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Leveraging technology for waste sustainability: understanding the adoption of a new waste management system

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Abstract

Many countries are under escalating pressure to meet legally binding targets in relation to recycling and waste management. This paper explores how innovative tools, including blockchain, economic incentives, and gamification, encourage consumer adoption of a novel household waste management system. We focus on developing a comprehensive framework that combines UTAUT2 (the unified theory of acceptance and use of technology 2) with novel features in the waste management context and additional behavioral construct, intention to recommend the system to others. We tested the proposed model using the partial least square structural equation modeling approach based on a survey of 400 respondents. The results indicate that in addition to effort expectancy, social influence, and hedonic motivation, trust, a property of blockchain technology, also impacts the respondent's behavioral intention to use the new system. Furthermore, trust has a significant effect on both the level of system use and intention to recommend waste management system to others. The role of gamification was identified as a moderator between behavioral intention and system use and between trust and system use but not between system use and facilitating conditions. This result demonstrates that gamification can be valuable to increase adoption in users with otherwise low levels of behavioral intention. However, we did not find a strong link between either economic incentives, facilitating conditions, or performance expectancy and behavioral intention. The paper concludes by presenting the application of the proposed framework and the implications for the design of future consumer-facing waste management systems. The introduction of the novel features such as blockchain and gamification is discussed.

Keywords Waste management system, Technology adoption, UTAUT2, Blockchain, Recycling, Gamification

1 Introduction

Waste and waste treatment is a modern global issue [1]. The expectation is that with the current population, consumption, and urbanization growth, in the next 30 years, the total amount of waste produced will surge from the 2,000 Mt evinced in 2016 to 3,500 Mt [2]. The potential adverse effect of this growth on the environment is substantial, with only limited available actions to minimize its impact.

One aspect of particular importance regarding this global waste management issue is household waste management. Consequently, there is an urgent call to establish new waste management practices that are able to achieve change at the household level. Given this challenge, in this study, we are interested in the role of new technology in encouraging waste reduction and separation at the household level. This paper analyzes and defines the main drivers of adopting a new waste management system (WMS) by consumers. We consider a WMS utilizing the latest technological advances as a

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proposed solution intended to improve waste collection and separation among citizens and promoters of new citizen behavior in terms of waste generation and handling. We consider and assess several potential technologies for the proposed WMS, including gamification [3], blockchain [4, 5], and economic incentives [6]. However, this combined system remains theoretical and questions rise about the potential response of consumers to these technologies in household waste management.

The unified theory of acceptance and use of technology 2 (UTAUT2) model is considered a definitive theory for understanding individual technology adoption [7]. However, in the authors' recommendation for future research, they emphasized the importance of using UTAUT2 as the base model and adjusting it to specific technologies and contexts [8]. To answer this call, we extend UTAUT2 with intention to recommend and the innovative features to be implemented in a new WMS: financial incentives (both rewards and penalties), gamification, and blockchain.

This paper aims to expand our understanding of how consumers react to new technologies in the waste management sector to ensure these technologies will be adopted successfully by consumers and achieve real-world change. To the best of our knowledge, this is the first research to analyze the combination of the UTAUT2 theory constructs with blockchain technology, financial incentives, and gamification together. Importantly, we find interactions between these potential technology solutions, particularly blockchain and gamification. Secondly, we demonstrate the role these new technological tools can play while pursuing the objective of higher consumer adoption and intention to recommend in the waste management sector. Finally, our research provides insight into the drivers of consumer adoption and the use of waste management technologies. These drivers suggest invaluable directions for municipalities and waste management companies when developing and implementing new household systems. The proposed WMS will provide detailed instructions, frequently asked questions, and information on how to sort different products that the user can access at any time. The provision of information and more broadly environmental education has proved to be a particularly effective method in improving recycling performance.

2 Literature review

A pivotal aspect of global waste production is household waste management [9, 10]. Sorting waste at the source, such as household, is a key to enabling recycling and the circular economy. However, there are differences in the levels of household waste-related behaviors and significant room for improvement to achieve sustainability. Household waste management remains a crucial challenge due to the high dependency on social behaviors [10].

