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Adoption of new household waste management technologies: The role of financial incentives and pro-environmental behavior

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ABSTRACT

New technological solutions can encourage lower household waste production and higher levels of waste separation. This paper focuses on analyzing the role of different behavioral factors, such as empowerment and pro-environmental behavior (PEB), have on citizens' intention to use a novel household waste management and separation system and how these interact with the financial incentives typically applied in this area, pay-as-you-throw (PAYT) and save-as-you-throw (SAYT). The proposed model was tested in Portugal using the structural equation modeling approach. Survey data from 400 respondents found that empowerment plays a vital role in adopting an innovative waste management system. The research discerns pro-environmental behavior (PEB) both as an antecedent and a moderator between system use and empowerment, system use and behavioral intention, and also between system use and financial incentives. We discovered that for people with low perceived PEB, PAYT actually reduces the use of the new waste management system, while SAYT can increase the use of the system. Furthermore, increasing the empowerment of users in the system can work exceptionally well at encouraging consumers that already have a high level of PEB. The paper concludes with a discussion section about the developed framework's application and implication in the waste management sector. This study is valuable for understanding how citizens will adopt a new waste management system and essential for encouraging citizens to engage in recycling behavior regularly.

1. Introduction

Environmental problems threaten the health and economic prospects of many countries. One of the factors, which accounts for a substantial portion of global warming in addition to environmental degradation, is waste generation (Tan et al., 2021). In order to reduce and combat the adverse effects of climate change, effective waste management is positioned as a sustainable solution. Countries worldwide struggle to improve their household solid waste management procedures (Azevedo et al., 2021). Recently, under the pressure of unrestrained solid waste generation, household waste sorting has gained immense attention (Li and Wang, 2021). The achievement of a well-functioning waste management system (WMS) for municipal solid waste is still a demanding issue for many countries (Campitelli and Schebek, 2020). Therefore, there is an urgent call to develop and integrate new waste management practices that can positively influence citizens' behavior in waste separation and production.

This study proposes and analyzes a model of the mechanisms that define important factors of adopting a new waste management system by consumers. Axsen et al. (2012) define pro-environmental technologies (PETs) as "*any technology that can be perceived by consumers as having pro-environmental attributes*" (p. 64). We consider a WMS as an example of a PET that is intended to encourage environmentally beneficial behavior such as increasing recycling separation and minimizing waste production. Kim et al. (2020) discovered in two studies that in the case of household food waste reduction campaigns, consumers have a higher preference to use technology. Hence, there is a consumers' willingness to use and adopt technological tools in the context of pro-environmental actions. The research of Manika et al. (2021) dedicated to spillovers of PET adoption emphasized the importance of actual technology adoption behavior analyses in future research. To answer this call, we evaluate several factors that are crucial for technology adoption and waste sorting behavior: empowerment theory (Naranjo-Zolotov et al., 2019), financial and economic incentives (Botetzagias et al., 2020; Taleb and Al Farooque, 2021), and pro-environmental behavior (PEB) (Pierini et al., 2021; Steg, 2016).

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Firstly, we include psychological empowerment, which has been proven to be a key factor for citizens' engagement (Kang, 2014). Empowerment is a process by which organizations and/or people acquire competence over certain issues (Rappaport, 1987). The level of public engagement has been highlighted as an essential motivator for consumers to adopt recycling behavior schemes (Xevgenos et al., 2015).

In waste management, encouraging the use of PET and sustainable behavior is typically done with incentives (Park, 2018; Skumatz, 2008; Taleb and Al Farooque, 2021; Yau, 2010). Further investigation of how and when financial incentives induce maintained behavior is essential (Maki et al., 2016). Here we examine two typical approaches to incentives; pay-as-you-throw (PAYT) and save-as-you-throw (SAYT). PAYT is a system where: "*each citizen has to economically contribute to the overall cost of service based on the actual waste quantity they threw away*" (Elia et al., 2015, p. 188). For instance, users are charged a rate based on how much unsorted waste their household produces. An alternative approach to PAYT is to provide rewards, referred to as SAYT – users are rewarded based on how well they separate their waste in a household.

This is the first research to investigate empowerment theory and environmental incentives together. Additionally, we analyze the role of a more general measure of PEB in adopting an innovative WMS. Stern (2000) defined PEB as "*the extent to which it changes the availability of materials or energy from the environment or alters the structure and dynamics of ecosystems or the biosphere itself*" (p. 408). In the PEB literature, the main objective of many researchers was to identify the critical components of PEB (Barr, 2007; Bockarjova and Steg, 2014; Hansmann et al., 2020). To our knowledge, however, no research has so far examined how PEB affects the behavioral intention and system use of new technology in the context of waste management. Understanding such relationships is vital for identifying how new system can improve current practices. If new WMSs are only adopted by those already practicing PEB, this reduces their effectiveness. Conversely, if specific features of a new WMS, or incentive structure, are found to be more effective for those with lower levels of PEB, this could provide the opportunity for significant behavioral improvements.

Our conceptual model is developed as a part of a BEE2WasteCrypto project which intends to develop a new and innovative IT tool to empower Regional Waste Management Utilities (RWMU) and to encourage new citizen behavior in terms of waste generation and handling. More details about the project's objectives can be found in Appendices A–F and an overview of the WMS can be found in the research of Scott et al. (2021).

The rest of the paper is structured as follows. The next section stipulates the theoretical background and the conceptual model's development followed by the hypotheses' elaboration. Section 3 presents the collected data and the methodology applied to analyze the proposed conceptual model. Section 4 examines the main obtained results in a consecutive manner. Finally, Section 5 discusses the theoretical and managerial implications, proposing valuable suggestions for waste management facilities and municipalities dealing with a household waste system. We conclude section 5 with limitations and suggestions for future research.

