Optimizing cell phone recycling for sustainable development: Integrating consumer behavior analysis, digital transformation strategies, and innovative incentive mechanisms

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Dedication

I dedicate this dissertation to my parents,

who strived tirelessly to be the best parents they could be,

while giving me the freedom to become myself.

Your love, sacrifice, and understanding have been my greatest support.

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Abstract

Cell phone’s swift proliferation has led to a significant increase in electronic waste, posing substantial environmental and resource management challenges. As one of the world's largest markets for cell phone devices, China faces a critical need for effective obsolete cell phone (OCP) recycling strategies. This comprehensive research addresses the complex issue of OCP recycling in China through an innovative approach that integrates consumer behavior analysis with a digital transformation framework, aiming to enhance recycling management and increase public participation. The study is structured in two main parts: a behavioral analysis of consumer intentions towards OCP recycling, and the development of a digital transformation framework for OCP recycling management.

The first part of the research employs the Theory of Planned Behavior (TPB) to investigate the factors influencing Chinese consumers' intentions to recycle OCPs. This well-established theoretical framework was extended to include emotional factors, providing a more comprehensive model of recycling behavior. A middle-scale survey was conducted, collecting data from a diverse sample of Chinese consumers. The final analysis included 621 valid responses, ensuring a robust dataset for statistical analysis. The survey instrument was designed to measure traditional TPB constructs (attitude, subjective norm, and perceived behavioral control) as well as emotional factors (privacy concerns and object attachment) and demographic variables.

Data analysis was performed using Partial Least Squares Structural Equation Modeling (PLS-SEM), allowing for the simultaneous examination of multiple relationships between variables, providing insights into the relative importance of different factors in predicting recycling intentions. Additionally, fuzzy-set Qualitative Comparative Analysis (fs-QCA) identified specific configurations of factors that lead

to high recycling intentions, offering a nuanced understanding of the complex interplay between various predictors. The PLS-SEM analysis revealed that the traditional TPB constructs significantly predict OCP recycling intention among Chinese consumers. Specifically, attitude towards recycling showed the strongest positive influence on intention. Perceived behavioral control, reflecting the ease or difficulty of recycling, also positively impacted intention. Subjective norm, representing social pressure to recycle, had a significant but relatively weaker effect on intention. Importantly, the inclusion of emotional factors provided additional insights. Privacy concerns negatively impacted recycling intentions, reflecting consumers' worries about personal data stored on their devices. Object attachment also showed a negative relationship with recycling intentions, indicating that sentimental value attached to obsolete cell phones may hinder recycling behavior. The fs-QCA analysis complemented these findings by identifying specific combinations of factors that lead to high recycling intentions. Notably, the absence of both privacy concerns and object attachment, combined with positive attitudes and high perceived behavioral control, was strongly associated with increased recycling intentions.

Building on the insights from the behavioral analysis, the second part of the research proposes a digital transformation framework for OCP recycling management, aiming to address the challenges identified in consumer behavior while leveraging technological advancements to improve overall recycling efficiency. The development of the digital transformation framework employed a design science research (DSR) methodology, ensuring a rigorous and systematic approach to creating a practical solution.

The proposed framework centers on a blockchain-based OCP Recycling Management System (OCP RMS), designed to enhance information transparency, foster stakeholder collaboration, and introduce novel incentivization mechanisms. To evaluate the feasibility and development potential of the OCP RMS, an integrated SWOT-AHP (Strengths, Weaknesses, Opportunities, Threats - Analytic Hierarchy Process) analysis was conducted. The SWOT-AHP analysis revealed several key findings. For strengths, the proposed blockchain-based system showed significant potential for improving transparency, traceability, and stakeholder collaboration in the recycling process. As the main weaknesses, initial implementation costs and potential resistance to technological change were identified as primary challenges. For opportunities, the system offers possibilities for improved resource recovery, enhanced data management, and integration with broader circular economic initiatives. Main threats included cybersecurity concerns and potential regulatory hurdles as external challenges. The AHP component of the analysis prioritized these factors, providing guidance for strategic implementation of the OCP RMS. Additionally, the research explored the potential of Non-Fungible Tokens (NFTs) as innovative incentives for consumer participation. The Contingent Valuation Method (CVM) was employed to assess consumer acceptance and willingness to participate in NFT-based recycling incentive programs. High consumer acceptance was observed in the exploration of NFTs as recycling incentives, with a significant portion of respondents expressing willingness to participate in NFT-based recycling programs. The CVM analysis also provided estimates of consumers' willingness to pay (WTP) partial compensation in the form of NFTs, offering valuable insights for designing economically viable incentive schemes.