2.1 The conceptual model development

2.1.1 UTAUT2

UTAUT2 was chosen as a baseline template for our conceptual model over other highly common theories such as theory of planned behavior (TPB), innovation diffusion theory, or the technology acceptance model. Crucially, UTAUT outperformed such theories [11]. A modified UTAUT2 approach can significantly impact the knowledge of key phenomena in consumer adoption [12]. To consider the case of a new waste management technology we include the UTAUT2 model almost all the proposed drivers of adoption (see Fig. 1). Habit was excluded from the research model due to issues with discriminant validity. Additionally, the WMS is a new technology, combining novel features as blockchain, gamification, and financial incentives all at once, that has not yet earned widespread attention among Portuguese citizens to become a habit.

UTAUT2 not only provides an exceptional opportunity to achieve a greater perception of consumer's technology adoption mechanism but also the recent study proves that it is an effective tool for exploring the blockchain adoption process [13]. UTAUT2 argues that behavioral intention (BI) can be directly predicted by performance expectancy (PE), effort expectancy (EE), social influence (SI), facilitating conditions (FC), hedonic motivation (HM), and price value. Furthermore, FC also impacts system use in our model, which is influenced by BI [12], which is aligned with research in waste management: waste management intention is a direct predictor of waste management behavior [2]. We include all the above-mentioned variables in our conceptual model as compulsory elements of technology adoption process.

PE has been proven to be the strongest predictor of BI to use technology, regardless of the environment [14]. PE is defined as the degree to which WMS users believe that using the system will benefit the users and their daily life. PE implies that users notice that they can improve the productivity of recycling rate and waste management at home. Then, we define EE as the degree of ease connected with a WMS's use. The users' digital skills might become a barrier to adopt a WMS [15]. Using a WMS is voluntary, users dedicate their effort not only for personal benefits but mainly for the whole community. As we can see from the previous research, both variables are crucial in a process of technology adoption by users and therefore will be added to the conceptual model.

Next key construct of the UTAUT2 model is SI, which is "*the degree to which an individual.perceives that*

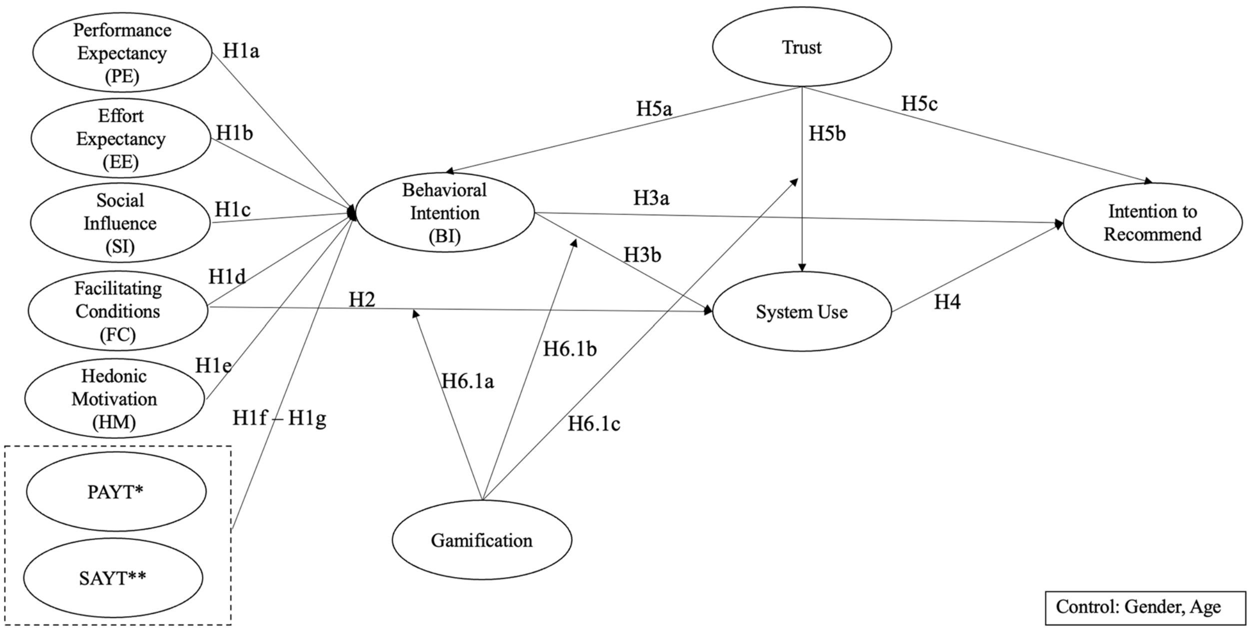

Fig. 1 Research model. Note: *PAYT – pay-as-you-throw, **SAYT—save-as-you-throw

important others (relatives, friends, etc.) *believe he or she should use the new system*" [11]. SI or subjective norms is central for spreading and accepting a new technology [12], such as WMS**.** In waste management-related studies, SI (as subjective norms) influences BI to recycle or sort waste [2, 16]. Hence, based on the previous research dedicated to UTAUT2 variables in waste management and environmental context, the current study hypothesizes that PE positively influences BI to use WMS (H1a), as well as both EE and SI have a positive impact on BI to use WMS (H1b and H1c).