2. Theoretical background and hypotheses development

The factors that encourage citizens to engage with technologies have long motivated scientists, in particular in the goal to understand the willingness of consumers to adopt novel and innovative technologies (Manika et al., 2021). Meanwhile, despite the potential of PET for driving sustainable change, there is still a relative lack of research about PETs' adoption and use. Which factors are the most important when we aim to achieve the long-lasting use of a new innovative PET remains an open question. The use of PETs may relate to many constructs found in the literature, to name a few, environmentally-friendly lifestyle, technology exploration, and financial frugality. Alternatively, users' rejection of PETs may be affected by an inconsistency between the technology and the individual's present engagement (Axsen et al., 2012).

This paper focuses on technology that aims to encourage more efficient household waste management. Effective household waste management is a demanding task due to the high dependency on social behaviors (Jiang et al., 2021). Dealing with household waste generation and distinguishing specific policies to promote recycling behavior is challenging (Pierini et al., 2021). Changes in attitudes and behavior are crucial to deal effectively with the waste problem (Barr et al., 2001). Indeed, it is widely accepted that changes in behavior are needed to promote a more sustainable future (Bockarjova and Steg, 2014). The main agents in eco-friendly behavior alteration are individuals and households (Kim et al., 2020).

In the proposed conceptual model, we include different factors which can assist in designing and supporting sustained behavioral change. The suggested approaches are efficient for different types of users: those already actively included in pro-environmental actions and the ones that are still reluctant to conduct waste separation and minimization. Di Talia et al. (2019) for instance, found that consumers with high pro-environmental awareness do not require any specific additional encouragement, nevertheless, they should share their sustainable practices with others.

2.1. The model development

2.1.1. Behavioral intention and use behavior

In our study, we attempt to evaluate the behavioral intention of consumers and the use behavior, or system use of the proposed new WMS. We define behavioral intention as the intention to use the WMS and system use as the use of the WMS's features (rewards, tracking, smart waste bags, etc.; see Appendices A–F). Previous research revealed that the correlation between behavioral intention and behavior in environment-related studies can be high (Ateş, 2020; Nguyen et al., 2019; S. Wang et al., 2020). Regular use of WMS to sort waste should become a part of a user's sustainable lifestyle escalating a proper waste management technology implementation. However, Rausch and Kopplin (2021) discussed in their recent work a substantial gap between behavioral intention and behavior citing the research that proved that consumers' pro-environmental intention does not always make them acquire green behavior (Young et al., 2010). A similar discussion was deliberated by Nguyen et al. (2019) and S. Wang et al. (2020). Although their empirical studies proved a significant effect of behavioral intention on behavior.

Hence, we adopted behavioral intention and system use as target variables from the unified theory of acceptance and use of technology 2 (UTAUT2) (Venkatesh et al., 2012). The UTAUT2 model is often regarded as the most comprehensive theory for analyzing technology adoption by individuals (Tamilmani et al., 2020). Conversely, UTAUT2 should be altered to particular technologies and contexts (Venkatesh et al., 2016). Contextual variables are critical when an explanation of consumer behavior is required (Nguyen et al., 2019; Peattie, 2010). Thus, behavioral intention (i.e., behavioral intention to use WMS) and actual behavior (i.e., system use) connection should be reinforced by favorable contextual variables. In the context of household waste management, we propose the following additional variables: empowerment, financial incentives, and PEB.

2.1.2. Contextual variables: empowerment, financial incentives, and PEB

At present, the majority of studies about psychological empowerment are mainly dedicated to organizational behavior (Chen et al., 2019). Nevertheless, empowerment is essential in training responsible citizens in the environmental context (Cottrell, 2003). It is a multilevel construct in which each level of analysis is interdependent from the other (Zimmerman, 1995). Therefore, empowerment has been considered a set of dimensions rather than one concept (Naranjo-Zolotov et al., 2019; Peterson, 2014). Following Peterson's (2014) suggestion, we

define empowerment as a second-order reflective-formative type construct embodied by its first-order dimensions: self-determination, meaning, impact, and competence.

It has previously been found that the higher the perception of waste separation empowerment, the more motivated an individual will be to contribute to waste separation and reduction (Chen et al., 2019). Hartmann et al. (2018) addressed the role of psychological empowerment in PEB, focusing on climate protection, and discovered that empowerment moderates the relationships between personal norms and climate-protective consumer behavior. Additionally, the literature has shown that empowerment is a crucial element for public participation and engagement (Kang, 2014). Findings imply that psychological empowerment impacts pre-and post-adoption behavior (Naranjo-Zolotov et al., 2019). Therefore, we include empowerment in the conceptual framework as the engagement of participants is a primary success factor for the adoption of a new WMS by citizens.

In general, people are more likely to engage in PEB when the behavior is considered more beneficial and has lower costs (Steg, 2016). Financial incentives are not only widely investigated in the waste management literature (Botetzagias et al., 2020; Elia et al., 2015; Maki et al., 2016; Park, 2018; Skumatz, 2008; Taleb and Al Farooque, 2021; Yau, 2010) but also found in practical implications in many countries (Botetzagias et al., 2020). Seacat and Boileau (2018) conducted research in Massachusetts and discovered strong evidence for the effectiveness of PAYT programs. PAYT is a highly used instrument for improving municipal solid waste management (Taleb and Al Farooque, 2021). One of the tactics for policymakers to enhance citizens' eco-friendly behavior is to fortify their feeling of responsibility through monetary incentives (Punzo et al., 2019). Although, the effectiveness of such campaigns is partially contingent on their ability to adjust consumer behavior (Agovino et al., 2018). Empirical research of S. Wang et al. (2020, 2021) established that incentive measures influence waste reduction intention and waste sorting behavior. Consequently, we propose to add the following constructs to the conceptual model: PAYT and SAYT.

