



ARTICLE



<https://doi.org/10.1057/s41599-022-01347-6>

OPEN

Motivating factors behind the public's use of smart recycling systems: perceived playfulness and environmental concern

Liyuan Liu ^{1✉} & Yen Hsu ²

Smart cities around the world are seeking effective ways to recycle waste. A smart recycling service system is a new recycling method that allows people to engage in environmental protection. Previous studies on recycling have only focused on environmental concerns. Whether public intention to use smart recycling is influenced by environmental concern or perceived playfulness has yet to be explored. Therefore, this study proposes a modified technology acceptance model to discuss the impact of perceived playfulness and environmental concern on public intention to use smart recycling systems. We adopted the maximum likelihood estimation method as the measurement model for this study. The results show that both environmental concern and perceived playfulness motivate people to use smart recycling systems. However, perceived playfulness impacts public intention more than environmental concern and had the most significant impact among the four factors discussed in this study. Therefore, when seeking to improve and promote smart recycling systems, the focus should shift to promoting public intention to use and enhance their environmentally-friendly behavior in a playful way. This study provides new insights into the improvement of smart recycling systems and the implications for promoting them.

¹ College of Science & Technology, Ningbo University, 315300 Ningbo, China. ² The Graduate Institute of Design Science, Tatung University, 104 Taipei, Taiwan. ✉email: liuliyuan@nbu.edu.cn

Introduction

The increase in waste generation and accumulated environmental pollution have become significant threats to the sustainable development of many countries worldwide (Zhang et al., 2016). Therefore, it is necessary to implement smart waste management systems to eliminate or reduce waste and maintain hygienic conditions (Gupta et al., 2019). In recent years, due to the extensive application of the Internet and communication technology, as well as the Internet of Things in waste management, smart recycling has emerged as a new recycling mode (Xue et al., 2019).

Smart recycling is based on new and evolving technology; it allows for user convenience (Hong et al., 2014) and enables real-time interaction (Chen et al., 2017). Specifically, smart recycling integrates various smart components for efficient waste sorting and recycling (Murugaanandam et al., 2018). In addition, smart recycling uses gamification and rewards users with points, which makes it fun (Briones et al., 2018). Users can learn about waste sorting and relevant recycling knowledge through the interactive display screens of smart recycling systems.

Smart recycling systems were first placed as public facilities in smart cities to promote a clean and tidy environment (Xue et al., 2019). However, reports indicate that the majority of smart recycling systems are inefficient, and the promotion of smart recycling systems has been unsuccessful. A change in public intention to participate in recycling affects the recycling effectiveness and the utilization rate of the recycling facilities (Bonino et al., 2016). The use of recycling facilities is closely related to environmental awareness, but the intention of residents to participate in recycling is at odds with efforts to support the environmental initiative (B. Zhang et al., 2019). Therefore, encouraging active public participation in smart recycling is a challenge (Ma et al., 2017; Xiao et al., 2017).

Several studies have demonstrated the motivational effect of playtime on user intention in various fields, including education (Padilla-Meléndez et al., 2013), computing (Bozionelos and Bozionelos, 1997), and mobile communications (Hsieh and Tseng, 2017). In the field of recycling, previous studies (Jekria and Daud, 2016; Mtutu and Thondhlana, 2016; Yu et al., 2019) have discussed the intention to recycle from the perspective of environmental concern, but without probing into the intention to use smart recycling systems motivated by perceived playfulness and environmental concern. The preliminary survey of this study found that the fun features of smart recycling systems attract users to participate in recycling. Therefore, it is necessary to evaluate the influencing factors of the intention to use smart recycling systems to create a method consistent with the public intention to use them. The findings of this study can provide an understanding of the factors that influence the degree of public participation in smart recycling, and offers suggestions for developing smart recycling systems.

In this study, the factors influencing the intention of urban residents to use smart recycling systems are environmental concerns, perceived playfulness, perceived usefulness, and perceived ease of use. Moreover, we modified the technology acceptance model (TAM) to explore the impact of environmental concern and the sense of fun on public intention to use smart recycling systems. The specific research objectives are as follows:

1. To explore whether the related hypotheses of environmental concern and perceived playfulness are valid and whether they affect residents' intention to use smart recycling systems;
2. To determine whether environmental concern and perceived playfulness are the main variables that influence

public intention to use smart recycling systems, and their effects and relationship;

3. To discuss how smart recycling systems could be improved.

The remainder of this paper is organized as follows: Section "Literature review and hypotheses" is a literature review and presents research hypotheses. Section "Methodology" describes the research methods; section "Results" presents the results; section "Discussion" discusses the results; and section "Conclusion" provides conclusions. Section "Limitations and future research" describes research limitations and proposes suggestions for future research.

Literature review and hypotheses

Literature review

Technology acceptance model (TAM). Ajzen (1985) proposed the Technology Acceptance Model (TAM) based on the Theory of Rational Action (TRA) (Fishbein and Ajzen, 1977) and the Theory of Planned Behavior (TPB), which are derived from predicting behavioral intention (Ajzen, 1991). The TAM proposes the concept of perceived ease of use, perceived usefulness, and individuals' behavioral intentions to use technology (Davis et al., 1989). The TPB, and its extended model, are used to analyze the recycling behavior in previous studies (e.g., Botetzagias et al., 2015; Chan and Bishop, 2013; Cheung et al., 1999; Nigbur et al., 2010; Oztekin et al., 2017; Tonglet et al., 2004). Smart recycling is a new development with a technological orientation (Xue et al., 2019), and many studies adopted the TAM to predict users' acceptance of technology (Davis et al., 1989). The modified TAM is a widely used theory to evaluate users' acceptance of technology, and the effectiveness of this model has been verified by previous studies (Chen and Chao, 2011; Davis et al., 1989; Fishbein et al., 1980; Moon and Kim, 2001). Wu et al. (2019) discussed the role of public environmental concern through the TAM (Wu et al., 2019). Moon and Kim (2001) introduced perceived playfulness into the TAM (Moon and Kim, 2001). Therefore, this study adopted the modified TAM to explore the public's intention to use smart recycling systems according to four dimensions, namely perceived usefulness, perceived ease of use, environmental concern, and perceived playfulness.

Flow theory. Moon and Kim (2001) extended the TAM by including the flow-theory-based intrinsic motivation factor of perceived playfulness. One variable that may affect users' acceptance is the flow of intrinsic motivation factors, which can be described as the process of the "best experience" or "most pleasant experience" (Csikszentmihalyi, 1990). According to flow theory, positive subjective experience is important for one's engagement in activities. People are more likely to participate in an activity if they "feel good" about it, i.e., having an intrinsic motivation (Hoffman and Novak, 1996; Moon and Kim, 2001). Flow theory emphasizes that playfulness is the most widely used concept to measure people's motivational behaviors (Lee et al., 2009). Moon and Kim (2001) defined perceived playfulness as "the degree to which an individual perceives his/her attention to the interaction, maintains curiosity in the interaction process, and finds the interaction pleasant or interesting in nature." Perceived playfulness is an important factor that motivates users to engage with a system (Moon and Kim, 2001). Csikszentmihalyi (2014) discussed the application of perceived playfulness as a dimension in human-computer interaction, which provides a theoretical method for measuring and studying perceived playfulness in human-computer interactions (Webster et al., 1993).

Motivation theory. The motivation theory explains people's behaviors (Benabou and Tirole, 2003). Motivation refers to the broad tendency to engage in activities with intrinsic or extrinsic orientation, including intrinsic and extrinsic motivation (Vallerand, 2000). Benabou and Tirole (2003), Vallerand (2000), and Davis et al. (1992) regarded perceived usefulness as extrinsic motivation and enjoyment as intrinsic motivation (Benabou and Tirole, 2003; Davis et al., 1992; Vallerand, 2000). Igbaria et al. (1996, 1994) found that people's use of systems is subject to the influence of extrinsic motivation (perceived usefulness) and intrinsic motivation (perceived enjoyment) (Igbaria et al., 1996, 1994). Moon and Kim (2001) regarded perceived playfulness as an intrinsic motivation, positively correlated with perceived usefulness and perceived ease of use (Moon and Kim, 2001). Intrinsic motivation factors contribute to people's acceptance of technology (Malone, 1981). Previous psychological studies have emphasized two basic methods to motivate recycling behavior. The first method focuses on the influence of the last event or the latter event on behavioral change but pays little attention to the possible cognitive process; the second method focuses on evaluating and changing the values, beliefs, intentions, and attitudes that are considered to be the motivations for most behaviors (Vining et al., 1992). Davis et al. (1992) pointed out that enjoyment can explain the significant difference in intention to use and the concept of perceived usefulness (Davis et al., 1992). Moon and Kim (2001) proposed "perceived playfulness" as an individual's significant internal belief to explain their behaviors under intrinsic motivation (Moon and Kim, 2001). Intrinsic motivation is also used to describe various environmental attitudes and behaviors (Iacob et al., 2013; Koo and Chung, 2014; Poortinga et al., 2004; Stern, 2000).

Hypotheses development

Perceived playfulness. Playfulness is the inherent motivation for a person when using any new system (Venkatesh and Bala, 2008). Playfulness is a complex variable that includes an individual's enjoyment, psychological stimulation, and interest (Csikszentmihalyi, 2014). Moon and Kim (2001) explained perceived playfulness from an individual's perspective as follows: a person (1) thinks that their attention is focused on the interaction; (2) is curious about the interaction; and (3) finds the interaction intrinsically interesting (Moon and Kim, 2001).