Resources and knowledge about the technology facilitate the adoption of such technology [17], which brings us to the importance of FC. The definition of FC is the users' assessment of the available resources to support the use of the system. Easier access to resources such as computers, smartphones, and the internet will enhance users' intention to use WMS. The proposed WMS will provide detailed information on how to sort different waste, which will positively influence BI and the use of WMS. Furthermore, in waste management-related studies, FC (as perceived behavioral control) impacts BI to recycle or sort waste [2, 16]. According to the TPB, perceived behavioral control (FC in our model) is a substantive antecedent of environmental behaviors [18]. Hence, we propose that FC not only positively influences BI to use WMS (H1d) but also impacts system use (H2).

The next two important constructs of UTAUT2 model: HM and price value. The definition of HM is the fun derived from using WMS, while price value is defined as pay-as-you-throw (PAYT) and save-as-you-throw (SAYT). With PAYT system, citizens which generate more waste are charged accordingly to the waste quantity they produce. An alternative approach to PAYT is to provide rewards, referred to as SAYT. Models with applied fees are estimated to have a weightier effect on pro-environmental behavior than those that use rewards [19]. In case of low pro-environmental behavior, applied PAYT can reduce the use of WMS, conversely, SAYT has an opposite effect and increases the use of WMS [20]. It is important to note, the scale for both variables is self-developed. PAYT and SAYT as an adjustment of the price value from UTAUT2 to incorporate both economic costs and benefits in our model. Next, WMS will have various entertainment features that aim to make the system more enjoyable and fun (collecting points and rewards for proper sorting). The higher values of HM will influence higher values of BI and consequently higher values for consumer use of technology [21]. In our model we expect that financial incentives and HM will facilitate the adoption of WMS. Therefore, our study hypothesizes that HM (H1e), PAYT (H1f), SAYT and (H1g) positively influence BI to use WMS.

According to the TPB, the intention to behave in an ecofriendly fashion is the important antecedent of environmental behaviors [18]. Multiple studies have supported the impact of pro-environmental behavior intention on pro-environmental behavior [16, 22]. The meta-analysis across 60 studies using UTAUT2 found the strongest path with all significant values between BI and use [7]. Adapted to our context of waste management, we define BI as the intention to use WMS, system use as the use of the WMS' features. It should be noted that in our model we do not evaluate the actual use of the system by citizens, as a system combining all the features discussed here is not widely available, but instead the potential system use. However, understanding the underlying mechanism between perceived intention and use is paramount for further guaranteeing that new WMS will be accepted by users and used systematically. Therefore, we can expect that BI of users to use WMS will positively impact WMS use itself (H3).

2.1.2 Intention to recommend

A recommendation is a type of post-adoption behavior. Consequently, the intention to recommend is considered a crucial element for the successful diffusion of technologies [17] and can easily impact a positive or negative recommendation in a consumer context [23]. We anticipate that WMS users will have high intention to use the system and use the main features of WMS actively, then they will be more inclined to recommend this system to others. Thus, based on the previous research, the paper hypothesize that BI (H3) and system use (H4) positively influence the intention to recommend a WMS to others.

2.1.3 Contemporarily tools: Blockchain technology

Blockchain technology is introduced as a potential system feature. Blockchain technology is characterized by their ability to introduce trust. In the case of waste management, blockchain can allow for trusted and transparent tracking of both household waste management behavior [4] and the supply chain of waste products as they are incinerated, landfilled, or recycled. Trust is an integral of a blockchain foundation and is introduced in the model as an additional construct. This approach simplified the task of representing blockchain technology to the model, as we do not need to explain this technical topic that is likely unfamiliar to most users. Moreover, trust has been found to be all-important for household sorting behavior [24]. It should be noted that question of whether consumers will trust a blockchain system in practice remains an open one and we believe it should be the focus of future research.