This research offers several important implications for OCP recycling management in China. The behavioral analysis highlights the need for strategies that address both rational and emotional factors influencing recycling intentions. Public education campaigns should focus on improving attitudes and perceived behavioral control while also addressing privacy concerns and emotional attachment to devices. The exploration of NFTs as recycling incentives opens new possibilities for engaging consumers in recycling programs, potentially overcoming some of the barriers identified in the behavioral study, particularly by addressing the issue of perceived value in recycling obsolete devices.

The proposed blockchain-based OCP RMS presents a promising solution for enhancing transparency and efficiency in the recycling process. The implementation of such systems could significantly improve stakeholder collaboration and resource recovery rates. The research findings provide a strong foundation for policymakers and business sectors to develop more effective OCP recycling regulations and initiatives. Policies should consider the multifaceted nature of recycling behavior and the potential of digital technologies in improving recycling management. For cell phone manufacturers and recycling companies, the research offers insights into consumer preferences and behavior, as well as potential technological solutions for improving recycling processes.

In conclusion, this research presents a holistic approach to addressing the challenges of OCP recycling in China. By combining in-depth consumer behavior analysis with innovative digital solutions, the study offers a comprehensive framework for improving recycling rates and efficiency. The integration of blockchain technology and NFT-based incentives represents a significant advancement in e-waste management strategies, aligning circular economy principles with sustainable development goals. Future research directions include longitudinal studies to track changes in recycling behavior over time, pilot implementations of the proposed OCP

RMS to validate its effectiveness in real-world settings, and cross-cultural comparisons to explore the applicability of these findings in different socio-economic contexts.

Keywords: Obsolete cell phone; Recycling participation; Pro-environmental behavior; System optimizing; Digital transformation; Design science; Blockchain; NFTs.

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Introduction

1.1. General background

The rapid proliferation of electronic devices, particularly cell phones, has revolutionized global communication and connectivity, profoundly impacting modern society. However, this technological advancement has led to an unprecedented increase in electronic waste (e-waste) (Cecere et al., 2015), posing significant environmental and health challenges. The swift obsolescence of cell phones, driven by continuous innovation and consumer demand for the latest models, has exacerbated the e-waste problem. According to The ICT Development Index (2023), cell phone subscriptions have now exceeded the global population, highlighting the scale of potential e-waste generation and the urgent need for effective recycling solutions. Enhancing cell phone recycling management has become a critical global research priority, focusing on addressing the challenges posed by numerous obsolete devices and effective management of e-waste (Gu et al., 2019; Islam et al., 2021; Liu et al., 2019).

A survey conducted among Chinese consumers revealed a prevalent preference to store replaced devices at home, with the idle rate of cell phones surpassing 50% (Su et al., 2024). This trend underscores the urgent need to understand and improve consumer participation in cell phone recycling. Besides, the environmental implications of improper OCP disposal are severe. Used cell phones contain various harmful substances, which can adversely affect the environment and human health if improperly treated (Zhang et al., 2021). Additionally, the production of cell phones involves substantial resource extraction, with each device carrying an "ecological rucksack" of approximately 75 kg of resources (Welfens et al., 2016). Consequently, non-recycled OCPs contribute significantly to resource depletion and environmental degradation.

The concentration of toxic components in mobile devices has escalated in recent years, further exacerbating environmental and health concerns (Singh et al., 2019).

In China, cell phone recycling involves both formal and informal sectors, with the informal sector serving as a significant economic activity despite environmental and health risks (Umair et al., 2015; Wang et al., 2017). The lack of well-designed formal collection systems and the prevalence of informal recycling practices pose significant barriers to effective e-waste management (Tan et al., 2018). Informal recycling frequently occurs outside regulated frameworks, resulting in hazardous practices that potentially harm both human health and the environment (Chi et al., 2011; Li et al., 2017). Stakeholders, particularly regulators, face significant challenges in tracking the lifecycle information of cell phones and ensuring compliance with environmental regulations.