Further research has found that some subjects mentioned engaging in environmental protection behavior to have fun (Koo et al., 2015). Playfulness positively affects perceived usefulness and ease of use (Moon and Kim, 2001). Previous studies (Lin et al., 2005; Moon and Kim, 2001; Terzis et al., 2012) also confirmed the positive effect of perceived playfulness on the intention to use a new system. Padilla-Meléndez et al. (2013) verified that perceived playfulness is positively correlated with perceived usefulness, perceived ease of use, and intention to use (Padilla-Meléndez et al., 2013).

Based on the above research, the perception of having fun, such as perceived playfulness, is an incentive factor to promote human-computer interaction, and the use of smart recycling systems is a process of human-computer interaction. Therefore, this study introduced perceived playfulness into TAM and proposed the following hypotheses:

- H1 Perceived playfulness has a positive influence on perceived usefulness.
- H2 Perceived playfulness has a positive influence on perceived ease of use.
- H3 Perceived playfulness has a positive influence on intention to use.

- H4 Perceived playfulness has a positive influence on environmental concerns.

Environmental concern. Environmental concern is an inherent factor that affects people's actions regarding waste sorting and recycling (Meng et al., 2019). With the deterioration of the environment, the public has gradually become more aware of the importance of environmental protection (Wang et al., 2017). Previous studies have shown that environmental concern is positively related to people's environmental behaviors (Minton and Rose, 1997), and those with a high level of environmental concern show a high intention to engage in environmental protection activities (Greaves et al., 2013; Ha and Janda, 2012). Related studies (Gamba and Oskamp, 1994; Jekria and Daud, 2016; Schahn and Holzer, 1990; Schultz and Oskamp, 1996) also clarified the role and impact of environmental concern in recycling. Wu et al. (2019) confirmed the positive influence of environmental concern on perceived usefulness, perceived ease of use, and behavioral intention. Therefore, the following hypotheses are proposed:

- H5 Environmental concern has a positive influence on perceived usefulness.
- H6 Environmental concern has a positive influence on perceived ease of use.
- H7 Environmental concern has a positive influence on behavioral intention.

Perceived usefulness. Perceived usefulness indicates the degree to which a person believes using a particular system would improve their job performance (Davis, 1989). Smart recycling can improve the efficiency of waste recycling and sorting (Zhang et al., 2019). In extensive studies, the influence of perceived usefulness on intention to use has been verified, and the impact of perceived usefulness changes with external variables and structures (Wu et al., 2019). In a simple model, without an antecedent variable, perceived usefulness significantly influences intention to use and sometimes attitude (Chen and Lu, 2016). When the model contains other antecedent variables, perceived usefulness has a positive and significant influence on intention to use, and external variables play a role through perceived usefulness (Cheng and Huang, 2013). The positive impact of perceived usefulness on intention to use has been confirmed in smart systems (Kianpisheh et al., 2011; Koo and Chung, 2014; Park et al., 2015; Wang et al., 2014); therefore, the following hypothesis is proposed:

- H8 Perceived usefulness has a positive influence on the behavioral intention to use smart recycling systems.

Perceived ease of use. Perceived ease of use refers to the extent to which people think they are free from the physical and mental effort when using a particular system or technology. Smart recycling is easy to use (Zhang et al., 2019), and people like to use relatively easy products (Davis, 1989). Previous research on smart devices and systems has found that perceived ease of use impacts perceived usefulness and intention to use. Previous research on smart devices and systems (Chen et al., 2009; Dong et al., 2017; Kranz et al., 2010; Stragier et al., 2010) found that perceived ease of use affects intention to use and perceived usefulness. Therefore, the following hypotheses are proposed:

- H9 The perceived ease of use has a positive influence on the behavioral intention to use the smart recycling system.
- H10 The perceived ease of use has a positive influence on the perceived usefulness.

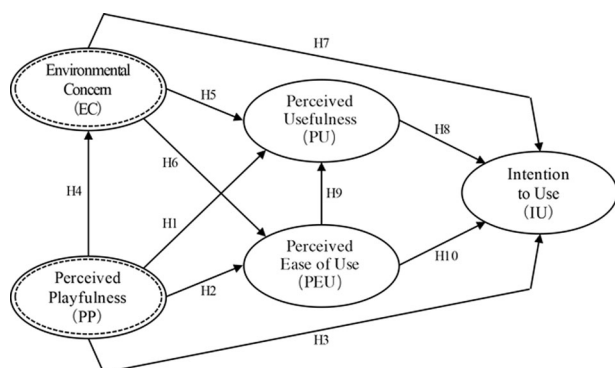


Fig. 1 The proposed theoretical model and hypotheses. This figure shows that perceived playfulness and environmental concern are the modified TAM that affects the intention to use smart recycling. This figure is not covered by the Creative Commons Attribution 4.0 International License. Reproduced with permission of Liyuan Liu; copyright © Liyuan Liu, all rights reserved.



Fig. 2 Residents using the smart recycling system. This picture shows residents using smart recycling. This figure is not covered by the Creative Commons Attribution 4.0 International License. Reproduced with permission of Liyuan Liu; copyright © Liyuan Liu, all rights reserved.

Proposed theoretical model. Based on the above discussion on perceived playfulness, environmental concern, perceived ease of use, perceived usefulness, and intention to use, the theoretical model and hypotheses are put forward, as shown in Fig. 1. Perceived playfulness and environmental concern in the modified TAM affect the intention to use smart recycling systems.

Methodology

Survey design. This study's questionnaire consists of three parts: an introduction to the smart recycling systems, respondents' demographic characteristics, and the measurement items (see Supplementary Questionnaire).

In the first part, pictures (see Fig. 2) and videos were presented to the respondents about the operational process of smart recycling systems. Specifically, the operating procedure is as follows: (1) open the interactive interface of the smart recycling system or smart recycling application (app) on their smartphones; (2) sort recycled items in the smart recycling bins according to the type of recyclables; (3) score points on

the app, based on the weight and sorting accuracy of the recyclables; and (4) collect points for small gifts, or play interactive games in the smart recycling app.

The second part includes the respondents' demographic characteristics: gender, age, family income, family size, and usage.

The third part contains the items of the measurement theory model and its hypotheses.

Research measurements. This study referred to the previous scales and modified the items to meet the research purposes. The scale of environmental concern (EC) was modified from Ho et al. (2015), containing five items; the scale of perceived playfulness (PP) was modified from Terzis et al. (2012), including four items; the scale of perceived usefulness (PU) was modified from Davis (1989) and Park et al. (2015), containing four items; the scale of perceived ease of use (PEU) was modified from Bettiga et al. (2020) and Venkatesh and Davis (2000), containing three items; the scale of intention to use (IU) was modified from Li et al. (2019) and Perrini et al. (2010), containing three items. The research model consists of five constructs, including 19 items, as shown in Table 1.

Selection of respondents and data collection. This study focused on residents living in urban communities with smart recycling systems to investigate the factors that impact the public use of smart recycling systems. Ningbo City in China was chosen as the research site for the following reasons:

1. Ningbo is one of China's first 46 pilot cities for waste sorting and recycling. It is the first city in China to receive loans from the International Bank for the household waste sorting project. Since the launch of waste sorting in 2013, Ningbo has realized the full coverage of waste sorting in central cities, and the public's awareness of garbage sorting and recycling has increased from 35.7% to 93.7% (Xie, 2020).
2. Ningbo is a representative city of smart cities, and its experience and efficiency in recycling are higher than in other cities (Wang et al., 2020). Waste recycling is an integral part of a smart city and significantly impacts modern society (Dabran et al., 2018). Since 2018, Ningbo has actively explored smart recycling and set up a city-wide smart recycling system in many communities, which sets a paradigm for other cities (Zhejiang Provincial Party Committee Political Research Office Industry Division, 2020).

Based on the above reasons, Ningbo was chosen as a representative and typical city for this study. The map of the study area is shown in Fig. 3. The subjects of this study were residents of local communities in Ningbo City equipped with smart recycling systems.

Since smart recycling differs from traditional recycling modes, this study focused on the impact of perceived playfulness and environmental concern on public intention to use smart recycling systems. Therefore, the respondents of this study all lived in communities with smart recycling systems, and the data were analyzed to compare the influence of these two factors and their relationship.

The questionnaire was uploaded to a survey website (<https://www.wenjuan.com/list/>), and electronic copies were sent via social networking platforms (WeChat group) of those communities in the form of a network link. Residents could click the website link of the electronic questionnaire and answer the questions voluntarily and anonymously. The initial research hypotheses and items of the conceptual model were all

Table 1 Scales adopted to measure the psychological constructs antecedent to the recycling behavior.		
Constructs	Measuring Items	Literature
Environmental concern	EC1 Using the smart recycling system means I am concerned about the environment.	Ho et al. (2015)
	EC2 Using the smart recycling system means I am sensitive to ecological problems.	
	EC3 Initiating the smart recycling system means that society is concerned about the environment.	
	EC4 Initiating the smart recycling system means that society is sensitive to ecological problems.	
	EC5 Initiating the smart recycling system means that society has built sound environmental concerns.	
Perceived usefulness	PU1 I think the smart recycling system is handy for garbage recycling.	Davis (1989), Park et al.(2015)
	PU2 The smart recycling system can improve recycling efficiency.	
	PU3 The smart recycling system is a beneficial tool to recycle waste.	
	PU4 Using the smart recycling system improves my performance and effectiveness.	
Perceived playfulness	PP1 Using the smart recycling system keeps me happy while doing my task.	Terzis et al. (2012)
	PP2 Using the smart recycling system brings me enjoyment while I learn.	
	PP3 The smart recycling system stimulates my curiosity.	
	PP4 Using the smart recycling system will lead to exploration.	
Perceived ease of use	PEU1 My interaction with the smart recycling system is clear and understandable.	Bettiga et al. (2020), Venkatesh and Davis (2000)
	PEU2 Interactions with the smart recycling system do not require too much thinking.	
	PEU3 I think the smart recycling system is straightforward to use.	
Intention to use	IU1 It is worth using the smart recycling system.	Li et al. (2019)
	IU2 I will be interested in the smart recycling system.	
	IU3 It is a good idea to use the smart recycling system.	