The lack of trust is one of the most frequently cited reasons why consumers do not acquire technology [25]. Accordingly, trust is considered a vital element for the effective diffusion of technologies model. Blockchain technology systems are designed to provide integrity, trust, and security between parties [5]. Blockchain will enable for WMS users to track the movement of the waste starting with collection till the moment when the waste is recycled into new products (more details about the system can be found in Text S1 and S2 in the supplementary materials). Therefore, we believe that when users perceive WMS as a reliable and trustworthy system, their BI, WMS use, and intention to recommend it to others will increase significantly. Besides, Harring et al. [24] found a positive link between generalized trust on reported household recycling rate. We propose the following hypothesis that trust positively influences BI to use WMS (H5a), system use (H5b), and the intention to recommend WMS to others (H5c).

2.1.4 Contemporarily tools: Gamification

Gamification is another promising technology that provides enjoyable interaction for users making their experience more pleasurable. Furthermore, providing an enjoyable environment can positively influence users' adoption of technology [12]. Thus, we add a final variable in the model, gamification. Gamification can be defined as the application of game components in non-game settings [26]. Gamification tools, such as awards, feedback, collaboration, and competitive elements, can be applied to stimulate and engage people to recycle [3]. In psychology research, gamification was also found as a significant driver for environmentally sustainable behavior [27]. In our model we assume that the mechanisms of gamification will shift individuals' attitudes and intention to recommend, meaning it has a positive impact on BI (H6a), system use (H6b), and the intention to recommend WMS to others (H6c).

Though, gamification also has an indirect effect [28]; it moderates the relation between individual impact and organizational impact. Treiblmaier and Putz [26] recommended exploring gamification impact as a moderator rather than an antecedent. Thus, we propose that gamification forms a moderating factor that can potentially impact the relationships between system use and FC (H6.1a), system use and BI to use WMS (H6.1b), and between system use and trust (H6.1c).

Therefore, this paper explores whether the distinctive features of the new WMS based on the latest technologies can influence a customer's BI, system use, and intention to recommend that are determined by a customer's interaction with WMS. Two demographical variables, age and gender, are also included in the model as control variables since they indicated as significant in different research [20, 29]. The research model is shown in Fig. 1.

3 Materials and methods

3.1 Data collection

A survey strategy was designed so that results would be generalizable to the Portuguese population by targeting a sample representative by geographic area, gender, and age. Portugal was selected as the target country as it has relatively poor recycling performance in comparison to its European peers and the European Regional Development Fund project BEE2WasteCrypto intends to trial new technology solutions to this problem. Achieving a sample representative by gender and age was considered important to ensure that input from groups with different experiences with technology, particularly different age groups, would be included. The geographic criteria were incorporated as waste management and sorting policies and systems can differ by region. To achieve this goal within Portugal it was determined that a market research specialist would be required and the company Netsonda was commissioned for final data collection. All the respondents belonged to the company's internal panel, and Netsonda compensated them for their participation. The survey was conducted in the Portuguese language and took place during April 2021 in Portugal. The company first selected from its panel based upon region in such a way. The survey took approximately 10 min to complete the questionnaire (including 3 min of an introductory video explaining the new WMS and 7 min for questions). The video explaining how the system works, including the principal features and benefits of WMS, was created and shared before the respondents started answering the related questions. For instance, they were informed that users will receive points, unlock achievements for their recycling efforts, and will be able to check how their performance compares to the average for their neighborhood (for more details see Text S1 in the supplementary materials). We then assessed factors relating to the respondent's response to the different components of the system, as captured by the variables of the study. After reading the introduction of the survey, participants were moved to the video which they could not skip due to the predefined settings. Then, they needed to answer if the video worked well, and they could watch it without any interferences. If participants experienced any troubles with the video, they could not progress with the survey.

The research model indicates all the measurement items. A seven-point range Likert scale from 1 (strongly disagree) to 7 (strongly agree) was applied, except for system use which was measured from 1 (never) to 7 (every time) and gamification from 1 (not at all important) to 7 (extremely important) (see Table S1 in the supplementary materials). Overall, 400 valid answers were obtained. We then applied Harman's one-factor test to explore the common method bias [30]. Next, the marker variable approach [31] was tested where the maximum shared variance value for the variable, which is not theoretically connected to the research constructs, was 1.39%. Both tests found no significant common method bias in the obtained data.