However, the efficacy of any recycling system is fundamentally contingent on consumer engagement (Qu et al., 2019). Many individuals tend to retain OCPs rather than recycle them, often due to insufficient awareness and acceptance of recycling programs. This phenomenon, termed "hibernation," reflects a broader challenge in promoting sustainable disposal practices among consumers (Inghels and Bahlmann, 2021). Previous research has demonstrated that consumers' attitudes, perceived behavioral control, subjective norms, and privacy concerns regarding OCP recycling (Bai et al., 2018), significantly influence their recycling intention and behavior. Furthermore, object attachment (OA), a significant psychological concept, refers to people’s emotional bonds with inanimate objects that potentially influence their disposal behaviors (Norberg and Rucker, 2021). Understanding these factors is crucial for developing effective strategies to promote OCP recycling participation.

Recent advancements in digital technologies have created novel opportunities for enhancing recycling management strategies. The ongoing digital transformation, characterized by the integration of big data, artificial intelligence (AI), Internet of Things (IoT), digital twins, and blockchain, is revolutionizing diverse industries, including waste management (Kraus et al., 2022). These technologies have the potential to enhance production efficiency, improve process safety, optimize resource recovery, and reshape business strategies (Abiodun et al., 2023; Calderon-Monge and Ribeiro-Soriano, 2024; Yaqub and Alsabban, 2023; J. Zhang et al., 2023). Among these technologies, blockchain has emerged as a particularly potent tool for resource management and supply chain traceability, leveraging its core attributes of decentralization, transparency, and immutability (Zhang et al., 2024). By leveraging blockchain technology, waste management entities could establish a transparent and immutable record of waste transactions, facilitating regulatory enforcement and ensuring proper waste processing (Bułkowska et al., 2023; Scott et al., 2023).

Based on the blockchain tech, NFT is defined as "a unique digital identifier that cannot be copied, substituted, or subdivided, that is recorded in a blockchain, and that is used to certify authenticity and ownership (as of a specific digital asset and specific rights relating to it)" ("Definition of NFT," 2024). Its function as blockchain-verified digital certificates of ownership for unique assets, have gained popularity in art, collectibles, and gaming (Ante et al., 2023; Chalmers et al., 2022; Yilmaz et al., 2023). The decentralized nature of blockchain technology underpinning NFTs ensures the provenance and authenticity of each asset without requiring a centralized authority (Wu et al., 2023). The unique attributes of NFTs, particularly their capacity to represent ownership of both digital and physical assets, present novel opportunities for preserving the sentimental value of physical OCPs while potentially stimulating consumer interest in recycling. This approach offers the recycling sector an opportunity to enhance its innovative image and engage in indirect economic activities (Bao and Roubaud, 2022; Bellagarda and Abu-Mahfouz, 2022; Król and Zdonek, 2023).The integration of NFTs into recycling programs may create a mutually beneficial scenario, incentivizing both consumers and businesses to engage in recycling efforts, thereby potentially enhancing OCP recycling management.

Despite the demonstrated potential of digital technologies in resource management, systematic research on effectively combining blockchain and NFT technologies for OCP recycling management remains limited. This research gap presents an opportunity to explore innovative solutions that address both the technical challenges of recycling management and the behavioral aspects of consumer participation.

1.2. Research questions

The overarching goal of this dissertation is to develop and evaluate innovative approaches to OCP recycling management that address both the technological and behavioral challenges inherent in the current system. In this study, an OCP refers to a device that is rarely or never used for various reasons, following the definition by Zhang et al. (2021). To achieve this objective, the research is structured around two interconnected milestones, each addressing specific aspects of the OCP recycling challenge. The following research questions of each milestone guide this investigation.

In the 1st milestone: Analysis of factors influencing consumer participation in obsolete cell phone recycling. Research questions go to: How do rational factors, as described by the Theory of Planned Behavior (TPB), influence Chinese consumers' intentions to recycle OCPs? What roles do emotional factors, specifically privacy concerns and object attachment, play in shaping OCP recycling intentions? How can the integration of rational and emotional factors enhance our understanding of OCP recycling behavior?