EC environmental concern, PU perceived usefulness, PP perceived playfulness, PEU perceived ease of use, IU intention to use.

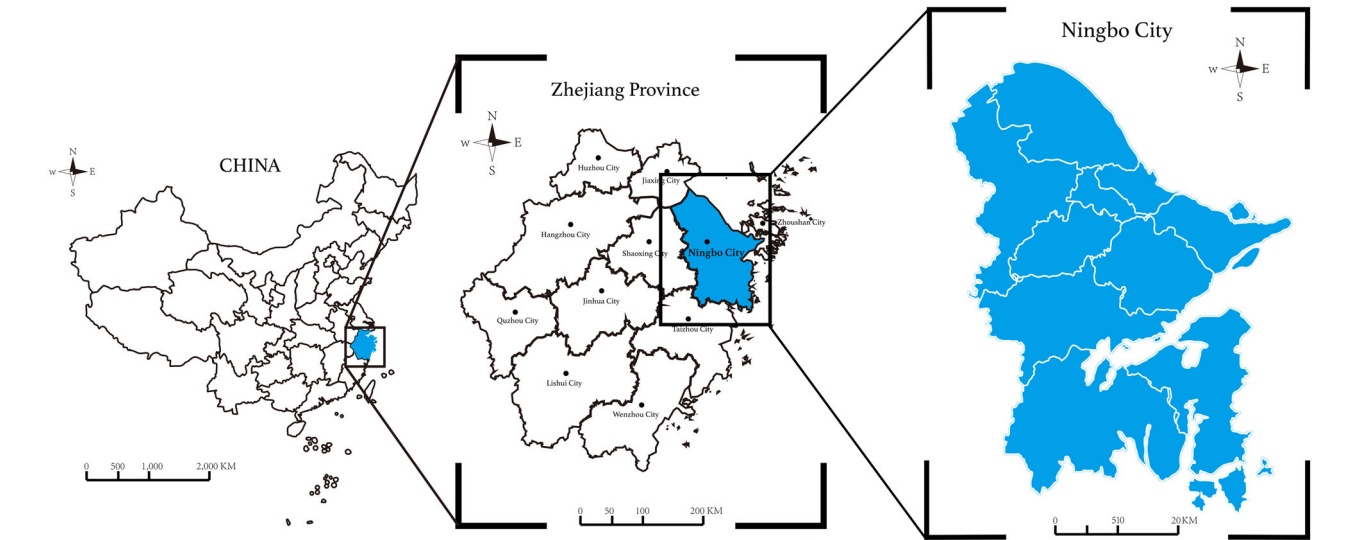


Fig. 3 Map of the study area. This picture shows the location of Ningbo. Ningbo was chosen as a representative and typical city for this study. This figure is not covered by the Creative Commons Attribution 4.0 International License. Reproduced with permission of Liyuan Liu; copyright © Liyuan Liu, all rights reserved.

measured with a seven-point Likert scale, where 1 = “strongly disagree” and 7 = “strongly agree” (Ryu and Jang, 2006). The researchers tested the questionnaires and answered them within four minutes. For the electronic questionnaire, the respondents were asked to take more than four minutes to answer the questions, and those who responded to questions for longer than four minutes were rewarded. A total of 378 questionnaires were received and 230 were valid after the data quality control process, with a valid response rate of 60.8%.

Reasonable sample size in studies using structural equation models is 10 times larger than the measured item (Bentler and Chou, 1987; Jackson, 2003; Kline, 1998). Since there were 19 measurement items in this study, according to the suggestions of Kline et al. (1998), a sample size >190 is considered reasonable. The sample size of this study was 230, which is more significant than 190, suggesting that our sample size was reasonable. The primary data collected from the respondents included their gender, age, educational level, income, family size, and

Table 2 Basic data of the respondents.

	Category	Number	Percentage
Gender	Male	78	33.9
	Female	152	66.1
Age	Under 20	6	2.6
	21–30	36	15.7
	31–45	146	63.5
	46–60	36	15.7
	Above 61	6	2.6
Educational level	Junior middle school or below	16	7.0
	Senior high school and vocational school	28	12.2
	Junior college	64	27.8
	Bachelor	96	41.7
	Graduate and above	26	11.3
Income (RMB)	Under 2000	11	4.8
	2000–3000	8	3.5
	3000–4500	38	16.5
	4500–6000	41	17.8
	6000–8000	42	18.3
	8000–10,000	41	17.8
	10,000–20,000	37	16.1
	20,000–30,000	10	4.3
	Above 30,000	2	0.9
Family size	1–2 persons	20	8.7
	3–4 persons	176	76.5
	5–6 persons	30	13.0
	7–8 persons	2	0.9
	More than 8 persons	2	0.9
Usage	Unused	124	53.9
	Less than once a week	47	20.4
	About once a week	34	14.8
	Two or three times a week	21	9.1
	About once a day	3	1.3
	Several times a day	1	0.4

usage of smart recycling systems. Among the respondents, 33.9% were males 66.1% were females; they were primarily between the ages of 31 and 45 (63.5%), and 80.8% had a junior college degree or above. A personal monthly income of less than 6000 (CNY) accounted for 42.6%, while a higher than 6000 (CNY) accounted for 57.4%. Furthermore, 76.5% of the families had three to four members. Regarding the use of smart recycling systems, 46% of the respondents had used smart recycling systems; among those, 20.4% used them less than once a week, followed by once a week (14.8%) and once a day (1.3%). Moreover, 53.9% of the residents had never used smart recycling systems. The detailed sample base data are shown in Table 2.

This study analyzed the valid samples according to gender, age, educational level, monthly income, and household size. According to the age groups adopted in Wang et al. (2018), this study divided the respondents into five age groups: under 20, 21–30, 31–45, 46–60, and above 61. Regarding age and gender ratio, since the questionnaire required family members to know about smart recovery, most respondents were women over 30 years old, and women in this age group are typically responsible for the family chores (Wang et al., 2016). Among them, the age group of 31–45 was the largest sample size, followed by 21–30, and 46–60, which corresponded to real-life scenarios (Wang et al., 2018). In addition, the respondents' educational level, income, and family size are consistent with the demographic characteristics of Ningbo City (NBSC, 2021). Therefore, the samples obtained in this study are meaningful overall.

Table 3 Analysis of the measurement model results.

Construct	Item	SE	p-value	Std.	CR	AVE
EC	EC1			0.790	0.930	0.729
	EC2	0.075	0.000	0.790		
	EC3	0.065	0.000	0.915		
	EC4	0.071	0.000	0.869		
	EC5	0.070	0.000	0.896		
PU	PU1			0.875	0.950	0.826
	PU2	0.061	0.000	0.895		
	PU3	0.047	0.000	0.939		
	PU4	0.055	0.000	0.924		
PP	PP1			0.879	0.898	0.688
	PP2	0.052	0.000	0.902		
	PP3	0.065	0.000	0.752		
	PP4	0.065	0.000	0.774		
PEU	PEU1			0.899	0.910	0.771
	PEU2	0.054	0.000	0.881		
	PEU3	0.058	0.000	0.853		
IU	IU1			0.935	0.947	0.857
	IU2	0.041	0.000	0.912		
	IU3	0.037	0.000	0.930		

EC environmental concern, PU perceived usefulness, PP perceived playfulness, PEU perceived ease of use, IU intention to use, SE standard error, Std. Standardized factor loadings, CR composite reliability, AVE average variance extracted.

Structural equation modeling. This study adopted structural equation modeling (SEM) to test the relationship between the variables and the intention to use smart recycling systems. SEM is a complex methodology in social science for testing the relationship between the potential variables in observation targets. It has great advantages for determining the interaction between potential variables (Gefen et al., 2000; Ullman and Bentler, 2003). In previous studies, SEM was used to analyze the behavioral intention for recycling (Best and Kneip, 2011; Chen and Tung, 2010; Fan et al., 2019; Ng, 2019; Wan et al., 2017, 2014; Zhang et al., 2016). It is also suitable for testing the relationship between other variables and behavioral intention (Wu et al., 2019), while a confirmatory factor analysis is used to evaluate the measurement model through a maximum-likelihood assessment (MLE), and the structural model is verified through a path analysis (Anderson and Gerbing, 1988; Hatcher and O'Rourke, 2013).

Results

Measurement model. This study adopted the MLE method as the measurement model. The results are as follows: the standardized factor loadings are between 0.752 and 0.939, indicating that all items are reliable (Chin, 1998). The composite reliability (CR) values of the dimensions are between 0.898 and 0.95, which are all above 0.7, indicating a good internal consistency (Nunnally, 1994). The average variance extracted (AVE) values are 0.688–0.857, which are all >0.5, indicating a good convergent validity (Fornell and Larcker, 1981). The above results are shown in Table 3.

This study used the AVE method, which is very rigorous, to test the discriminant validity of the measurement model. Fornell and Larcker (1981) held that the model has discriminant validity if the square root of the AVE of each dimension is greater than the correlation coefficient between the dimensions (Fornell and Larcker, 1981). As shown in Table 4, the square roots of the AVE of most dimensions on the diagonal are larger than the correlation coefficients of the diagonal, suggesting that most of the dimensions in this study have good discriminant validity and are within the acceptable range.