The demographic profile of the respondents is displayed in details in Table S2 in the supplementary materials. Since the data was collected by professional company specializing in market research, we could regulate the demographic sample and align it with official statistics; our sample does not present statistically significant differences of the Portuguese population in terms of gender (male = 46.3%, female = 53.7%) and age (20–29 = 13.1%, 30–44 = 24.6%, 45–64 = 35.2%, 64 and more = 27.1%) [32]. Therefore, the external validity of the study is also reassured.

3.2 Evaluation method

We aim to investigate the key drivers of the continued intention to use and recommend new WMS in the current study. Partial least squares (PLS) is a variance-based method and has been applied in this research since: (1) it does not call for any restrictive assumption about distribution; (2) the research model is complex and has not been verified in the literature; (3) the sample size is at least ten times higher the number of paths connected to a construct in the research model; and (4) PLS is also a method that allows having formative indicators estimating the constructs [33]. PLS approach allows to obtain a stronger predictive accuracy and a lower possibility of chance correlation [33]. For these reasons, the conceptual model and proposed hypothesis were assessed by the means of PLS structural equation modeling method which estimates pre-determined connections that should elucidate the dependent variables of the conceptual model.

4 Results

4.1 Measurement model

Internal consistency, convergent validity, and discriminant validity are analyzed for reflective constructs. First, Cronbach's alpha/composite reliability were calculated (Table S3, in the supplementary materials), the results are higher than 0.7 for all constructs, proving internal consistency [33]. Second, the average variance extracted (AVE) and indicator reliability are assessed to prove convergent validity. In Table S3 in the supplementary materials we can see that the AVE values of constructs are higher than 0.5. These results reveal convergent validity [33].

Then, we tested discriminant validity. The Fornell-Larker criterion was analyzed (Table S3, in the supplementary materials), the AVE square root of every construct should be greater than the correlation between the constructs. Then cross-loadings were used to assess discriminant validity as well. Table S4 (in the supplementary materials) demonstrates the loadings and cross-loadings. All loadings are higher than the cross-loadings, confirming the condition. Finally, the hetrotrait-monotrait ratio was investigated. This ratio is required to be lower than 0.9 [33], as noted in Table S5 (in the supplementary materials). Therefore, all criteria are supported, and we can conclude that our model obtained good discriminant validity, and reflective constructs can be applied to test the structural model.

The formative construct is evaluated by multicollinearity, statistical significance, and the weights' sign. The variance inflation factor (VIF) was applied to assess multicollinearity. The result should be below 5 [33]. In Table S6 (in the supplementary materials), all VIF are lower than 5. This outcome reveals no collinearity problems. Further, the weights are positive and statistically significant except for items system use 3 (SU3) and system use 4 (SU4), but the outer loadings are greater than 0.5 (see Table S6 in the supplementary materials). Thus, we preserved the indicators in the formative construct system use, even though the outer weights are not significant.

After obtaining satisfactory results of the reflective and formative constructs analyses, we assessed the structural model as a next step.

4.2 Structural model

First, it is necessary to analyze possible collinearity issues with VIF to assess the research model [33]. All VIF values are below the threshold of 5, indicating no collinearity problems for all constructs. We did a bootstrapping with 5,000 iterations to measure the path coefficients significance. We also assessed the original UTAUT2 model using the same data to estimate whether the explanatory ability of the proposed research model is better than UTAUT2 itself. Table S7 in the supplementary materials presents the results of the two models. In the waste management context, based on R^2_{adj}, we found that the whole research model (UTAUT2 + WMS features) performed better than UTAUT2 on its own. First, our model explains 64.3% of the variation on BI to use WMS. Furthermore, constructs such as PE ($\widehat{\beta}=$ 0.016, $p>0.10$), FC ($\widehat{\beta}=$ 0.077, $p>0.10$), PAYT ($\widehat{\beta}=$ 0.045, $p>0.10$), SAYT ($\widehat{\beta}=0.021$, $p>0.10$), and gamification ($\widehat{\beta}=$ -0.028, $p>0.10$) are not statistically significant for BI (where $\widehat{\beta}$ is an estimated path coefficient). Meanwhile, EE ($\widehat{\beta}=0.350$, $p<0.01$), SI ($\widehat{\beta}=0.094$, $p<0.05$), HM ($\widehat{\beta}=0.132$, $p<0.10$), and trust ($\widehat{\beta}=$ 0.267, $p<0.01$) are statistically significant for BI. Thus, H1a, H1d, H1f, and H1g, H6a are not supported, but H1b, H1c, H1e, H5a are supported.