PAYT is about penalizing and SAYT is about rewarding the consumer. It is crucial to analyze an alternative approach to fees: the use of penalties can be perceived as an example of a problem policy (Seacat and Boileau, 2018). While some researchers (Elia et al., 2015; Morlok et al., 2017; Park, 2018) claimed that financial incentives proved their efficacy in increasing the waste recycling behavior rate, Yau (2010) doubted the effectiveness of the reward in promoting domestic waste recycling behavior. Similarly, models with applied penalties are expected to have a stronger impact on PEB than those that apply rewards (Maki et al., 2016). Thus, in our research, we attempt to analyze both approaches to financial incentivization and their influence on a WMS's adoption. PAYT and SAYT are self-developed scales. However, the antecedent of PAYT and SAYT is price value construct from UTAUT 2 (Venkatesh et al., 2012).

As a result of environmental issues, the theory of PEB has become the center of attention of many researchers (Ateş, 2020; Bamberg and Möser, 2007; Barr et al., 2001). Diverse theoretical approaches and a complex nature make it difficult to investigate PEB (Punzo et al., 2019). Different types of environmentally-friendly behavior have been found to have a positive correlation with other types of PEB such as green food consumption (Laureti and Benedetti, 2018). Maki et al. (2019) proved that when individuals are inclined to embrace initial PEB (i.e., saving energy), they have a slightly higher tendency to engage in other more advanced PEB (i.e., saving water). Therefore, we believe that PEB may have a direct impact on other types of PEB such as WMS use. Recent research of Liu et al. (2020) has discovered another remarkable role of PEB as a moderator: daily green behaviors moderated the relationship between travelers' intentions to behave sustainably at destinations and their actual PEBs at their destinations. Besides, the moderating effect was also supported between perceived aesthetic risk, purchase intention, and purchase behavior of sustainable clothes (Rausch and Kopplin, 2021).

The key target of several researchers has been to identify PEB's key elements (Barr, 2007; Bockarjova and Steg, 2014; Elgaaied, 2012; Hansmann et al., 2020). Our research will look from a different perspective and will endeavor to explore the role PEB can play as an independent variable and a moderator rather than the target construct. PEB usually describes a wide range of behaviors that are in general in line with the goals of increasing waste sustainability. Citizens' pro-environmental behavior will be a crucial component in adopting new PETs. In particular, we will be interested in encouraging adoption in citizens without an existing openness to PEB.

In Xevgenos et al. (2015) research, the factors influencing the adoption of recycling behavior schemes were identified, including establishing financial incentives and the level of public awareness and engagement. Additionally, we also propose to take into account the crucial environmental indicator, PEB. Hence, this research merges the factors discussed above to investigate customers' behavioral intention and system use determined by a customer's interaction with a WMS. Age and gender are two demographical factors much discussed in literature (Laureti and Benedetti, 2018). The results of Lee and Paik (2011) showed that age strongly influences waste management behaviors. It is revealed that women were more inclined to engage in environmental behaviors than men (Hunter et al., 2004). Therefore, we also added two control variables in our model, gender and age. The research model is demonstrated in Fig. 1.

2.2. Empowerment

Empowerment combines a proactive attitude towards life, an understanding of personal control, and a critical perception of the sociopolitical environment (Zimmerman, 1995). These factors have also been found to be essential for understanding the processes behind people's green behavior (Varela-Candamio et al., 2018). Furthermore, psychological empowerment proved to significantly influence intention to use and recommend technologies (Naranjo-Zolotov et al., 2019) and empowers people to have a sense of ownership of their work and enhance their performance (Kirkman and Rosen, 1999). These findings indicate that psychological empowerment theory may influence the adoption behavior of any new and innovative WMS. We posit that citizens being empowered will experience a greater behavioral intention and intention to use the WMS:

H1a. Empowerment positively influences behavioral intention.

H1b. Empowerment positively influences system use.

2.3. Financial incentives – PAYT and SAYT

PAYT provides a continual economic signal to alter behavior (Skumatz, 2008). Furthermore, in multiple studies, PAYT was found to be the most significant factor positively predicting recycling behavior (Seacat and Boileau, 2018; Starr and Nicolson, 2015). Though economic incentives usually demonstrate temporary effects (Bolderdijk and Steg, 2015), they still play a crucial role in shaping household recycling behavior. In the research of Timlett and Williams (2008) in England, the reward model was discovered to be the leading influencer of the recycling behavior rate. Incentive measures were found as a significant antecedent of waste reduction intention (S. Wang et al., 2021) and residents' waste sorting behavior (S. Wang et al., 2020). Overall, financial incentives have become a valid instrument in adjusting household waste behavior (Park, 2018; Skumatz, 2008 ; Yau, 2010). Thus, we expect that financial incentives such as PAYT and SAYT will facilitate adopting and using any waste management system. The paper hypothesizes that:

H2a. PAYT positively influences behavioral intention.

H2b. PAYT positively influences system use.