Table 4 Discriminant validity of the measurement model.

	AVE	EC	PU	PP	PEU	IU
EC	0.729	0.854				
PU	0.826	0.813	0.909			
PP	0.688	0.790	0.753	0.829		
PEU	0.771	0.764	0.804	0.801	0.878	
IU	0.857	0.815	0.820	0.855	0.732	0.926

Table 5 A comparison of the fit of the congeneric model and the constrained model.

	χ^2	df	$\Delta\chi^2$	Δ df	p-value
Non-congeneric	397.4	141	79.993	18	0
Congeneric	317.407	123			

Table 6 A comparison of restricted and unrestricted models.

	χ^2	df	$\Delta\chi^2$	Δ df	p-value
Constrained model	299.76	133	17.647	10	0.061
Congeneric model	317.407	123			

Common method variance (CMV). The CMV mainly comes from the errors of the measurement tools, which affect the validity of the measurement outcomes of the relationships between dimensions (Podsakoff et al., 2003). This study adopted the unmeasured latent method construct (ULMC), which uses a potential variable without observation variables to represent the CMV. If the observation variables are subject to the impact of the CMV of common factors, then the impact of CMV exists. In this study, ULMC was used to measure the CMV. If the model is affected by the CMV, then the CMV would be further modified.

According to the comparison results in Table 5, the Chi-square difference ($\Delta\chi^2$) of the two models is 79.993, the difference in the degrees of freedom (Δ df) is 18, and the *p*-value is 0, indicating that there is a significant difference between the two models. The Chi-square value of congeneric is low, suggesting that the congeneric model is better than the non-congeneric model. The results confirmed that the congeneric model is affected by the CMV.

The congeneric model analyzes CFA after excluding the CMV impact. The constrained model sets the covariance as that of the CFA model affected by the CMV to test the significance of the Chi-square difference between the two models.

According to Table 6, the Chi-square value difference ($\Delta\chi^2$) of the two models is 17.647, and the degree of freedom difference (Δ df) is 10, and the *p*-value is 0.061, indicating that the Chi-square value of the two models is not significantly different. Even if there is CMV, it does not affect the parameters estimated by the model; hence, the model does not require CMV correction.

Structural model analysis. After using the MLE to analyze the structural model, the degree of fit of the model, the significance test of the research hypothesis, the explanatory variance (R^2), and other results are obtained.

Model fit. In this study, the nine fit indices that were most widely used in many studies, such as Jackson (2003), were used to test the fit of the model to the data. The model fitness includes Satorra–Bentler $\chi^2 = 424.605$, 142.00 df, Normed Chi-sqr (χ^2 /DF) = 2.99, RMSEA = 0.093; SRMR = 0.035, NNFI = 0.929; CFI = 0.941; GFI = 0.914, AGFI = 0.896.

Table 7 Regression coefficient.

DV	IV	Unstd.	SE	Unstd./SE	p-value	Std.	R ²
EC	PP	0.743	0.065	11.503	0.000	0.790	0.624
PU	EC	0.397	0.073	5.416	0.000	0.441	0.743
	PP	0.072	0.074	0.967	0.334	0.085	
	PEU	0.362	0.076	4.766	0.000	0.399	
PEU	EC	0.345	0.086	4.015	0.000	0.348	0.687
	PP	0.491	0.081	6.075	0.000	0.526	
IU	EC	0.200	0.078	2.575	0.010	0.206	0.819
	PU	0.403	0.086	4.719	0.000	0.375	
	PP	0.487	0.076	6.368	0.000	0.535	
	PEU	−0.152	0.081	−1.878	0.060	−0.156	

EC environmental concern, PU perceived usefulness, PP perceived playfulness, PEU perceived ease of use, IU intention to use, Unstd. unstandardized regression coefficient, SE standard error, Std. standardized regression coefficient, R² coefficient of determination.

Testing hypotheses. The results of path effectiveness are shown in Table 7. As seen, perceived playfulness (Unstd. = 0.743, $p < 0.001$) significantly affect environmental concern (Unstd. = 0.397, $p < 0.001$). Perceived ease of use (Unstd. = 0.362, $p < 0.001$) significantly affect perceived usefulness. Environmental concern (Unstd. = 0.345, $p < 0.001$) and perceived playfulness (Unstd. = 0.491, $p < 0.001$) significantly affect perceived ease of use. Environmental concern (Unstd. = 0.200; $p = 0.010$), perceived usefulness (Unstd. = 0.403, $p < 0.001$), and perceived playfulness (Unstd. = 0.487, $p < 0.001$) significantly affect intention to use. Perceived ease of use (Unstd. = −0.152, $p > 0.001$) does not have a significant influence on environmental concerns.

The R^2 value is another important indicator of path model predictive power. The results indicate that 62.4% of environmental concern can be explained by perceived playfulness; 74.3% of perceived usefulness can be explained by environmental concern, perceived playfulness, and perceived ease of use; 68.7% of perceived ease of use can be explained by environmental concern and perceived playfulness; 81.9% of intention to use can be explained by environmental concern, perceived usefulness, perceived playfulness, and perceived ease of use.

This study compared the effects of environmental concern and perceived playfulness on intention to use with normalized regression coefficients. According to Table 7, the standardized regression coefficient of perceived playfulness to intention to use is 0.535, while that of environmental concern to intention to use is 0.206, and the effect of perceived playfulness on people's intention to use smart recycling is more significant than that of environmental concern.

Table 8 summarizes all the path coefficients of the SEM and the analysis results of the hypotheses testing. Except for H1 and H10, the other eight hypotheses are supported.

Figure 4 shows the important relationships between the variables in the structural model.

Mediation effect analysis. This study used bootstrapping for the effect analysis. Testing the indirect effects by using bootstrapping has more statistical test power than the causal and coefficient product methods (Mackinnon et al., 2004; Williams and Mackinnon, 2008). According to Hayes (2009), the resampling process in bootstrapping should be repeated 1000 times for all samples. Based on deviation correction and the percentile method, zero is not included between the lower limit and upper limit of the total effect and the indirect effect (Hayes, 2009). Table 9 shows the effect of environmental concern and perceived playfulness.

Table 8 Summary of hypothesis testing results.						
Hypothesis	Path	Estimate (β)	SE value	CR value	p-value	Decision
H1	PP \rightarrow PU	0.072	0.074	0.967	0.334	Not Support
H2	PP \rightarrow PEU	0.491	0.081	6.075	0.000	Support
H3	PP \rightarrow IU	0.487	0.076	6.368	0.000	Support
H4	PP \rightarrow EC	0.743	0.065	11.503	0.000	Support
H5	EC \rightarrow PU	0.397	0.073	5.416	0.000	Support
H6	EC \rightarrow PEU	0.345	0.086	4.015	0.000	Support
H7	EC \rightarrow IU	0.200	0.078	2.575	0.010	Support
H8	PU \rightarrow IU	0.403	0.086	4.719	0.000	Support
H9	PEU \rightarrow PU	0.362	0.076	4.766	0.000	Support
H10	PEU \rightarrow IU	-0.152	0.081	-1.878	0.060	Not Support

EC environmental concern, PU perceived usefulness, PP perceived playfulness, PEU perceived ease of use, IU intention to use, SE standard error, CR critical ratio.

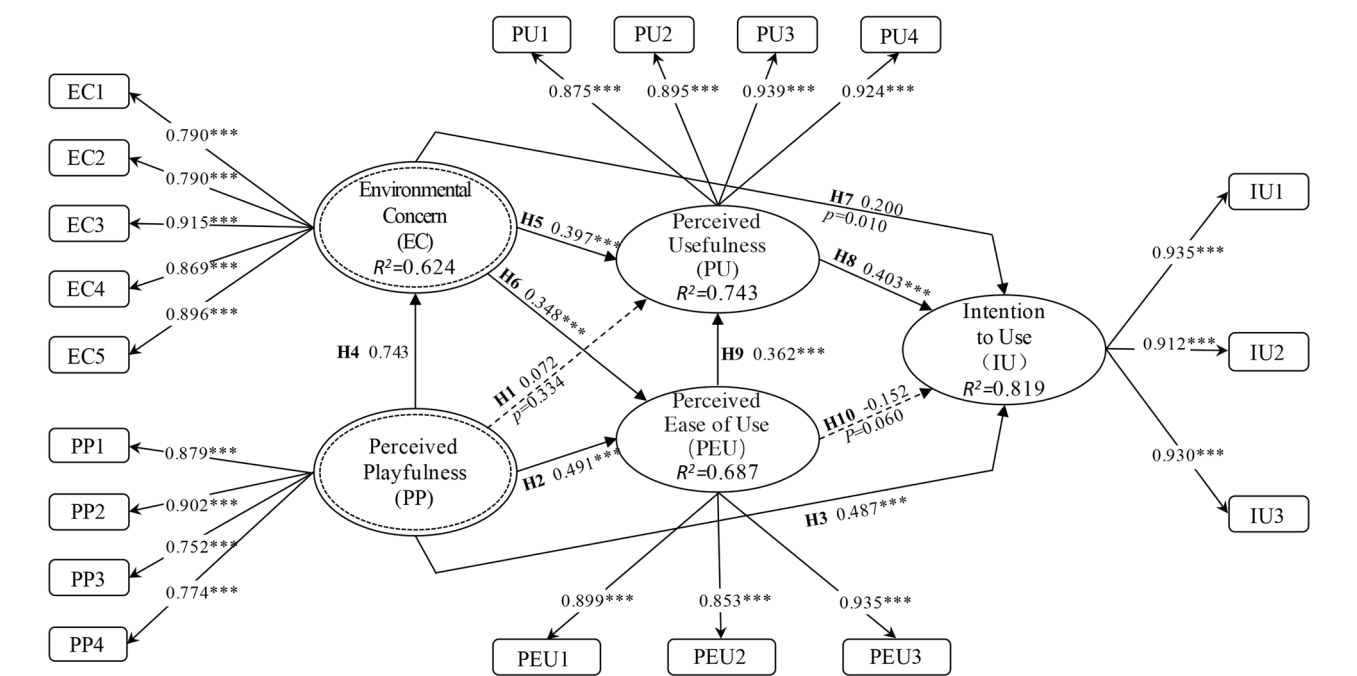


Fig. 4 Research structure pattern diagram. This picture shows the important relationships between the variables in the structural model. This figure is not covered by the Creative Commons Attribution 4.0 International License. Reproduced with permission of Liyuan Liu; copyright © Liyuan Liu, all rights reserved.

