-demographic characteristics are considered.

Robustness Analysis and Mediation Patterns

To assess the stability of the models and to disentangle direct and indirect pathways, three incrementally specified regressions were estimated. The first model included only BI as a predictor of the BRF; the second model added the demographic variables together with Barriers and RB – variables that did not influence BI in earlier analyses; and the third model introduced the full set of psychological constructs (UX, PEOR, PU, EA, FB), allowing a detailed assessment of mediation and suppression mechanisms. Results are presented in Table 5.

The initial model demonstrated that BI is a very strong standalone predictor of actual return behaviour ($\beta=0.41$), explaining over 21% of the variance in BRF on its own. This reflects the canonical findings of TPB. Individuals with stronger intentions to use the system do, in fact, return bottles more frequently. The predictive power of BI remained exceptionally stable when demographics, Barriers, and RB were added, indicating that intention is largely independent of sociodemographic background or broader environmental beliefs. Barriers emerged as a significant positive predictor once entered alongside BI, suggesting that individuals who experience practical obstacles to at-home selective waste collection may rely more heavily on the REpont system as a convenient alternative. RB remained non-significant, implying that general environmental beliefs do not meaningfully shape return frequency once system-specific perceptions are considered.

The full model revealed the clearest structure of direct and indirect pathways. When BI was included together with all psychological predictors, its effect remained the strongest in the model, confirming its central role as the proximal determinant of behaviour. Numerically, BI showed a large and highly significant effect on actual return frequency ($\beta=0.255$, $p<0.001$), far exceeding the magnitude of any other predictor in the model. The coefficients for UX, PEOR, and EA all declined substantially but remained significant. UX decreased from 0.157 to 0.107 (both $p<0.001$), PEOR decreased from 0.167 to 0.100 (both $p<0.001$), and EA decreased from 0.164 to 0.073 ($p<0.01$). This pattern highlights partial mediation: these constructs influence behaviour partly through BI, yet they retain smaller direct effects even after accounting for intention (Table 6).

FB similarly showed a stable direct positive relationship with behaviour, suggesting that financial incentives operate independently of motivational and attitudinal processes. The coefficient changed only minimally, from 0.123 to 0.112 (both $p<0.001$), confirming that FB exerts a persistent behavioural influence even after intention is controlled. Two constructs behaved in theoretically important but contrasting ways. First, Barriers maintained a positive direct effect in all specifications, underscoring that difficulties linked to household waste management shape actual return behaviour but not intention. In the full model, Barriers remained significant ($\beta=0.037 \rightarrow 0.043$, $p<0.05$), indicating that their behavioural

relevance is stable and intention-independent. Second, PU exhibited a textbook suppressor effect. While PU strongly predicted BI, it did not significantly predict behaviour in the intention-only model.

However, when BI was added to the regression, which absorbs the positive component of PU, the remaining variance of PU correlated negatively with BRF, producing a statistically significant negative coefficient. Specifically, PU shifted from a non-significant −0.035 to a significant −0.072 ($p<0.05$). This highlights that the "usefulness" component of PU is transmitted primarily via BI, and the residual PU variance, once intention and related constructs are controlled, captures elements that are negatively associated with return behaviour. This is a classic suppression pattern and confirms that PU's role is almost entirely indirect.

RB showed a stable direct negative association with behaviour across models. Its coefficient changed only slightly (–0.070 → −0.065, both $p<0.01$), suggesting that RB captures a persistent behavioural mechanism unrelated to intention. The set of robustness checks demonstrates that the empirical relationships are theoretically coherent, statistically stable across model specifications, and consistent with well-established intention–behaviour frameworks. System-related perceptions and pro-environmental attitudes shape intention, intention shapes behaviour, and only a small subset of constructs (Barriers, FB, and the suppressed residual of PU) exert direct influences on actual return frequency.

Discussion

Interpretation and Discussion of the Findings

The results provide an extended picture of how motivational, experiential, and structural factors jointly shape consumer engagement with DRS. The findings confirm the central role of behavioural intention as the proximal driver of bottle-return frequency, while also revealing systematic intention–behaviour gaps and several direct pathways that bypass intentions altogether. First, the analyses show that behavioural intention is a substantial predictor of actual bottle-return frequency (Table 7), supporting H1 and aligning with the core proposition of the TPB that intention is the most immediate antecedent of behaviour [11, 12]. Intention alone explains more than one fifth of the variance in return frequency, and its effect remains strong and significant even when all psychological and sociodemographic variables are included in the model. This pattern is consistent with the literature indicating that intention is a robust, though imperfect, predictor of recycling behaviour [13, 14]. At the same time, the more modest explained variance in behaviour compared to intention, as well as the divergent predictor profiles across the two models, clearly indicate an intention–behaviour gap. This result is in line with prior research on sustainable consumption and circular practices [15, 77].