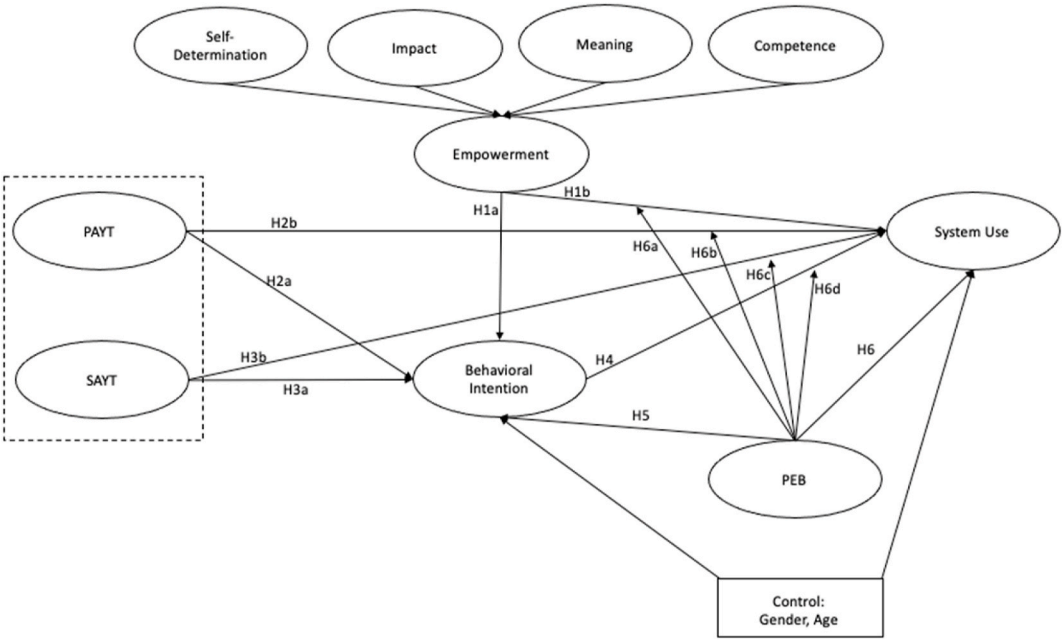

Fig. 1. Research model (developed by the authors, 2021).

H3a. SAYT positively influences behavioral intention

H3b. SAYT positively influences system use.

2.4. Behavioral intention and system use

Tamilmani et al. (2020) conducted empirical analyses of 60 studies and discovered the most robust path was between behavioral intention and use. Different studies endorsed eco-friendly intention as the crucial antecedent of PEB (Ateş, 2020; Barr et al., 2001; de Leeuw et al., 2015; Barr, 2007; Wang et al., 2019); purchase intention has significant influence over purchase behavior about sustainable clothing (Rausch and Kopplin, 2021); green consumption intention is a antecedent of green consumption behavior (Nguyen et al., 2019). Hence, when customers have strong intention to use a WMS, we expect they will be actively using the system's features. However, understanding the exact relationship between intention and use will be essential in ensuring that any new system achieves actual change. It is also important to acknowledge that we do not measure the real use of the system, the WMS adoption process will only be successful in the long run if a sufficient number of users embrace the system as a daily or weekly routine activity. Hence, the current study hypothesizes that:

H4. Behavioral intention positively influences system use.

2.5. Pro-environmental behavior

PEB is not simply the outcome of regulatory control conditions through social norms but also evolves from the intrapersonal principles held by people (Varela-Candamio et al., 2018). Such intrapersonal values strongly influence behavioral intention (Eyal et al., 2009; M. Li and Cai, 2011). Environmental values are one of the factors that play a significant role in the prediction of waste management behavior (Barr, 2007). Previous research has shown that people who are more attentive to the environment are more likely to take part in actions to help the environment (Bamberg and Möser, 2007; Hinds and Sparks, 2008), which could be the intention to use and actual use of the new WMS. Therefore, we can expect that PEB will positively impact users' behavioral intention to use WMS and WMS use itself. Thus, the paper hypothesizes that:

H5. PEB positively influences the behavioral intention to use the WMS.

H6. PEB positively influences the WMS use.

As discussed, several studies demonstrated that there is a PEB's spillover effect: one type of PEB can incite another type of PEB (Laureti and Benedetti, 2018; Maki et al., 2019). Furthermore, PEB can be not only a target variable (Elgaaied, 2012; Hansmann et al., 2020; Laureti and Benedetti, 2018) or an antecedent of other variables (Maki et al., 2019) but also moderate relationships between different variables in environmental studies (Liu et al., 2020). Hence, we are interested in the interaction between existing PEB and the other factors identified as important for system use, hypothesizing the following:

H6a. PEB moderates the relationship between empowerment and system use.

H6b. PEB moderates the relationship between PAYT and system use.

H6c. PEB moderates the relationship between SAYT and system use.

H6d. PEB moderates the relationship between behavioral intention and system use.

3. Data and methodology

3.1. Pre-test

After the survey was created, partners and waste management professionals from BEE2WasteCrypto project (see Appendices A–F) were asked to review each construct and the survey as a whole in order to guarantee the survey's comprehensibility. The pre-test's respondents were asked to provide their feedback and comments regarding the questions and items, whether it was clear and understandable. They shared their insights for the proposed model. The online version of the survey was distributed between 26 experts to secure the adequacy of the survey's questions and items. The survey was adjusted accordingly after collecting and analyzing participants' responses and comments.

3.2. Data collection

The final survey distribution was carried out by Netsonda,[1] a Portugal-based market research company that used its internal pool of participants. Netsonda rewarded respondents' participation. The study was pre-registered. The survey was in the Portuguese language. It took approximately 5 min to answer the questions with an additional 3 min of introductory video describing a new WMS (the video script can be found in Appendices A–F). An informed consent form was present in the introduction to the survey in which the purpose of the questionnaire was provided. Confidentiality and anonymity of participants were guaranteed. Then, participants opened the window with the video, which they could not skip without watching it, the timer was set to evaluate how long they spent on this video page. Next, they were asked if the video worked correctly. Only participants who responded affirmatively could proceed with the survey.

The video at the beginning of the survey explains the WMS's main features and advantages of a new PET. The WMS is a new and unfamiliar system that requires additional explanation, as provided in the video. Respondents who did not watch the video due to technical or other reasons could not proceed with the questionnaire.