As shown in Table 8, the total effect ($\beta = 0.778$), the direct effect ($\beta = 0.487$) and the indirect effect ($\beta = 0.292$) of perceived playfulness is greater than the total effect ($\beta = 0.357$), direct effect ($\beta = 0.200$) and indirect effect ($\beta = 0.158$) of environmental concern.

The results confirm the direct effects ($\beta = 0.200$) and indirect effects ($\beta = 0.158$) of environmental concern on intention to use. The indirect influence of environmental concern on intention to use can be divided into two paths: (1) the path of environmental concern, to perceived usefulness, to intention to use is 0.160; (2) the path of environmental concern, to the perceived ease of use, to perceived usefulness, to intention to use is 0.050.

The total effect of perceived playfulness is 0.778, and its direct effect is 0.292. It is interrelated to other variables of the research model, and indirectly affects intention to use. Perceived playfulness indirectly affects the intention to use via four paths. Among them, the path of perceived playfulness, environmental concern, to intention to use has the greatest effect ($\beta = 0.148$). The above results indicate that perceived playfulness indirectly affects the intention of respondents to use smart recycling.

Discussion

Based on the discussion of the results and thorough comparison, the intention of the public to use smart recycling systems in this study is mainly influenced by environmental concern, perceived playfulness, and perceived usefulness. The comparison of the influence of various variables on the intention to use smart recycling systems suggests that perceived playfulness, perceived usefulness, and environmental concern influence the intention to use smart recycling systems, in descending order. In conclusion, the effect of perceived playfulness on intention to use is greater than that of environmental concern, but perceived ease of use cannot significantly affect intention to use. Therefore, perceived playfulness should be a priority for researchers or system designers of smart recycling systems. The influence, comparison, and relationship of each factor will be discussed in the following sections.

The results of the hypothesis validation indicate that environmental concern significantly affects intention to use. Smart recycling is closely related to environmental protection, which can reduce waste and promote classified recycling. When people are more concerned about the environment, they are more likely

Table 9 The effect of environmental concern and perceived playfulness.

	Effects	Estimate (β)	Lower bounds	Upper bounds
The effect of environmental concern (EC)	Total effects	0.357	0.144	0.621
	Direct effects	0.200	0.007	0.429
	Indirect effect	0.158	0.045	0.319
	EC \rightarrow PU \rightarrow IU	0.160	0.063	0.337
	EC \rightarrow PEU \rightarrow PU \rightarrow IU	0.050	0.015	0.148
The effect of perceived playfulness (PP)	Total effects	0.778	0.627	0.939
	Direct effects	0.487	0.279	0.753
	Indirect effect	0.292	0.117	0.483
	PP \rightarrow EC \rightarrow IU	0.148	0.014	0.319
	PP \rightarrow EC \rightarrow PU \rightarrow IU	0.119	0.050	0.270
	PP \rightarrow PEU \rightarrow PU \rightarrow IU	0.072	0.021	0.207
	PP \rightarrow EC \rightarrow PEU \rightarrow PU \rightarrow IU	0.038	0.011	0.111

EC environmental concern, PU perceived usefulness, PP perceived playfulness, PEU perceived ease of use, IU intention to use.

to use smart recycling systems. Previous studies highlighted the strong effect of environmental concern on intention to use (Wu et al., 2019), and regarded environmental concern as the main factor for individual participation in waste recycling (Tonglet et al., 2004). This study, however, found that environmental concern has a relatively small influence on intention to use, which may be due to the fact that smart recycling is different from traditional recycling modes, and that there may be other more important factors affecting the intention to use smart recycling systems.

Perceived playfulness significantly affects intention to use. This can be explained by the fact that smart recycling systems are based on technologies to achieve recycling, and gamification methods, such as setting rewards, can generate fun for users when using smart recycling systems, thus promoting their intention to use. This finding is consistent with that of Bakker et al. (2020), which suggested that people have a natural tendency to play because play is intrinsically rewarding and satisfying. Therefore, it is necessary to investigate the fun elements that can enhance the intention to use smart recycling systems. Design engineers should pay attention to the application of gamification technology in the smart recycling systems, as well as the users' ability to understand the information (Gong et al., 2019) and interact with the systems. Increasing user participation in the recycling process by using the incentive of gamification technology is irrelevant to the implementation policy (Bakker et al., 2020), so this finding is universal.

Compared to environmental concerns, perceived playfulness has a greater influence on the intention to use smart recycling systems. Although some studies on environmental protection show that users are more concerned about the role of the environment, this study found that they pay more attention to the playfulness of smart recycling systems. There is a paradox between the intention and the actual behavior toward household garbage sorting (Chen et al., 2015). Even if the urban residents' environmental awareness is higher, the personal intention to participate in recycling is lower, due to the problem of the recycling facilities (Zhang et al., 2019). This suggests that people's intention of recycling is not primarily due to their environmental concerns. Perceived playfulness is more important and will become the new focus (Lin et al., 2005). The results of this study also indicate that the perception of playfulness has a more prominent influence on the intention to use smart recycling systems. Therefore, playfulness can be considered the main factor that attracts people to participate in smart recycling. In addition, a comparison of the analysis results indicates that the public pays more attention to the playfulness of smart recycling systems. In other words, once users experience fun with smart recycling

systems, they would be willing to use them; therefore, perceived playfulness should be an important consideration in the design of smart recycling systems. Perceived playfulness stimulates participation and interaction in the process of smart recycling, and promotes recycling in an interesting and interactive manner. Smart recycling systems, which take advantage of gamification technologies, are designed not just for fun, but rather for a clear focus on recycling.

Environmental concern is associated with perceived playfulness, and perceived playfulness significantly affects environmental concern; in other words, a higher level of playfulness can produce positive emotions and satisfaction (Pan et al., 2014; Poncin et al., 2017; Shin et al., 2011). Urban residents are curious about smart recycling systems, and participation and interaction in the smart recycling process encourage them to focus on recycling in an interesting and interactive way. As a result, more urban residents would be motivated to participate in waste recycling and sorting, thus increasing their attention to environmental interaction. The gamification of smart recycling systems makes urban residents feel as if they are playing a game of recycling and sorting. In this gamified recycling process, those who perform well are rewarded, which promotes environmentally friendly habits (Briones et al., 2018). Therefore, it is important to note that playful ways of increasing the intention of residents to use smart recycling systems are not intended to diminish the public's emphasis on smart recycling as a way of protecting the environment. With the improvement of living conditions, urban residents expect higher environmental quality and pay more attention to environment-related systems and equipment. Because of the large population in cities, enormous amounts of waste are produced. The government should pay attention to the incentive and role of fun in smart recycling, and also strengthen the publicity of the environmental protection role of smart recycling systems, so as to improve the public's environmental awareness and provide effective environmental protection facilities for the public.

The results of effect analysis show that perceived playfulness indirectly affects the intention of urban residents to use smart recycling systems. Environmental concern is the antecedent variable, which can enhance the public's intention to use smart recycling systems by improving other variables (e.g., perceived usefulness, perceived ease of use); this is consistent with the findings of Wu et al. (2019). However, whether the environmental concern has an indirect impact on the intention to use through the perceived ease of use is yet to be proven, which is inconsistent with the characteristics in previous studies.

In the process of using smart recycling systems, urban residents perceive the fun of smart recycling, which promotes

their attention to environmental protection and enhances their intention to use smart recycling systems. For example, some residents, who were not planning to engage in recycling, may participate in garbage sorting and recycling when they see interesting anime-type garbage sorting ads on the display screen of the smart recycling system. Therefore, in order to increase the public's intention to use smart recycling systems, it is necessary to provide them with more intelligent and inspiring services through interesting game-based technologies (Zhang et al., 2019), thereby promoting the development of environmentally friendly behaviors.

Conclusions and contributions

Conclusions. This study introduced environmental concern and perceived playfulness into smart recycling, proposed a modified TAM, and discussed the impact of environmental concern and perceived playfulness on the intention of urban residents to use smart recycling systems. The three main conclusions are as follows:

1. The results of this study validate the eight hypotheses of the theoretical model, only two of which are statistically insignificant. The model can predict the impact of environmental concern and perceived playfulness on the intention to use smart recycling systems.
2. When comparing people's environmental concern and perceived playfulness with their intention to use smart recycling systems, perceived playfulness has a greater influence on their intention to use. In addition, the environmental concern can be promoted by perceived playfulness, and the public's intention to use smart recycling systems can be enhanced.
3. The results of this study can provide a reference for improving the public's intention to use smart recycling systems. In the context of promoting smart recycling systems, the focus could be placed on strengthening the sustainability of public garbage sorting and recycling behavior, while the impact of environmental concerns cannot be ignored.