These questions aim to provide a comprehensive understanding of the psychological and behavioral factors that influence consumer participation in OCP recycling. By extending the TPB framework to include emotional factors, this research seeks to offer a more nuanced perspective on recycling behavior, particularly in the Chinese context.

In the 2nd milestone: Digital transformation of obsolete cell phone recycling management system based on blockchain featuring the NFT incentive mechanism. Research questions go to: How can a blockchain-based OCP recycling management system be designed to address current challenges in the recycling process? What are the potential opportunities and challenges associated with the digital transformation of

OCP recycling management systems? How effective are NFTs as an incentive mechanism in promoting consumer participation in OCP recycling? What is the level of consumer acceptance for this novel recycling system, and what factors influence this acceptance?

These questions focus on the technological and strategic aspects of improving OCP recycling management. By exploring the potential of blockchain technology and NFT-based incentives, this research aims to propose innovative solutions that can enhance the efficiency and effectiveness of OCP recycling processes.

By addressing the above research questions, this dissertation seeks to contribute to both the theoretical understanding of OCP recycling behavior and the practical development of more effective recycling management systems. The integration of behavioral insights with technological innovations offers a holistic approach to tackling the complex challenge of OCP waste management.

1.3. Structure of this dissertation

This dissertation is structured into five main chapters, each addressing specific aspects of the research questions as follows.

The content of the introduction part provides an overview of the research background, objectives, and structure of the dissertation. It sets the stage for the subsequent chapters by highlighting the significance of OCP recycling in the context of growing e-waste challenges and the potential of digital technologies to address these issues.

The second chapter talks about the 1st milestone, which analyzes factors influencing consumer participation in OCP recycling using the Theory of Planned Behavior (TPB) framework extended with emotional factors. This chapter employs Partial Least Squares Structural Equation Modeling (PLS-SEM) and fuzzy-set Qualitative Comparative Analysis (fs-QCA) to examine the complex interplay of rational and emotional drivers of recycling behavior. The findings from this chapter inform the design of effective strategies to enhance consumer participation in OCP recycling.

The 2nd Milestone as the third chapter, presents the design and evaluation of a blockchain-based OCP recycling management system. This chapter utilizes Design Science Research (DSR) methodology to construct an innovative recycling system framework, integrating blockchain technology and NFT-based incentives. It also employs SWOT-AHP analysis to evaluate the feasibility and strategic priorities of digital transformation in OCP RMS. The Contingent Valuation Method (CVM) is used to explore consumer acceptance and market potential of the blockchain-based OCP RMS characterized by novel NFT-based recycling incentives.

Chapter four builds the bridge of two milestones, discusses the linkages and complementarity between the two milestones, highlighting their integrated contributions to understanding and improving OCP recycling processes, providing a holistic perspective on enhancing OCP recycling. It also indicates the detailed limitations of the research, to pave the way for continued theoretical and practical advancements in sustainable e-waste management.

Conclusion as the last chapter summarizes the main findings of the dissertation and proposes directions for future research in the field of sustainable e-waste management and digital transformation of recycling processes, which reflects on the broader implications of the research for circular economic principles in the electronics sector and offers recommendations for researchers and industrial.

Through this comprehensive research framework, this study systematically explores the key issues of OCP recycling, proposes solutions from both consumer behavior and technological innovation perspectives, and provides theoretical basis and practical guidance for improving the efficiency of OCP recycling and promoting the sustainable development of e-waste management.

Milestone 1. Analysis of Factors Influencing Consumer Participation in Obsolete Cell Phone Recycling

The content of this chapter is derived from the research of Du et al. (2024). Specific citations will be provided throughout the chapter where appropriate.

2.1. Research development and objectives

As mentioned before, understanding the factors that influence consumer participation in OCP recycling is crucial for developing effective strategies to increase recycling rates. While previous research has explored various aspects of e-waste recycling behavior, there is a need for a more comprehensive examination of the specific factors affecting OCP recycling intentions among Chinese consumers. This study aims to address this gap by integrating rational and emotional factors within an extended theoretical framework.