Second, the model explains 67.9% of the variation on system use. The FC construct was statistically significant for system use ($\widehat{\beta}=$ 0.117, $p<0.01$), as well as BI ($\widehat{\beta}$ = 0.399, $p<0.01$), trust ($\widehat{\beta}=$ 0.150, $p<0.05$) and gamification ($\widehat{\beta}=$ 0.285, $p<0.01$) supporting H2, H3b, H5b and H6b.

The moderating effect of gamification in FC ($\widehat{\beta}=$ 0.016, $p>0.10$) and system use is not statistically significant, thus, we can reject H6.1a. For BI on system use ($\widehat{\beta}=$ -0.180, $p<0.01$) and trust on system use ($\widehat{\beta}=$ 0.098, $p<0.05$), the moderating effect of gamification is statistically significant. Thus, H6.1b and H6.1c are supported.

Finally, our model explains 70.9% of the variation on intention to recommend the WMS to others. BI ($\widehat{\beta}=$ 0.498, $p<0.01$), system use ($\widehat{\beta}=$ 0.271, $p<0.01$), trust ($\widehat{\beta}=$ 0.191, $p<0.01$), as well as gamification ($\widehat{\beta}=$ -0.059, $p<0.10$) are statistically significant for intention to recommend. Therefore, H3a, H4, H5c, H6c are confirmed. The structural model presented in Fig. S1 in the supplementary materials includes the path coefficients and variation explained. Overall, we can conclude that 14 hypotheses out of 20 are supported in our research model.

Gender, as one of the control variables, is not statistically significant ($p>0.10$) and does not influence any target variables. Though, age appeared to be significant in case of BI ($\widehat{\beta}=$ 0.061, $p<0.05$) and system use ($\widehat{\beta}=$ -0.087, $p<0.05$).

5 Discussion

5.1 Discussion of results and theoretical implications

The explanatory ability of the proposed research model has been proven to be better than UTAUT2 itself, meaning that the proposed WMS features improve the model's strength and can positively reinforce consumers' adoption of new technology in the context of household waste management. The results align with previous research stating that UTAUT2 can significantly increase the knowledge of key phenomena [12] when extended with suitable constructs [8]. Regarding the UTAUT2 constructs, EE is discovered to be the strongest predictor of BI to use the WMS, while PE and FC have no significant effect on the prediction of BI. Such findings vary from previous technology adoption studies where the path between PE and BI were the most significant ones, and no significant effect was found between EE and BI [7, 34]. Non-significant results for PE (i.e., usefulness) can potentially be explained by the fact that the WMS is an innovative product, and most of the Portuguese population have not had any experience with such waste management technology. This fact could also explain the finding of no relationship between FC and BI.

Per the findings of several waste sorting behavior papers and technology acceptance studies [2, 18, 35], SI plays a significant role in the adoption formation of WMS. Therefore, waste management remains a challenge due to the dependence on social behaviors [10];

respondents are likely to depend on others' opinions concerning WMS, which is considered very common for unknown products, meaning peer pressure can be considered for marketing purposes. Furthermore, HM also has a significant role in determining BI, which is in line with previous studies [15]. Thus, the enjoyment and entertainment derived from using WMS seem valuable to determine participants' intention to use this new technology, which can also explain the importance of gamification tools as a significant impact on system use and the intention to recommend the WMS to others. Furthermore, our findings support previous research that revealed the importance of gamification for use in waste management and reinforcement of waste sorting behavior [3].

Regarding the moderating effect, we can conclude that gamification influences the relationship between BI and system use as well as between trust and system use. A high level of gamification diminishes the effect of BI on use of WMS (Fig. 2). In contrast, when gamification is low, BI is considered more important in explaining system use, but overall gamification effect is low. On the other hand, when high gamification exists, the importance of trust in the system is even more important in explaining system use (Fig. 3). This facet means trust has a positive and more decisive influence to explain system use when gamification features are important to users. This factor amplifies the potential role of blockchain technology when combined with gamification features.

We did not find a significant moderation effect of gamification on the relationship between FC and system use. It reveals that FC does not have different impacts based on a high or low level of gamification, meaning that FC is valuable to determine system use on their own and does not depend on gamification's importance.