Contributions. Based on the modified TAM, this study focused on the influences of the public's environmental concern and perceived playfulness on the intention to use smart recycling systems. This study makes five important contributions:

1. Smart recycling is still in its early stage of development (Xue et al., 2019). Previous studies analyzed this topic from the perspective of the accessibility of recycling facilities or recycling behavior, but rarely discussed the interesting perspective of intention to use. This is one of the first studies to apply the TAM to the intention of smart recycling systems.
2. Although the focus of this study is smart recycling, the theoretical significance can be transferred to other smart devices or environmental protection devices. The modified TAM can enable researchers to further explore the users' intention to use smart devices, which makes up for the deficiencies of the existing theories in the literature.
3. A novel finding in this study, which is different from other studies on environmental protection devices, is that perceived playfulness has a higher impact on intention, as compared with the impact of environmental concern. This provides a theoretical reference for the improvement and promotion of smart recycling systems.

Limitations and future research

Limitations. This study has the following limitations:

1. During this study period, smart recycling was in its initial stage, and smart recycling systems were only installed for testing in residential communities, which made it difficult to collect data. Although the sample size was of a reasonable value, it was smaller than those in other studies.
2. Since the main purpose of this study was to explore the Influences of perceived playfulness and environmental concern on the intention to use smart recycling systems, other factors were not included.
3. The research background is based on China's smart recycling, which is in its early stage of development; hence, it has not been widely used by the public. At present, the fun design of smart recycling systems is relatively unique. Due to the popularity of smart recycling, the conclusions and suggestions of the research may not be applicable in the future development of smart recycling.

Future research. The suggestions for future research works are as follows:

1. With the popularization of smart recycling, more samples from other regions can help to further the universality of the results.
2. In order to analyze and compare the influences of environmental concern and perceived playfulness, no other variables were introduced in this study. In future studies, the influence of other factors on the intention to use the smart recycling system can be discussed.
3. With the popularization of smart recycling, the intention to use is likely to change. Therefore, a longitudinal survey can be adopted to understand the change in the public's intention to use smart recycling systems.
4. Research into the intention of different age groups and genders to use smart recycling systems can be carried out in future studies.

Data availability

The datasets generated during and analyzed during the current study are available from the corresponding author upon reasonable request.

Received: 7 April 2022; Accepted: 8 September 2022;

Published online: 22 September 2022

References

- Ajzen I (1985) From intentions to actions: a theory of planned behavior. In: Kuhl J, Beckmann J (eds) Action control. Springer, Berlin, pp. 11–39
- Ajzen I (1991) The theory of planned behavior. *Organizational behavior and human decision processes* 50(2):179–211. [https://doi.org/10.1016/0749-5978\(91\)90020-T](https://doi.org/10.1016/0749-5978(91)90020-T)
- Anderson JC, Gerbing DW (1988) Structural equation modeling in practice: a review and recommended two-step approach. *Psychol Bull* 103(3):411–423. <https://doi.org/10.1037/0033-2909.103.3.411>
- Bakker AB, Scharp YS, Breevaart K et al. (2020) Playful work design: introduction of a new concept. *Span J Psychol* 23:e19. <https://doi.org/10.1017/SJP.2020.20>
- Benabou R, Tirole J (2003) Intrinsic and extrinsic motivation. *Rev Econ Stud* 70(3):489–520. <https://doi.org/10.1111/1467-937X.00253>
- Bentler PM, Chou C-P (1987) Practical issues in structural modeling. *Sociol Methods Research* 16(1):78–117. <https://doi.org/10.1177/0049124187016001004>

- Best H, Kneip T (2011) The impact of attitudes and behavioral costs on environmental behavior: a natural experiment on household waste recycling. *Soc Sci Res* 40(3):917–930. <https://doi.org/10.1016/j.ssresearch.2010.12.001>
- Bettiga D, Lamberti L, Lettieri E (2020) Individuals' adoption of smart technologies for preventive health care: a structural equation modeling approach. *Health Care Manag Sci* 23(2):203–214. <https://doi.org/10.1007/s10729-019-09468-2>
- Bonino D, Alizo MTD, Pastrone C et al (2016) WasteApp: smarter waste recycling for smart citizens. Paper presented at the 2016 international multidisciplinary conference on computer and energy science, Split, Croatia. pp. 13–15
- Botetzagias I, Dima A-F, Malesios C (2015) Extending the theory of planned behavior in the context of recycling: the role of moral norms and of demographic predictors. *Resour Conserv Recycl* 95:58–67. <https://doi.org/10.1016/j.resconrec.2014.12.004>
- Bozionelos N, Bozionelos G (1997) Psychology of computer use: XLVIII: relation between playfulness and computer anxiety. *Psychol Rep* 81(3):956–958. <https://doi.org/10.2466/pr0.1997.81.3.956>
- Briones AG, Chamoso P, Rivas A et al. (2018) Use of gamification techniques to encourage garbage recycling. a smart city approach. Paper presented at the international conference on knowledge management in organizations, Žilina, Slovakia, 6–10 August 2018
- Chan L, Bishop B (2013) A moral basis for recycling: extending the theory of planned behaviour. *J Environ Psychol* 36:96–102. <https://doi.org/10.1016/j.jenvp.2013.07.010>
- Chen C, Zhou M, Hu P et al. (2017) Research on the "Internet+" urban classified garbage recovery and transportation system framework. Paper presented at the 6th international conference on energy and environmental protection, Zhuhai, China, June 2017. pp. 681–690
- Chen C-F, Chao W-H (2011) Habitual or reasoned? Using the theory of planned behavior, technology acceptance model, and habit to examine switching intentions toward public transit. *Transp Res Part F* 14(2):128–137. <https://doi.org/10.1016/j.trf.2010.11.006>
- Chen JV, Yen DC, Chen K (2009) The acceptance and diffusion of the innovative smartphone use: a case study of a delivery service company in logistics. *Inf Manag* 46(4):241–248. <https://doi.org/10.1016/j.im.2009.03.001>
- Chen M-F, Tung P-J (2010) The moderating effect of perceived lack of facilities on consumers' recycling intentions. *Environ Behav* 42(6):824–844. <https://doi.org/10.1177/0013916509352833>
- Chen S, Li R, Ma Y (2015) Paradox between willingness and behavior: classification mechanism of urban residents on household waste. *China Popul Resour Environ* 25(9):168–176
- Chen S-Y, Lu C-C (2016) A model of green acceptance and intentions to use bike-sharing: YouBike users in Taiwan. *Netw Spat Econ* 16(4):1103–1124. <https://doi.org/10.1007/s11067-015-9312-8>
- Cheng Y-H, Huang T-Y (2013) High speed rail passengers' mobile ticketing adoption. *Transp Res Part C* 30:143–160. <https://doi.org/10.1016/j.trc.2013.02.001>
- Cheung SF, Chan DK-S, Wong ZS-Y (1999) Reexamining the theory of planned behavior in understanding wastepaper recycling. *Environ Behav* 31(5):587–612. <https://doi.org/10.1177/00139169921972254>
- Chin WW (1998) Commentary: Issues and opinion on structural equation modeling. *JSTOR*. <https://www.jstor.org/stable/249674>
- Csikszentmihalyi M (2014) Toward a psychology of optimal experience. In: Csikszentmihalyi M (ed) *Flow and the foundations of positive psychology: the collected works of Mihaly Csikszentmihalyi*. Springer Netherlands, Dordrecht, pp. 209–226
- Csikszentmihalyi M (1990) *Flow: The psychology of optimal experience*. Harper, New York
- Dabran I, Cohen Y, Eden O et al. (2018) An intelligent recycle bin for smart cities. Paper presented at the Proceedings of the 11th ACM international systems and storage conference, June 2018. p. 119
- Davis FD (1989) Perceived usefulness, perceived ease of use, and user acceptance of information technology. *MIS Q* 13(3):319–340. <https://doi.org/10.2307/249008>
- Davis FD, Bagozzi RP, Warshaw PR (1989) User acceptance of computer technology: a comparison of two theoretical models. *Manag Sci* 35(8):982–1003. <https://doi.org/10.1287/mnsc.35.8.982>
- Davis FD, Bagozzi RP, Warshaw PR (1992) Extrinsic and intrinsic motivation to use computers in the workplace 1. *J Appl Soc Psychol* 22(14):1111–1132. <https://doi.org/10.1111/j.1559-1816.1992.tb00945.x>
- Dong X, Chang Y, Wang Y et al. (2017) Understanding usage of Internet of Things (IoT) systems in China: cognitive experience and affect experience as moderator. *Inf Technol People* 30(1):117–138. <https://doi.org/10.1108/ITP-11-2015-0272>
- Fan B, Yang W, Shen X (2019) A comparison study of 'motivation-intention-behavior' model on household solid waste sorting in China and Singapore. *J Clean Prod* 211:442–454. <https://doi.org/10.1016/j.jclepro.2018.11.168>
- Fishbein M, Ajzen I (1977) Belief, attitude, intention, and behavior: an introduction to theory and research. *Philos Rhetoric* 10(2):130–132
- Fishbein M, Jaccard J, Davidson AR et al. (1980) Predicting and understanding family planning behaviors. In: Ajzen I, Fishbein M (eds) *Understanding attitudes and predicting social behavior*. Prentice-Hall
- Fornell C, Larcker DF (1981) Evaluating structural equation models with unobservable variables and measurement error. *J Mark Res* 18(1):39–50. <https://doi.org/10.1177/002224378101800104>
- Gamba RJ, Oskamp S (1994) Factors influencing community residents' participation in commingled curbside recycling programs. *Environ Behav* 26(5):587–612. <https://doi.org/10.1177/0013916594265001>
- Gefen D, Straub D, Boudreau M-C (2000) Structural equation modeling and regression: guidelines for research practice. *Commun Assoc Inf Syst* 4(1):7. <https://doi.org/10.17705/1CAIS.00407>
- Gong Z, Shan C, Yu H (2019) The relationship between the feedback environment and creativity: a self-motives perspective. *Psychol Res Behav Manag* 12:825. <https://doi.org/10.2147/PRBM.S221670>
- Greaves M, Zibarras LD, Stride C (2013) Using the theory of planned behavior to explore environmental behavioral intentions in the workplace. *J Environ Psychol* 34:109–120. <https://doi.org/10.1016/j.jenvp.2013.02.003>
- Gupta PK, Shree V, Hiremath L et al. (2019) The use of modern technology in smart waste management and recycling: artificial intelligence and machine learning. In: *Recent advances in computational intelligence*. Springer, pp. 173–188
- Ha H-Y, Janda S (2012) Predicting consumer intentions to purchase energy-efficient products. *J Consum Mark* 29(7):461–469. <https://doi.org/10.1108/07363761211274974>
- Hatcher L, O'Rourke N (2013) A step-by-step approach to using SAS for factor analysis and structural equation modeling. SAS Institute
- Hayes AF (2009) Beyond Baron and Kenny: statistical mediation analysis in the new millennium. *Commun Monogr* 76(4):408–420. <https://doi.org/10.1080/03637750903310360>
- Ho C-W, Wang Y-B, Yen N (2015) Does environmental sustainability play a role in the adoption of smart card technology at universities in Taiwan: an integration of TAM and TRA. *Sustainability* 7(8):10994–11009. <https://doi.org/10.3390/su70810994>
- Hoffman DL, Novak TP (1996) Marketing in hypermedia computer-mediated environments: conceptual foundations. *J Mark* 60(3):50–68. <https://doi.org/10.1177/002224299606000304>
- Hong I, Park S, Lee B et al. (2014) IoT-based smart garbage system for efficient food waste management. *Sci World J* 2014:646953. <https://doi.org/10.1155/2014/646953>
- Hsieh SH, Tseng TH (2017) Playfulness in mobile instant messaging: examining the influence of emoticons and text messaging on social interaction. *Comput Hum Behav* 69:405–414. <https://doi.org/10.1016/j.chb.2016.12.052>
- Iacob M-E, van Sinderen MJ, Steenwijk M et al. (2013) Towards a reference architecture for fuel-based carbon management systems in the logistics industry. *Inf Syst Front* 15(5):725–745. <https://doi.org/10.1007/s10796-013-9416-y>
- Igbaria M, Parasuraman S, Baroudi JJ (1996) A motivational model of micro-computer usage. *J Manag Inf Syst* 13(1):127–143. <https://doi.org/10.1080/07421222.1996.11518115>
- Igbaria M, Schiffman SJ, Wiecekowsky TJ (1994) The respective roles of perceived usefulness and perceived fun in the acceptance of microcomputer technology. *Behav Inf Technol* 13(6):349–361. <https://doi.org/10.1080/01449299408914616>
- Jackson DL (2003) Revisiting sample size and number of parameter estimates: some support for the $N:q$ hypothesis. *Struct Equ Model* 10(1):128–141. https://doi.org/10.1207/S15328007SEM1001_6
- Jekria N, Daud S (2016) Environmental concern and recycling behaviour. *Procedia Econ Finance* 35(C):667–673. [https://doi.org/10.1016/S2212-5671\(16\)00082-4](https://doi.org/10.1016/S2212-5671(16)00082-4)
- Kianpisheh A, Mustaffa N, See JMY et al. (2011) User behavioral intention toward using smart parking system. Paper presented at the international conference on informatics engineering and information science, Kuala Lumpur, Malaysia, November 2011. pp. 732–743
- Kline RB (1998) *Principles and practice of structural equation modeling*. Guilford, New York
- Koo C, Chung N (2014) Examining the eco-technological knowledge of Smart Green IT adoption behavior: a self-determination perspective. *Technol Forecast Soc Change* 88:140–155. <https://doi.org/10.1016/j.techfore.2014.06.025>
- Koo C, Chung N, Nam K (2015) Assessing the impact of intrinsic and extrinsic motivators on smart green IT device use: reference group perspectives. *Int J Inf Manag* 35(1):64–79. <https://doi.org/10.1016/j.jinfomgt.2014.10.001>
- Kranz J, Gallenkamp JV, Picot A (2010) Exploring the role of control-smart meter acceptance of residential consumers. Paper presented at the AMCIS, Lima, Peru, August 2010. p. 315
- Lee B-C, Yoon J-O, Lee I (2009) Learners' acceptance of e-learning in South Korea: theories and results. *Comput Educ* 53(4):1320–1329. <https://doi.org/10.1016/j.compedu.2009.06.014>
- Li J, Ma Q, Chan AH et al. (2019) Health monitoring through wearable technologies for older adults: smart wearables acceptance model. *Appl Ergon* 75:162–169. <https://doi.org/10.1016/j.apergo.2018.10.006>