The primary objective of this research is to investigate the determinants of OCP recycling intentions among Chinese consumers. Specifically, this study seeks to: 1. Examine the current cell phone usage patterns and disposal practices among Chinese consumers. 2. Identify consumer preferences and concerns regarding OCP recycling services. 3. Analyze the influence of cognitive factors, as outlined in the Theory of Planned Behavior (TPB), on OCP recycling intentions. 4. Explore the impact of emotional factors, particularly object attachment and privacy concerns, on consumers' willingness to recycle OCPs. 5. Investigate the complex interplay between rational and emotional factors in shaping OCP recycling intentions.

To achieve these objectives, this study employs a mixed-method approach, combining Partial Least Squares Structural Equation Modeling (PLS-SEM) with fuzzy-set Qualitative Comparative Analysis (fs-QCA). This methodological integration allows for a nuanced understanding of both the individual effects of various factors and their complex configurations in influencing OCP recycling intentions.

By providing insights into the multifaceted nature of OCP recycling behavior, this research aims to contribute to the development of more effective recycling strategies and policies. The findings of this study have the potential to inform stakeholders across the OCP recycling ecosystem, including policymakers, manufacturers, recycling service providers, and environmental organizations. Ultimately, this research seeks to contribute to the broader goal of promoting sustainable consumption practices and mitigating the environmental impact of electronic waste in China and beyond.

2.2. Theoretical framework

This section discusses the core components of TPB, its application in environmental and recycling behavior studies, and the rationale for extending the model in the context of obsolete cell phone recycling behavior. Understanding the formation of pro-environmental behaviors is crucial to promoting participation in sustainable activities. The TPB, proposed by Ajzen (1991), has been widely recognized as a robust framework for examining the precursors of such behaviors and behavioral IN. TPB posits that behavioral IN, a key predictor of actual behavior, is shaped by three main factors: attitude (ATT), perceived behavioral control (PBC), and subjective norm (SN) (Ajzen, 1991).Although TPB has been extensively applied in various domains, including waste management and recycling behaviors (Knussen et al., 2004; Wan et al., 2014), its application to the specific context of OCP recycling in China offers a unique perspective. Also, this study aims to enhance its explanatory power by extending the original framework.

2.2.1. Theory of Planned Behavior

Refer to TPB, ATT represents an individual's overall evaluation of a behavior and significantly predicts behavioral intention(Ajzen, 1991; Fishbein and Ajzen, 2011). In consumer OCP recycling, ATT refers to consumer evaluations of the behavior's outcomes, including environmental benefits, resource conservation, and personal satisfaction (Wang et al., 2018).

Numerous studies have demonstrated the positive relationship between ATT and IN in various pro-environmental behaviors, including recycling (Alzubaidi et al., 2021; Gao et al., 2017; Knussen et al., 2004) . For example, Echegaray and Hansstein (2017) found that positive ATT towards e-waste recycling significantly influenced recycling intentions in Brazil. Similarly, Wang et al. (2016) reported that ATT was a strong predictor of IN to recycle e-waste among Chinese residents. Based on this theoretical foundation and empirical evidence, this study proposes the following hypothesis:

H1: ATT positively influences the IN of Chinese consumers to recycle OCP.

PBC reflects an individual's perception of their ability to perform a behavior (Ajzen, 1991), like Bandura and others' (1986) concept of self-efficacy. In this study, PBC denotes the consumer assessment of the ability and perceived difficulty of participating in the recycling process (Aboelmaged, 2021). PBC plays a crucial role in predicting behavioral IN, especially for behaviors that may involve obstacles or require specific resources (Ajzen, 2002).

Recent studies have shown that PBC significantly influences recycling IN in various contexts, including e-waste (Kumar, 2019; Z. Wang et al., 2016). When people perceive OCP recycling as manageable and within their control, they are more likely to form strong IN to engage recycling behavior. On the contrary, if the recycling process is perceived as complex or challenging, IN may be weakened. The significance of PBC in OCP recycling can also be understood through the lens of convenience and self-efficacy. If consumers perceive OCP recycling as simple, easy and convenient behavior, they are more likely to believe that they have sufficient capacity to perform recycling behavior. Conversely, if the process is perceived as complex, time-consuming, or labor-intensive, people may consider their PBC to be low, making it difficult for them to cope with recycling processes (Li et al., 2019; Sun et al., 2017). Therefore, this study proposes the following hypothesis:

H2: PBC positively influences the IN of Chinese consumers to recycle OCP.