System-specific perceptions, user experience, perceived ease of recycling, and perceived usefulness, emerge as key determinants of behavioural intention, supporting H2a–H2c and strengthening the relevance of technology-acceptance perspectives in a DRS context [16–18]. Individuals who enjoy using the REpont system, find it convenient, and perceive it as useful for managing bottle returns report markedly stronger intentions to continue participating. However, the present results also show that these system perceptions exert only smaller direct effects on actual return frequency once intention is controlled. This suggests

Table 7 Summary of hypotheses, expected effects, and empirical outcomes

Hypothesis	Expected effect/relationship	Result	Empirical support and interpretation
H1	Behavioural intention positively predicts bottle-return frequency.	Supported	Intention is a strong, significant predictor of actual behaviour.
H2a	User experience positively predicts behavioural intention.	Supported	User experience shows a robust positive association with intention, indicating that system enjoyment increases motivation to participate.
H2b	Perceived ease of recycling positively predicts behavioural intention.	Supported	Ease of recycling significantly increases intention, consistent with convenience-based models of recycling behaviour.
H2c	Perceived usefulness positively predicts behavioural intention.	Supported	Perceived usefulness strongly predicts intention; in line with TAM findings that perceived utility drives adoption intentions.
H3	Environmental attitude positively predicts behavioural intention and actual behaviour.	Supported	Attitude is a strong driver of intention, with an additional smaller direct effect on behaviour.
H4	Perceived barriers negatively predict behavioural intention.	Not supported	Barriers do not reduce intention once experiential and attitudinal factors are considered.
H5	Recycling beliefs positively predict behavioural intention.	Not supported	General recycling beliefs do not predict intention and show inconsistent associations across models.
H6a and H6b	Financial benefits positively predict behavioural intention and actual behaviour.	Supported	Perceived financial rewards significantly increase both intention and actual return frequency; one of the strongest behavioural predictors.
H7	Gender predicts participation: women → higher intention; men → higher return frequency.	Partially supported	Women report stronger intentions to use DRS, consistent with prior findings on gendered environmental motivation. Men exhibit higher actual return frequency, reflecting a gender-specific intention–behaviour gap.

that the primary function of user experience, perceived ease, and usefulness in DRS is to shape motivational readiness rather than directly determining everyday return habits. It is particularly true when structural and contextual constraints intervene between intention and action.

Environmental attitude proves to be one of the strongest predictors of behavioural intention and shows a positive direct association with actual bottle-return frequency, supporting H3. This dual role is broadly consistent with VBN theory and prior studies linking stronger environmental concern to higher recycling motivation and participation [19, 33, 34]. The fact that environmental attitude remains significant in the behaviour model, even after accounting for intention and system-specific perceptions, indicates that value-driven motivation not only strengthens willingness but also increases the likelihood of enacting bottle-return routines in practice. In other words, pro-environmental orientations appear to reduce the slippage between intention and behaviour in structured return systems such as REpont.

The findings for perceived barriers and recycling beliefs show a more complex picture. Contrary to H4, perceived barriers do not reduce behavioural intention once experiential

and attitudinal variables are considered. This suggests that system-specific perceptions and environmental attitudes dominate the formation of intention in a DRS context, while general constraints related to time, space, or information play a secondary role at the motivational stage. Yet, contrary to classical constraint models, barriers exhibit a small but positive direct association with actual bottle-return frequency. Rather than undermining participation, higher perceived barriers to traditional household recycling appear to motivate individuals to use REpont more frequently. Currently, store-based returns are experienced as a comparatively harder, more structured and complicated alternative to at-home sorting and storage. But at the same time, this finding suggests a substitution mechanism. Individuals who struggle with conventional selective collection may rely more heavily on DRS as a practical solution, thereby turning perceived obstacles into drivers of behavioural engagement.