The positive effect of price incentives on household recycling rates and municipal solid waste reduction has been demonstrated before [36], while other research shows the effect is too small or unclear [37]. In our model, financial incentives such as PAYT and SAYT have no significant influence on consumers' intention to use WMS. While Skumatz [38] argues that PAYT provides a persistent economic signal to change behavior, our results are different. One of the reasons could be that these two concepts were not directly presenting the price value of WMS but introducing possible costs or rewards for waste separation. Moreover, the lack of knowledge of respondents in this area could be another barrier. The majority of the Portuguese population has not experienced the reward or penalty system for waste sorting.

The next crucial part of the innovative WMS is blockchain technology which is represented by trust in the research model. Overall, trust was revealed as a significant predictor of all dependent variables: BI, system use, and the intention to recommend the WMS to others. This facet is in line with the various studies [24, 25, 39]. This detail indicates the high importance of a concept such as trust in the WMS and, consequently, the relevance of proposed blockchain technology which could encourage consumers to use the WMS continuously.

In complying with the previous studies, we discovered that age influences waste management behavior [20, 29]: younger generation has lower BI but higher system use

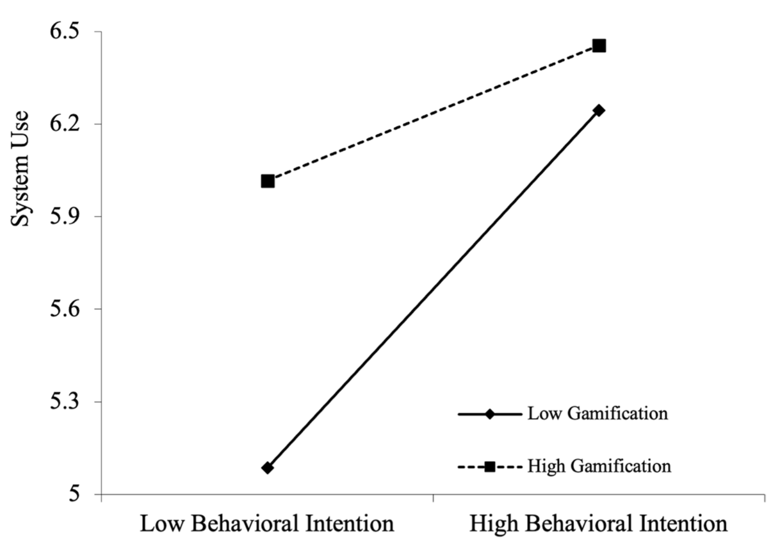

Fig. 2 Two-way interaction effects for regression analysis with system use (dependent variable, axis Y), behavioral intention (independent variable, axis X), and gamification as a moderator. All variables are measured by Likert scale from 1 (strongly disagree) to 7 (strongly agree)

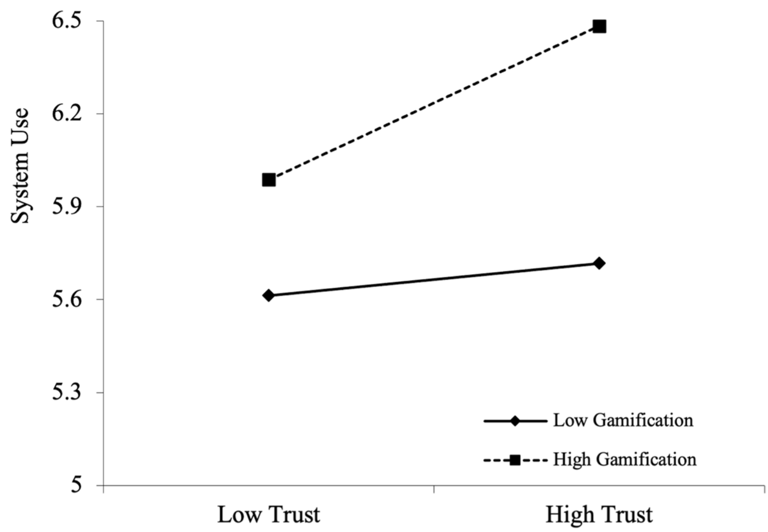

Fig. 3 Two-way interaction effects for regression analysis with system use (dependent variable, axis Y), trust (independent variable, axis X), and gamification as a moderator. All variables are measured by Likert scale from 1 (strongly disagree) to 7 (strongly agree)

implying that after the release of WMS, younger people will be the one using it.