- Lin CS, Wu S, Tsai RJ (2005) Integrating perceived playfulness into expectation-confirmation model for web portal context. *Inf Manag* 42(5):683–693. <https://doi.org/10.1016/j.im.2004.04.003>
- Ma J, Hipel KW, Hanson ML (2017) Public participation in municipal solid waste source-separated collection in Guilin, China: status and influencing factors. *J Environ Plan Manag* 60(12):2174–2191. <https://doi.org/10.1080/09640568.2017.1281798>
- Mackinnon DP, Lockwood CM, Williams J (2004) Confidence limits for the indirect effect: distribution of the product and resampling methods. *Multivar Behav Res* 39(1):99–128. https://doi.org/10.1207/s15327906mbr3901_4
- Malone TW (1981) Toward a theory of intrinsically motivating instruction. *Cogn Sci* 5(4):333–369. [https://doi.org/10.1016/S0364-0213\(81\)80017-1](https://doi.org/10.1016/S0364-0213(81)80017-1)
- Meng X, Tan X, Wang Y et al. (2019) Investigation on decision-making mechanism of residents' household solid waste classification and recycling behaviors. *Resour Conserv Recycl* 140:224–234. <https://doi.org/10.1016/j.resconrec.2018.09.021>
- Minton AP, Rose RL (1997) The effects of environmental concern on environmentally friendly consumer behavior: an exploratory study. *J Bus Res* 40(1):37–48. [https://doi.org/10.1016/S0148-2963\(96\)00209-3](https://doi.org/10.1016/S0148-2963(96)00209-3)
- Moon J-W, Kim Y-G (2001) Extending the TAM for a World-Wide-Web context. *Inf Manag* 38(4):217–230. [https://doi.org/10.1016/S0378-7206\(00\)00061-6](https://doi.org/10.1016/S0378-7206(00)00061-6)
- Mtutu P, Thondhlana G (2016) Encouraging pro-environmental behaviour: energy use and recycling at Rhodes University, South Africa. *Habitat Int* 53:142–150. <https://doi.org/10.1016/j.habitatint.2015.11.031>
- Muruganandam S, Ganapathy V, Balaji R (2018) Efficient IOT based smart bin for clean environment. Paper presented at the 2018 international conference on communication and signal processing, Chennai, India, November 2018. pp. 0715–0720
- NBSC (2021) China Statistical Yearbook. China Statistical Press. <http://www.stats.gov.cn/tjsj/ndsj/2021/indexch.htm>
- Ng S-L (2019) Predicting multi-family dwelling recycling behaviors using structural T equation modelling: a case study of Hong Kong. *Resour Conserv Recycl* 149:468–478. <https://doi.org/10.1016/j.resconrec.2019.06.007>
- Nigbur D, Lyons E, Uzzell D (2010) Attitudes, norms, identity and environmental behaviour: using an expanded theory of planned behaviour to predict participation in a kerbside recycling programme. *Br J Soc Psychol* 49(2):259–284. <https://doi.org/10.1348/014466609X449395>
- Nunnally JC (1994) Psychometric theory 3E. Tata McGraw-Hill Education
- Oztekin C, Teksoz G, Pamuk S et al. (2017) Gender perspective on the factors predicting recycling behavior: implications from the theory of planned behavior. *Waste Manag* 62:290–302. <https://doi.org/10.1016/j.wasman.2016.12.036>
- Padilla-Meléndez A, Del Aguila-Obra AR, Garrido-Moreno A (2013) Perceived playfulness, gender differences and technology acceptance model in a blended learning scenario. *Comput Educ* 63:306–317. <https://doi.org/10.1016/j.compedu.2012.12.014>
- Pan L-Y, Chang S-C, Sun C-C (2014) A three-stage model for smartphone use antecedents. *Qual Quant* 48(2):1107–1115. <https://doi.org/10.1007/s11355-012-9821-1>
- Park E, Kim H, Ohm JY (2015) Understanding driver adoption of car navigation systems using the extended technology acceptance model. *Behav Inf Technol* 34(7):741–751. <https://doi.org/10.1080/0144929X.2014.963672>
- Perrini F, Castaldo S, Misani N et al. (2010) The impact of corporate social responsibility associations on trust in organic products marketed by mainstream retailers: a study of Italian consumers. *Bus Strategy Environ* 19(8):512–526. <https://doi.org/10.1002/bse.660>
- Podsakoff PM, MacKenzie SB, Lee JY et al. (2003) Common method biases in behavioral research: a critical review of the literature and recommended remedies. *J Appl Psychol* 88(5):879–903. <https://doi.org/10.1037/0021-9010.88.5.879>
- Poncin I, Garnier M, Mimoun MSB et al. (2017) Smart technologies and shopping experience: are gamification interfaces effective? The case of the Smartstore. *Technol Forecast Soc Change* 124:320–331. <https://doi.org/10.1016/j.techfore.2017.01.025>
- Poortinga W, Steg L, Vlek C (2004) Values, environmental concern, and environmental behavior: a study into household energy use. *Environ Behav* 36(1):70–93. <https://doi.org/10.1177/0013916503251466>
- Ryu K, Jang S (2006) Intention to experience local cuisine in a travel destination: the modified theory of reasoned action. *J Hosp Tour Res* 30(4):507–516. <https://doi.org/10.1177/1096348006287163>
- Schahn J, Holzer E (1990) Studies of individual environmental concern: the role of knowledge, gender, and background variables. *Environ Behav* 22(6):767–786. <https://doi.org/10.1177/0013916590226003>
- Schultz PW, Oskamp S (1996) Effort as a moderator of the attitude-behavior relationship: general environmental concern and recycling. *Soc Psychol Q* 59(4):375–383. <https://doi.org/10.2307/2787078>
- Shin D-H, Shin Y-J, Choo H et al. (2011) Smartphones as smart pedagogical tools: implications for smartphones as u-learning devices. *Comput Hum Behav* 27(6):2207–2214. <https://doi.org/10.1016/j.chb.2011.06.017>
- Stern PC (2000) New environmental theories: toward a coherent theory of environmentally significant behavior. *J Soc Issues* 56(3):407–424. <https://doi.org/10.1111/0022-4537.00175>
- Stragier J, Hauttekeete L, De Marez L (2010) Introducing Smart grids in residential contexts: Consumers' perception of smart household appliances. Paper presented at the 2010 IEEE conference on innovative technologies for an efficient and reliable electricity supply, Waltham, MA, USA, November 2010. pp. 135–142
- Terzis V, Moridis CN, Economides AA (2012) The effect of emotional feedback on behavioral intention to use computer based assessment. *Comput Educ* 59(2):710–721. <https://doi.org/10.1016/j.compedu.2012.03.003>
- Tonglet M, Phillips PS, Bates MP (2004) Determining the drivers for householder pro-environmental behaviour: waste minimisation compared to recycling. *Resour Conserv Recycl* 42(1):27–48. <https://doi.org/10.1016/j.resconrec.2004.02.001>
- Tonglet M, Phillips PS, Read AD (2004) Using the Theory of Planned Behaviour to investigate the determinants of recycling behaviour: a case study from Brixworth, UK. *Resour Conserv Recycl* 41(3):191–214. <https://doi.org/10.1016/j.resconrec.2003.11.001>
- Ullman JB, Bentler PM (2003) Structural equation modeling. *Handbook of psychology*. pp. 607–634. <https://doi.org/10.1002/0471264385.wei0224>
- Vallerand RJ (2000) Deci and Ryan's self-determination theory: a view from the hierarchical model of intrinsic and extrinsic motivation. *Psychol Inq* 11(4):312–318
- Venkatesh V, Bala H (2008) Technology acceptance model 3 and a research agenda on interventions. *Decision Sci* 39(2):273–315. <https://doi.org/10.1111/j.1540-5915.2008.00192.x>
- Venkatesh V, Davis FD (2000) A theoretical extension of the technology acceptance model: four longitudinal field studies. *Manag Sci* 46(2):186–204. <https://doi.org/10.1287/mnsc.46.2.186.11926>
- Vining J, Linn N, Burdge RJ (1992) Why recycle? A comparison of recycling motivations in four communities. *Environ Manag* 16(6):785–797. <https://doi.org/10.1007/BF02645669>
- Wan C, Shen GQ, Choi S (2017) Experiential and instrumental attitudes: interaction effect of attitude and subjective norm on recycling intention. *J Environ Psychol* 50:69–79. <https://doi.org/10.1016/j.jenvp.2017.02.006>
- Wan C, Shen GQ, Yu A (2014) The moderating effect of perceived policy effectiveness on recycling intention. *J Environ Psychol* 37:55–60. <https://doi.org/10.1016/j.jenvp.2013.11.006>
- Wang B, Shen Y, Jin Y (2017) Measurement of public awareness of climate change in China: based on a national survey with 4,025 samples. *Chin J Popul Resour Environ* 15(4):285–291. <https://doi.org/10.1080/10042857.2017.1418276>
- Wang BR, Park J-Y, Chung K et al. (2014) Influential factors of smart health users according to usage experience and intention to use. *Wirel Personal Commun* 79(4):2671–2683. <https://doi.org/10.1007/s11277-014-1769-0>
- Wang M, Zhou T, Wang D (2020) Tracking the evolution processes of smart cities in China by assessing performance and efficiency. *Technol Soc* 63:101353. <https://doi.org/10.1016/j.techsoc.2020.101353>
- Wang Z, Guo D, Wang X (2016) Determinants of residents' e-waste recycling behaviour intentions: evidence from China. *J Clean Prod* 137:850–860. <https://doi.org/10.1016/j.jclepro.2016.07.155>
- Wang Z, Guo D, Wang X et al. (2018) How does information publicity influence residents' behaviour intentions around e-waste recycling? *Resour Conserv Recycl* 133:1–9. <https://doi.org/10.1016/j.resconrec.2018.01.014>
- Webster J, Trevino LK, Ryan L (1993) The dimensionality and correlates of flow in human-computer interactions. *Comput Hum Behav* 9(4):411–426. [https://doi.org/10.1016/0747-5632\(93\)90032-N](https://doi.org/10.1016/0747-5632(93)90032-N)
- Williams J, Mackinnon DP (2008) Resampling and distribution of the product methods for testing indirect effects in complex models. *Struct Equ Model* 15(1):23–51. <https://doi.org/10.1080/10705510701758166>
- Wu J, Liao H, Wang J-W et al. (2019) The role of environmental concern in the public acceptance of autonomous electric vehicles: a survey from China. *Transp Res Part F* 60:37–46. <https://doi.org/10.1016/j.trf.2018.09.029>
- Xiao L, Zhang G, Zhu Y et al. (2017) Promoting public participation in household waste management: a survey based method and case study in Xiamen city, China. *J Clean Prod* 144:313–322. <https://doi.org/10.1016/j.jclepro.2017.01.022>
- Xie H-B (2020) Investigation and analysis on the implementation of household waste classification in Ningbo. *Ningbo Econ (Sanjiang Forum)* 11:34–36
- Xue Y, Wen Z, Bressers H et al. (2019) Can intelligent collection integrate informal sector for urban resource recycling in China? *J Clean Prod* 208:307–315. <https://doi.org/10.1016/j.jclepro.2018.10.155>
- Yu T-K, Lin F-Y, Kao K-Y et al. (2019) An innovative environmental citizen behavior model: recycling intention as climate change mitigation strategies. *J Environ Manag* 247:499–508. <https://doi.org/10.1016/j.jenvman.2019.06.101>
- Zhang B, Lai K-H, Wang B et al. (2019) From intention to action: How do personal attitudes, facilities accessibility, and government stimulus matter for household waste sorting. *J Environ Manag* 233:447–458. <https://doi.org/10.1016/j.jenvman.2018.12.059>
- Zhang K, Xu Y, Liu W (2019) Empirical analysis of the intelligent influence factors of social network services effectiveness in e-commerce based on human