The survey's measurement items can be found in Appendices A–F. We used a Likert seven-point range scale from 1 (strongly disagree) to 7 (strongly agree) to measure the empowerment constructs (self-determination, meaning, impact, competence), behavioral intention, PAYT, and SAYT. System use and PEB were assessed from 1 (never) to 7 (every time). Overall, 400 valid responses were collected.

Table 1 presents the demographic profile of the survey's participants. The external validity of the study is present: gender and age are representative of Portuguese population (female = 53.73% and male = 46.27%; 20–29 = 13.09%, 30–44 = 24.57%, 45–64 = 35.19%, 64 and more = 27.16%) (PORDATA, 2019). We can see the numbers provided by official statistical research are aligned with the collected data in Table 1. Therefore, we can generalize the findings of the study. Harman's one-factor test was conducted to examine the common method bias (Podsakoff, 2003). To reinforce its results, we applied the second method, the marker variable approach (Lindell and Whitney, 2001). The maximum shared variance value for the variable, which is not theoretically related to study constructs, was 2.16%, which is considered low (Simmering et al., 2015). Both tests did not discover significant common method bias.

Table 1
Demographic Characteristics of Respondents (data collected in 2021).

Demographics		Sample (n = 400)	Percentage (%)
Age	From 20 till 29	52	13.00%
	30–44	100	25.00%
	45–64	147	36.75%
	more then 64	101	25.25%
Gender	Female	216	54.00%
	Male	184	46.00%
Level of education	No school degree completed	14	3.50%
	High school degree	177	44.25%
	Bachelor degree	73	18.25%
	Master or Postgraduate degree	123	30.75%
	Doctorate	13	3.25%
Number of people in a household	1	51	12.75%
	2	136	34.00%
	3	113	28.25%
	more then 3	100	25.00%
Number of children (up to 12 years old) in a household	0	305	76.25%
	1	72	18.00%
	2 and more	23	5.75%
Area of living	Urban	319	79.75%
	Rural	81	20.25%

[1] https://www.netsonda.pt/en/.

4. Results

This research aims to explore the factors influencing behavioral intention and system use of an innovative WMS. We applied a variance-based method, partial least squares (PLS), since our proposed research model has not been tested in the literature before, and PLS results are not affected by the data distribution. Moreover, PLS allows the model to have formative indicators (Hair et al., 2014). The model was analyzed in SmartPLS 3.0 software (Ringle et al., 2015).

4.1. Measurement model

First, we analyzed the reflective constructs of the model. To confirm internal consistency, we needed to obtain for all variables a result higher than 0.7. For this matter, we calculated composite reliability and Cronbach's alpha. The results are present in Table 2 (Hair et al., 2014). Then, convergent validity was estimated through the average variance extracted (AVE) and indicator reliability. AVE values of constructs are higher than 0.5, proving convergent validity (see Table 2) (Henseler et al., 2009).

Next, we analyzed the Fornell-Larker criterion to assess discriminant validity. As shown in Table 2, the results proved discriminant validity: the AVE square root of every variable is greater than the correlation between the variables (Fornell and Larcker, 1981). Furthermore, all loadings are higher than the cross-loadings (see Table C2, Appendices A–F), supporting discriminant validity (Chin, 1998). Lastly, according to Hair et al. (2014), we should analyze the hetrotrait-monotrait ratio (HTMT). HTMT should be lower than 0.9, which is shown in Table C3, Appendices A–F. Therefore, all necessary criteria for reflective constructs are confirmed, and we can move to the formative construct of our model.

For formative constructs, first, we assessed the variance inflation factor (VIF) to evaluate the presence of multicollinearity. The VIF should be below 5 (Hair et al., 2014). In Table D1, Appendices A–F, we see no evidence of collinearity issues. Next, the formative construct was evaluated by statistical significance and the weights' sign. Even though the outer weights of indicators US3 and US4 are not statistically significant, we kept it in system use construct because its loadings are greater than 0.5.

Following the analyses of reflective and formative constructs, we could continue analyzing the structural model.

4.2. Structural model

Before assessing the structural model, we tested possible collinearity between the constructs with the VIF. VIF values should fall below the threshold of 5 (Hair et al., 2014). Therefore, based on the VIF results, we can claim no multicollinearity issues. The structural model in Fig. 2 presents the explained variations and the path coefficients. Through the bootstrapping method with 5000 resamples, we evaluated the significance level of the constructs in the conceptual model.

Our model explains 67.6% of the variation in behavioral intention to use the WMS. Empowerment ($\widehat{\beta}$ =0.826, $p < 0.01$) and PAYT ($\widehat{\beta}$ =0.070, $p < 0.05$) are statistically significant for predicting behavioral intention. Meanwhile, SAYT ($\widehat{\beta}$ =-0.024, $p > 0.10$) and PEB ($\widehat{\beta}$ =-0.055, $p > 0.10$) are not statistically significant for behavioral intention. Hence, H1a and H2a are supported, but H3a and H5 are not supported.

Table 2
Cronbach's alpha (CA), Composite Reliability (CR), Average Variance Extracted (AVE) (authors' calculations, 2021).

Construct	Mean	SD	CA	CR	AVE	PAYT	SAYT	SD	IM	ME	CO	PEB	BI	US
PAYT	4.407	1.765	0.911	0.937	0.789	**0.888**								
SAYT	5.511	1.526	0.927	0.948	0.819	0.349	**0.905**							
Self-determination	5.892	1.210	0.906	0.941	0.841	0.216	0.210	**0.917**						
Impact	5.461	1.349	0.922	0.951	0.866	0.352	0.344	0.440	**0.930**					
Meaning	5.802	1.209	0.965	0.977	0.935	0.397	0.332	0.490	0.755	**0.967**				
Competence	6.132	1.012	0.957	0.972	0.920	0.254	0.332	0.485	0.583	0.694	**0.959**			
PEB	4.855	0.940	0.846	0.868	0.399	0.425	0.219	0.240	0.491	0.467	0.296	**0.631**		
Behavioral intention	6.094	1.115	0.969	0.979	0.941	0.347	0.285	0.521	0.670	0.826	0.642	0.348	**0.970**	
System use	5.970	1.044	NA	NA	NA	0.355	0.373	0.427	0.624	0.714	0.596	0.433	0.728	NA

Notes: AVE square root in bold.