5.2 Practical implications

The proposed model identifies the factors that can assist policymakers and waste management companies in improving household sorting behavior. First, when introducing the new WMS to consumers that will assist them in waste separation, it is crucial to emphasize the ease associated with the system's use, introduce fun and pleasant features, and not disregard the importance of word-of-mouth. According to Venkatesh et al. [12], technology entertainment features mainly appeal to early adopters. Once consumers get experience in using the system, its efficiency offsets all other attributes. Therefore, waste management companies should introduce novel product features to acquire more early adopters, especially during the beginning of the product life cycle.

Waste sorting should be promoted as not being challenging and time-consuming activities. Despite the results proving the non-significant influence of PE on intention to use the WMS, companies should retain users by offering powerful product features at the later stage of the life cycle, which can be perceived as valuable by the users and provide solutions for efficient waste management underscoring the importance of PE later on [7].

Next, trust and reliability of the new WMS are some of the key characteristics for effective technology adoption. The ability of blockchain technologies to produce credible information on waste management is an invaluable implication for practitioners. It is crucial for users to trust the system and its features. Problems surrounding a lack of transparency of recycling infrastructure and where sorted waste goes can be solved by blockchain technology applied in innovative WMS: the WMS users will be able to track the movement of the waste starting with collection till the moment when the waste is recycled into new products (see Text S1 in the supplementary materials).

The gamification approach should play another central role in the WMS: when entertaining system features are important for users, they amplify the system's trust and use. The collected points should have a value for the users, they should have an opportunity to redeem points for valuable rewards (local museum or theater tickets, discounts for electricity, etc.). Furthermore, competition between neighbors or neighborhoods can be effectively used by local policymakers producing a positive outcome in each community using the WMS.

Finally, the positive effect of FC on the use of the WMS implies the importance of facilitating the environment around how to use different system features, for instance, providing instructions and chat rooms to foster community involvement. It is especially relevant for older people since their use can be lower than younger citizens. Furthermore, due to the high level of importance of SI of the new technology, sharing the experience of using the WMS is a fundamental value proposition as well as presenting household waste sorting as a widespread shared activity in a community.

5.3 Limitations and future research

A completely new WMS combining the latest technology was examined in this study. Currently, we lack real user experience, therefore, the investigation of the actual usage of the WMS may differ after consumers become more familiar with the technology, and consequently, this should be analyzed. Second, the data for this study was only collected in Portugal, different WMS and consumers' experience with them is likely to vary internationally (indeed, the effectiveness of these systems and recycling rates do). Thus, it would be beneficial to apply this model in other countries and compare results that will leverage the process of identifying new variables to enhance the model's predictive power.

6 Conclusions

This study puts forward a complete framework for understanding the consumer adoption of a new, more efficient, and sustainable (environmentally and monetarily) WMS. The research identifies the factors for policymakers and waste management companies to consider improving household separation behavior with the adoption of new technology. Theoretically, the proposed conceptual model has strong explanatory ability, implying that additional novel features added to the classic UTAUT2 model secure consumers' adoption of new technology in the context of household waste management. In practice, when waste management companies' goal is to introduce new technology and to attract more consumers, great emphasis should be given to novel product features. With the passage of time, companies should focus on offering powerful product features to deliver solutions for efficient waste management to retain more experienced consumers. For instance, blockchain technology is a valuable and unique feature to sustain the creditability of the WMS, it can assist in gaining the trust of consumers. Gamification is another eminent approach: when entertaining features of WMS are appealing to users, they magnify the system's trust and use. Furthermore, future research is needed after the actual WMS will be adopted and used by consumers. A similar study conducted in different countries can convey stimulating benchmarking results.

Supplementary Information

The online version contains supplementary material available at https://doi.org/10.1186/s42834-023-00174-x.

Additional file 1.

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Authors' contributions
CRediT authorship contribution statement. Darina Vorobeva: Conceptualization, Data curation, Formal analysis, Methodology, Writing. Ian J. Scott: Conceptualization, Data curation, Methodology, Project administration, Supervision, Writing—review & editing. Tiago Oliveira: Conceptualization, Data curation, Formal analysis, Methodology, Supervision, Writing—review & editing. Miguel Neto: Conceptualization, Funding acquisition, Resources, Supervision. The author(s) read and approved the final manuscript.

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Availability of data and materials
The datasets used and/or analyzed during the current study are available from the corresponding author on reasonable request.

Declarations

Competing interests
The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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