learning behaviors. *Psychol Res Behav Manag* 12:415–427. <https://doi.org/10.2147/PRBM.S203007>

Zhang S, Zhang M, Yu X et al. (2016) What keeps Chinese from recycling: accessibility of recycling facilities and the behavior. *Resour Conserv Recycl* 109:176–186. <https://doi.org/10.1016/j.resconrec.2016.02.008>

Zhejiang Provincial Party Committee Political Research Office Industry Division (2020) Exploration and enlightenment of ningbo garbage classification intelligence—Investigation on the operation of “handlehand” renewable resources recycling system. *Policy Outlook* 210:26–27

Acknowledgements

This research was supported by the Humanities and Social Science Research Program of the Ministry of Education of China (Grant No. 21YJA760025) and the Philosophy and Social Science Planning Foundation of Zhejiang Province (Project No. 19NDJC293YB).

Author contributions

Conception/design of the work (LL); analysis of data and interpretation of findings (LL and YH); drafted and revised the work (LL and YH); these authors jointly supervised this work.

Competing interests

The authors declare no competing interests.

Ethical approval

Approval was obtained from the Internal Review Committee of the Neural Ergonomics Laboratory. The procedures used in this study adhere to the tenets of the Declaration of Helsinki.

Informed consent

Informed consent was obtained from all participants. All participants were informed about the purpose and aims of the study, their participation is entirely voluntary and the ways the data would be used.

Additional information

Supplementary information The online version contains supplementary material available at <https://doi.org/10.1057/s41599-022-01347-6>.

Correspondence and requests for materials should be addressed to Liyuan Liu.

Reprints and permission information is available at <http://www.nature.com/reprints>

Publisher's note Springer Nature remains neutral with regard to jurisdictional claims in published maps and institutional affiliations.



Open Access This article is licensed under a Creative Commons Attribution 4.0 International License, which permits use, sharing, adaptation, distribution and reproduction in any medium or format, as long as you give appropriate credit to the original author(s) and the source, provide a link to the Creative Commons license, and indicate if changes were made. The images or other third party material in this article are included in the article's Creative Commons license, unless indicated otherwise in a credit line to the material. If material is not included in the article's Creative Commons license and your intended use is not permitted by statutory regulation or exceeds the permitted use, you will need to obtain permission directly from the copyright holder. To view a copy of this license, visit <http://creativecommons.org/licenses/by/4.0/>.

© The Author(s) 2022