Recycling beliefs, by contrast, do not support H5. While general beliefs about the environmental benefits of recycling are positively associated with attitudes in previous research [23, 53, 79], they neither strengthen behavioural intention nor promote actual return frequency in the present study. In fact, once system-specific perceptions and environmental attitudes are controlled, recycling beliefs show a small negative association with behaviour. One interpretation is that broad, abstract beliefs about recycling capture a more idealized environmental self-image that does not necessarily translate into structured, technology-mediated return practices such as REpont. The negative coefficient may also reflect a disillusionment effect. Individuals who hold strong pro-recycling beliefs but perceive systemic shortcomings, infrastructural gaps, or inconsistencies in waste policy may be more critical and less likely to engage in specific schemes, particularly when these are perceived as inconvenient or insufficiently integrated into everyday routines like in the introduction of the current DRS system. This pattern strengthens critiques of value-based models that rely heavily on general environmental beliefs to explain concrete recycling actions [35].

Financial benefits demonstrate a distinct and more structurally oriented pathway. In line with H6a and H6b, perceived financial benefits are positively associated with both behavioural intention and actual bottle-return frequency, with strong and stable direct effects on behaviour. These results should, however, be interpreted with some caution due to the relatively lower level of internal consistency of the financial benefits construct. But the findings support earlier literature on DRS showing that economic incentives increase participation and elevate return rates by providing clear, immediate rewards for environmentally desirable actions [6, 20, 37]. The fact that financial benefits remain a significant predictor of return frequency even after controlling for intention indicates that monetary incentives operate partly outside attitudinal and motivational processes. Rather than merely boosting willingness, they appear to shape habitual compliance and routine participation in DRS, consistent with studies showing that perceived economic value enhances adherence to structured bottle-deposit programs [55, 56]. Together with the barrier findings, this highlights that structural and experiential factors can influence behaviour via both motivational and non-motivational channels.

Finally, the sociodemographic patterns highlight important heterogeneities in how intentions and behaviours are formed. Women report stronger behavioural intentions than men, consistent with extensive evidence that women tend to hold stronger environmental attitudes and higher self-reported willingness to engage in pro-environmental behaviour [34, 58, 59]. At the same time, men show higher actual bottle-return frequency, even after controlling for psychological constructs, pointing to a gender-specific intention–behaviour gap. This “gen-

der paradox" means that men often display greater compliance and more frequent return behaviour, particularly when financial incentives are salient. One possible explanation is that pro-environmental intentions may not always translate into individual-level actions, particularly when recycling tasks are embedded in shared or household-level routines. In such contexts, intentions reported by one household member may be realised through the actions of another. At the same time, situational factors and informal task allocation patterns may also influence who performs the actual return behaviour. Educational differences also follow established patterns, with higher education associated with stronger intentions and, to a lesser extent, more frequent returns, reflecting greater environmental awareness and familiarity with sustainability practices. Income, by contrast, shows a positive relationship with intention but not with behaviour, suggesting that higher-income individuals may endorse DRS participation at a normative level while being less sensitive to the financial incentive in day-to-day routines.

Implications

The findings highlight several actionable directions for improving the performance and long-term sustainability of DRS. First, system-specific perceptions play a central role in shaping behavioural intention. Improving the clarity, speed, and reliability of the return process, along with the physical design and accessibility of return points, can further strengthen consumers' willingness to participate. These results highlight that technological and interface-related improvements are not marginal details. They directly support more stable usage patterns and help minimize intention–behaviour inconsistencies. Second, the strong influence of environmental attitudes suggests that communication strategies emphasizing environmental benefits remain effective. However, the lack of predictive power associated with general recycling beliefs indicates that broad pro-recycling messages are insufficient on their own. Campaigns that highlight the specific environmental impact of DRS (e.g., reduced littering, closed-loop material recovery, and measurable CO_2 savings [80, 81]) are likely to be more persuasive. Messaging should also address the observed gender differences. Women respond more strongly to value-based and responsibility-focused appeals, whereas men appear more responsive to practical and reward-driven cues.

Third, financial benefits are robust and independent driver of actual participation. This indicates that stable economic incentives remain essential for maintaining high return rates. Policymakers should ensure that deposit values keep pace with inflation and remain salient at the point of return. The positive role of perceived barriers in predicting behaviour also suggests that DRS can act as a practical alternative for individuals who face difficulties with household recycling. Integrating the system more explicitly into broader waste-management strategies (e.g., offering combined guidance for selective collection and deposit returns) can help align consumer habits across different recycling routes. Thus, the results of this study demonstrate that effective DRS design requires the joint consideration of motivational, experiential, and structural factors. Improvements in system usability, targeted and evidence-based communication strategies, and the preservation of meaningful financial incentives can collectively strengthen both intention and actual return behaviour, supporting higher participation levels and more reliable material recovery within circular-economy frameworks.