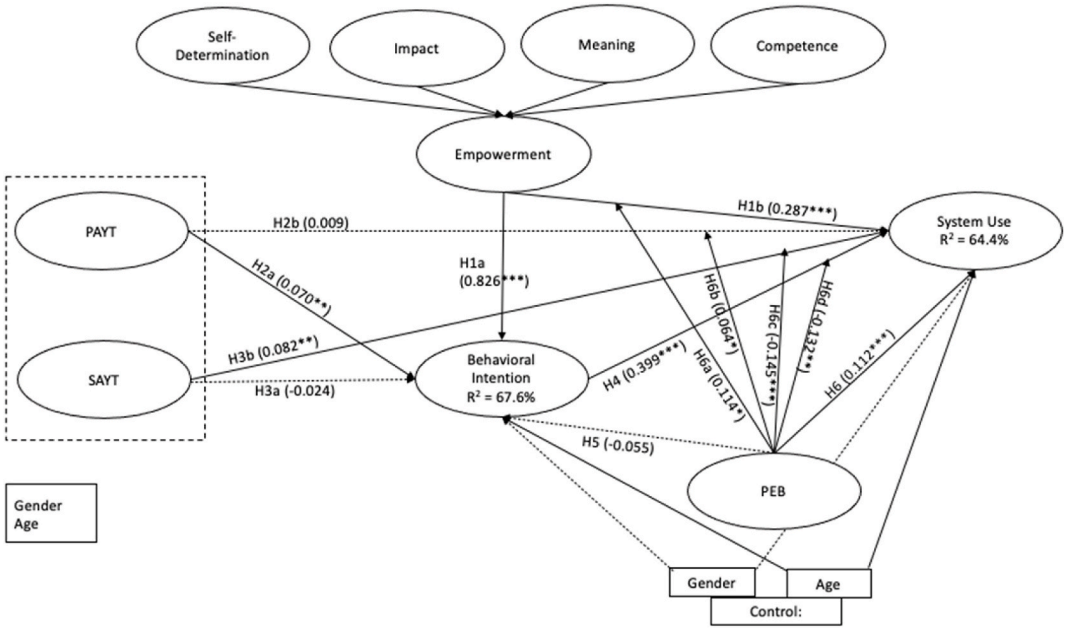

Fig. 2. Structural model results. Note: ***p < 0.01, **p < 0.05, *p < 0.10, not significant paths are dotted arrows (developed by the authors, 2021).

Then, the model explains 64.4% of the variation in use of the WMS. The SAYT construct ($\widehat{\beta}$ =0.082, $p < 0.05$), empowerment ($\widehat{\beta}$ =0.287, $p < 0.01$), PEB ($\widehat{\beta}$ =0.112, $p < 0.01$) as well as behavioral intention ($\widehat{\beta}$ = 0.399, $p < 0.01$) are statistically significant for system use supporting H3b, H1b, H6, and H4. While PAYT was found to be not statistically significant ($\widehat{\beta}$ =0.009, $p > 0.10$) rejecting H2b. The moderating effect of PEB on use is statistically significant in all cases: with empowerment ($\widehat{\beta}$ =0.114, $p < 0.10$), with PAYT ($\widehat{\beta}$ =0.064, $p < 0.10$), with SAYT ($\widehat{\beta}$ =-0.145, $p < 0.01$), and with behavioral intention ($\widehat{\beta}$ =-0.132, $p < 0.05$). Thus, H6a, H6b, H6c, and H6d are supported. Finally, we can conclude that ten hypotheses out of 13 are supported in the model (Appendices A–F).

Control variables such as gender are not statistically significant ($p > 0.1$) except for age influencing behavioral intention ($\widehat{\beta}$ =0.068, $p < 0.05$) and system use ($\widehat{\beta}$ =-0.112, $p < 0.01$). Therefore, gender has no impact and is not related to the innovative WMS's behavioral intention and use. However, age demonstrates some evidence of predicting citizens' system adoption.

The results demonstrate that empowerment positively impacts the behavioral intention and the use of a new WMS. Furthermore, our results reveal that PAYT influences behavioral intention but not system use. On the other hand, SAYT does not influence consumers' behavioral intention but positively affects system use. As predicted, behavioral intention is a significant predictor of the use of the WMS. Remarkably, PEB has a

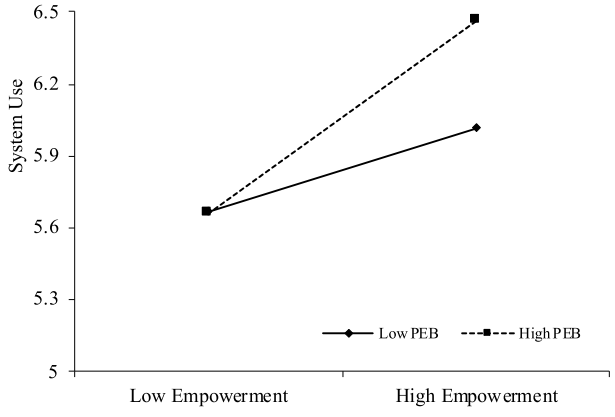

Fig. 3. Moderating effect of PEB between empowerment and system use (authors' calculations, 2021).

positive impact on system use but not on behavioral intention. Finally, PEB is identified as a crucial moderator. We can conclude that it has an influence on all proposed relationships: between empowerment and system use, PAYT/SAYT and system use, also between behavioral intention and use. A high level of PEB increases the effect of empowerment on the use of WMS (Fig. 3). This result indicates that increasing the empowerment of users of the system can work particularly well at encouraging consumers that already have a high level of PEB.