Conclusion

The findings of the study confirm that DRS participation cannot be reduced to any single theoretical lens or model. Motivational constructs rooted in TPB and VBN, system perceptions from TAM, and structural factors such as barriers and financial incentives all contribute to explaining intention and behaviour but they do so through partly distinct pathways. The REpont system thus exemplifies a context where intentions are strongly predictive yet insufficient, and where environmental attitudes, experiential evaluations, structural constraints, and monetary rewards interact to shape how often consumers return bottles. Based on the results, behavioural intention emerges as the strongest predictor of return frequency, yet several system-level and sociodemographic variables exert independent influences that highlight the limits of intention alone. User experience, perceived ease of recycling, and perceived usefulness strengthen intention, while environmental attitudes play a dual role by supporting both willingness and actual engagement. Financial benefits represent the most consistent driver of return behaviour, highlighting the importance of maintaining salient economic incentives within DRS schemes. The results also reveal a gender-specific intention–behaviour gap and show that difficulties with household recycling can redirect consumers toward more structured return channels.

The study contributes to the literature in three key ways. First, it brings together TPB-, TAM-, and VBN-based mechanisms within a single analytical framework, demonstrating how motivational, experiential, and structural pathways jointly shape DRS participation. Second, it provides empirical evidence on intention–behaviour discrepancies in a real-world system and identifies factors (such as financial incentives and perceived barriers) that can bypass or compensate for motivational drivers. Third, it offers one of the first large-scale examinations of user perceptions and return behaviour within a European DRS system, generating evidence that can inform both policy design and operational improvements.

Despite its strengths, the study faces several limitations that future research should address. The cross-sectional design prevents causal inference, and experimental or longitudinal approaches could provide an opportunity to examine how return behaviours evolve over time. In addition, the empirical analysis is based on a convenience sample collected through online platforms, which may introduce selection bias. More environmentally engaged or digitally active individuals may be overrepresented, which should be considered when interpreting the generalizability of the findings. Self-reported measures may not fully capture actual return behaviour; in particular, they may be affected by recall bias and social desirability bias, potentially leading to an overestimation of pro-environmental behaviour. Furthermore, the study focuses on one national DRS system, and comparative analyses across countries or system designs would help determine which mechanisms are context-specific and which are more universal. Further work could also explore the psychological processes underlying the gender-specific intention–behaviour gap and examine how digital feedback, personalized incentives, or infrastructural changes influence return patterns. In addition, future research should incorporate observed behavioural data and household-level analysis to better understand how pro-environmental intentions are translated into actual behaviour across individuals. Overall, the findings show that effective DRS require more than pro-environmental motivation. They depend equally on the usability of return infrastructure, the clarity of system benefits, and the stability of financial incentives. Strengthening these dimensions can support higher and more consistent return rates, contributing to more efficient material recovery and more resilient circular-economy practices.

Appendices

Table A.1. Chi-square goodness-of-fit tests and Cramér's V for demographic variables

Variable	Chi²	df	*p*	Cramér's V
Gender	220.06	1	<0.001	0.288
Age	570.95	3	<0.001	0.267
Education	298.37	2	<0.001	0.237
Region	586.17	6	<0.001	0.192

Note: Population proportions based on Hungarian Central Statistical Office [65]. All tests conducted against known population parameters

Table A.2. Sensitivity analysis: regression coefficients across demographic subgroups

Variable	Male (*n* = 1,648)	Female (*n* = 1013)	Young 18–39 (*n* = 1,117)	Older 40+ (*n* = 1,544)
UX	0.163	0.139	0.152	0.155
PEOR	0.149	0.206	0.210	0.138
PU	−0.036	−0.021	−0.085	0.005
EA	0.149	0.182	0.164	0.157
Barriers	0.044	0.052	0.026	0.054
RB	−0.073	−0.067	−0.038	−0.085
FM	0.108	0.163	0.125	0.120
R²	0.213	0.336	0.265	0.235

Note: Standardised regression coefficients shown. Models estimated with robust standard errors. All models include education, income, and settlement controls

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Declarations

Competing Interests The authors declare that they have no competing interests.

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Authors and Affiliations

József Ráti[1] · Zalán Márk Maró[2]

✉ Zalán Márk Maró
zalan.maro@uni-corvinus.hu

József Ráti
Rati.Jozsef@uni-nke.hu

[1] Department of Economics and International Economics, Ludovika University of Public Service, Üllői út 82., 1083, Budapest, Hungary

[2] Department of Agricultural Economics, Institute of Sustainable Development, Corvinus University of Budapest, Fővám tér 8, Budapest 1093, Hungary