Interestingly, when PEB is low, high PAYT negatively affects system use, and in contrast, high PEB increases system use with higher acceptance of PAYT (Fig. 4). Furthermore, the case of SAYT is the opposite: for low PEB, high acceptance of SAYT increases the use, while for high PEB, SAYT negatively influences the use of WMS (Fig. 5). This result indicates that the type of financial incentive is important for different user types, depending on their existing level of PEB. Financial incentives framed as penalties can reduce the use of the system for the important target group of those with low existing levels of PEB. However, rewards are particularly effective at encouraging their response. Finally, system use is affected by PEB while behavioral intention is low, and it is contrary to high behavioral intention when PEB's level does not influence the use of WMS much (Fig. 6).

We also find younger people have higher system use than older people meaning they will be the one using the system's features. Older people have a higher behavioral intention to use the WMS than younger respondents. Other studies have found that older people reduce waste more than their younger counterparts (Barr, 2007). The results of Lee and Paik (2011) demonstrated that age affected waste management behaviors significantly. Overall, our model explains 67.6% of the variance in behavioral intention and 64.4% in system use.

5. Discussion

5.1. Theoretical and practical implications

The proposed model provides insight into the core elements that motivate users' intention to adopt and use innovative environmental technology in waste management. This study is motivated by the development of a future WMS technology called Bee2WasteCrypto (Scott et al., 2021), with the intention to provide RWMU with the best set of technologies to be applied in their operations. This project broadly lies within the concept of Territorial Social Responsibility, "*the ability of a territorial system (*i.e. municipality*) to ensure, over time, the respect of the different dimensions of sustainability*" (Rusciano et al., 2019, p. 543). This study provides clear implications for the design of future WMS to ensure household adoption. Citizens' behavioral changes and technological development have to mature together in order to accomplish most of sustainability goals (Axsen et al., 2012).

This paper reveals insights into which incentives (financial, environmental, and behavioral) should be the area of focus for research dedicated to the citizens' behavioral intention and PET's use behavior in waste management field. In our model, the connection between behavioral intention to use the system and use behavior is determined by the joint effect of contextual factors: financial incentives, empowerment, and PEB. Hereby, we show the importance of relevant contextual

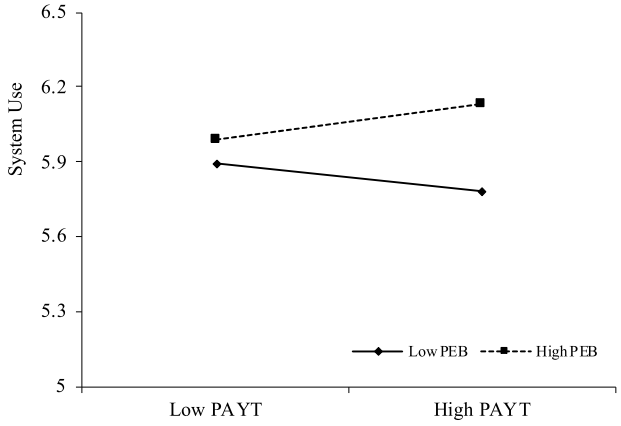

Fig. 4. Moderating effect of PEB between PAYT and system use (authors' calculations, 2021).

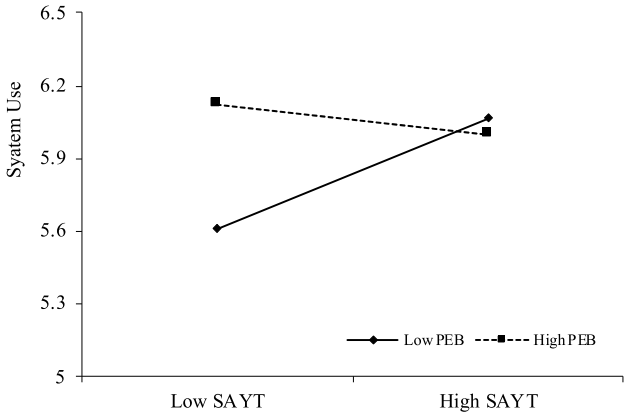

Fig. 5. Moderating effect of PEB between SAYT and system use (authors' calculations, 2021).

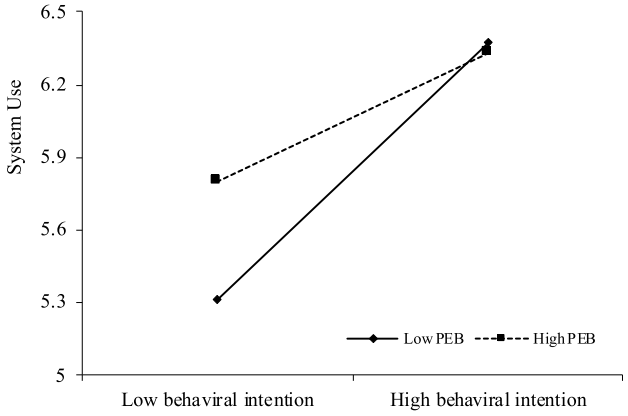

Fig. 6. Moderating effect of PEB between behavioral intention and system use (authors' calculations, 2021).

variables in the determination of the intention-behavior path (Nguyen et al., 2019; Venkatesh et al., 2016; Zsóka, 2008).

PEB is again found to be complex in nature (Punzo et al., 2019), being not only an antecedent of other constructs but also moderating 4 different connections between system use and behavioral intention, PAYT, SAYT, and empowerment. We discover then further evidence reinforcing a spillover effect of PEB (Liu et al., 2020; Maki et al., 2019). However, the moderator's role adds important nuance to this relationship. Such a positive effect between different PEBs might be an outcome of a presence of consistency across behaviors (Maki et al., 2019).

Furthermore, empowerment has the most decisive influence on the behavioral intention and the use of WMS, which is aligned with previous findings of Chen et al. (2019), arguing that individuals with a higher perception of waste separation empowerment are more motivated to engage in waste separation and reduction activities. We add to these findings by identifying that this is mainly the case in those with existing high levels of PEB, indicating empowerment will be crucial in attaining improvements in countries that have already achieved high levels of PEB as the norm.

These findings have practical implications, they imply that the strategies for promoting and distributing PET in waste management should encourage the citizens' positive perception of psychological empowerment's components: self-determination, impact, meaning, and competence. Municipalities should inform citizens about their impacts on society using WMS: increased waste separation, lower waste production, and lower landfills' volumes. Such activities will empower citizens; thus, the use of the WMS technology increases over time, leading to more sustainable and persistent environmentally friendly behavior and the use of PETs. Furthermore, when people feel empowered and possess high PEB, they will actively use WMS, meaning empowerment is a crucial instrument to encourage consumers with a high level of PEB. This aspect means targeting empowerment will be particularly useful for citizens with existing high levels of PEB. Conversely, for citizens with lower levels of PEB, potentially focusing on empowerment is less valuable (although it still has a positive impact). The users of WMS should have a chance to master their skills in using such technology, which is particularly important for older generations: elaborated FAQ, friendly and easy interface, and clear structures of how to use the technology itself are particularly crucial for successful WMS adoption and continuous use.

In our model, PAYT was proved to be pivotal for behavioral intention but not for system use. On the other hand, SAYT has no significant influence on consumers' behavioral intention, but it is a significant predictor of the use of WMS. While Skumatz (2008) discovered that PAYT fosters a persistent economic incentive to change behavior, our research adds the crucial discovery of a moderating effect of PEB on financial incentives and system use: high PEB increases system use in case of high acceptance of PAYT and decreases for people with lower acceptance of PAYT. Meaning better acceptance of PAYT incentives for people with higher PEB and, as a result, higher system use. On the other hand, SAYT increases the WMS use for people with lower PEB and has an opposite effect on people with high PEB. Our discovery is supported by psychological research, which determined that rewards (e.g., SAYT in our case) for conventional performance (eco-friendly activities are everyday and conventional for respondents with high PEB) decrease intrinsic motivation (Eisenberger and Shanock, 2011). Moreover, PEB has been linked in the literature to intrinsic motivation (Silvi and Padilla, 2021).

When policymakers consider applying financial incentives to promote municipal waste separation and minimization as part of a new WMS, these crucial findings from our research should be considered. We find that depending on citizens existing PEB incentivizing WMS adoption requires two diametrically opposite approaches. The introduction of PAYT can reduce the use of WMS for citizens with low PEB. Such people are more accepting of SAYT measures which increase their use of WMS. This is particularly crucial as people with the lowest levels of PEB possibly have a tremendous potential to reduce their impact on the environment. In addition, for people with higher PEB, who are more used to environmental activism and eco-friendly activities, the introduction of SAYT and similar rewarding systems can actually decrease system use. It can be explained by the fact that PEB is a usual everyday activity for them, and it does not require compensation. Moreover, it can even have a negative impact on the use of WMS. We argue that municipalities and policymakers should consider such findings more frequently when developing and introducing new WMS or similar PETs: people with different levels of PEB should be targeted differently through economic incentives to have successful and long-lasting use of innovative waste-related technologies.

Consequently, the assumption that citizens have similar behavioral responses when new waste management tools are introduced is incorrect. Policymakers should implement more flexible policy instruments that target segmented groups of citizens, with financial incentive schemes adopted accordingly.

5.2. *Limitations and future research*

Our research is not without limitations. Our empirical data is self-reported data which can raise some self-reported behavior issues (Gram, 2010; Kim et al., 2020) such as social desirability bias (Morgado et al., 2018). Therefore, the investigation of the real user behavior should be analyzed through real-time observations, for example. Then, after the WMS is introduced in Portuguese municipalities, the model should be tested again to see the behavioral patterns of citizens when they become more familiar with such technology. Despite the internal consistency of PAYT and SAYT, these constructs were self-developed and require further analysis and adaptation for other contexts. In fact, the impact of financial incentives not only on WMS but also on other PETs should be investigated as well as the role of PEB, meaning further analyses of the relationships between financial incentives, PEB, and use of other PETs is needed. Future research can extend the model with other relevant constructs to improve the model's predictive power.

CRediT authorship contribution statement

Darina Vorobeva: Conceptualization, Data curation, Formal analysis, Methodology, Writing – original draft, Writing – review & editing. **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.

Declaration of competing interest

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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Appendices A–F. Supplementary data

Supplementary data to this article can be found online at https://doi.

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Abbreviation

Term	
AVE	Average Variance Extracted
BI	Behavioral Intention
CO	Competence
HTMT	Hetrotrait-Monotrait Ratio
IM	Impact
ME	Meaning
PAYT	Pay As You Throw
PEB	Pro-environmental behavior
PET	Pro-environmental technologies
PLS-SEM	Partial least squares structural equation modeling
RWMU	Regional Waste Management Utilities
SAYT	Save As You Throw
SD	Self-Determination
SU/US	System Use
UTAUT2	Unified Theory of Acceptance and Use of Technology 2
VIF	Variance Inflation Factor
WMS	Waste Management System

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