SN involves the perceived social pressure from important individuals or groups to engage in a behavior (Ajzen, 1991; Ham et al., 2015). In OCP recycling, SN signifies the perceived external pressures on consumers to participate in recycling activities (Zhang et al., 2015).

The influence of SN on behavioral IN has been well documented in environmental behavior research. As Xu et al. (2017) found that SN significantly influenced Chinese consumers' waste separation IN. Similarly, Wan et al. (2014) reported that social influence or pressure, closely related to SN, was a significant predictor of recycling IN. Moreover, the role of IN in OCP recycling can be particularly important in collectivist cultures such as China, where social influences and conformity to group norms play a significant role in shaping individual behavior (Hofstede, 2001). The perceived expectations of family members, friends, colleagues, and society at large can exert a strong influence on an individual’s IN to recycle OCP. Based on these considerations, this study proposes the following hypothesis:

H3: SN positively influences the IN of Chinese consumers to recycle OCP.

2.2.2. Extending the TPB for obsolete cell phone recycling participation

As we mentioned before, while TPB has been widely applied and validated in various behavioral contexts, including waste management and recycling, several researchers have argued that the original framework may not be comprehensive enough to fully understand specific behaviors (Berki-Kiss and Menrad, 2022; Gao et al., 2017; Padel and Foster, 2005). Research also suggests that key TPB factors that influence OCP recycling decisions vary by context, geographical location, and timing (B. Wang et al., 2019; Zhang et al., 2021, 2020). Additionally, TPB focuses primarily on cognitive and rational predictors, based on the assumption that individuals make rational decisions (Demarque et al., 2015). Numerous studies have recommended incorporating emotional factors into the TPB framework to improve understanding of behavioral decisions, particularly in pro-environmental contexts (Ajzen, 2011; Berki-Kiss and Menrad, 2022; Kals et al., 1999; Kollmuss and Agyeman, 2002; Lam et al., 2022). In response to these recommendations and to address the specific context of OCP recycling, this study extends the TPB framework by incorporating two emotional factors: PC and OA. This extended model not only addresses the cognitive aspects of decision making but also incorporates emotional factors that may play a crucial role in shaping recycling behavior. The hypothesized relationships discussed subsequently.

The rapid growth of information and communication technologies has significantly improved daily life, but also increased the collection and sharing of personal information, often without consent (Yun et al., 2019). Cell phones now store sensitive personal information, including emails, photos, and account passwords, and support various Internet activities beyond making phone calls (Zhang et al., 2021). According to Bai et al. (2018) and Zhang et al. (2019), information security is the primary barrier to consumer participation in OCP recycling.

In this study, PC refers to consumers' apprehensions about the possible leakage of personal information that remains in their OCPs during the recycling process. The integration of PC into the theoretical framework is supported by recent studies in the field of e-waste recycling. As Dhir et al. (2021) indicated that PC as risk barrier negatively influences e-waste recycling IN. While Zhang et al. (2020) demonstrated that risk perception, which includes concerns about information security, could mediate the relationship between TPB variables and recycling IN, underscoring the complexity of PC. The influence of PC on TPB constructs can also be explained through the lens of the Privacy Calculus Theory (Dinev and Hart, 2006) and the Protection Motivation Theory (Rogers, 1975). These theories suggest that people weigh the potential risks and benefits when making decisions about disclosing personal information. In the context of OCP recycling, high PC may lead to a less favorable ATT towards recycling, lower PBC, and ultimately, a reduced IN to recycle OCP. By comminating empirical evidence with these theories, this study proposes the following hypotheses:

H4: PC negatively influences the ATT of Chinese consumers to recycle OCP.

H4m: PC indirectly reduces the OCP recycling IN through ATT.

H5: PC negatively influences the PBC of Chinese consumers to recycle OCP.

H5m: PC indirectly reduces the OCP recycling IN through PBC.

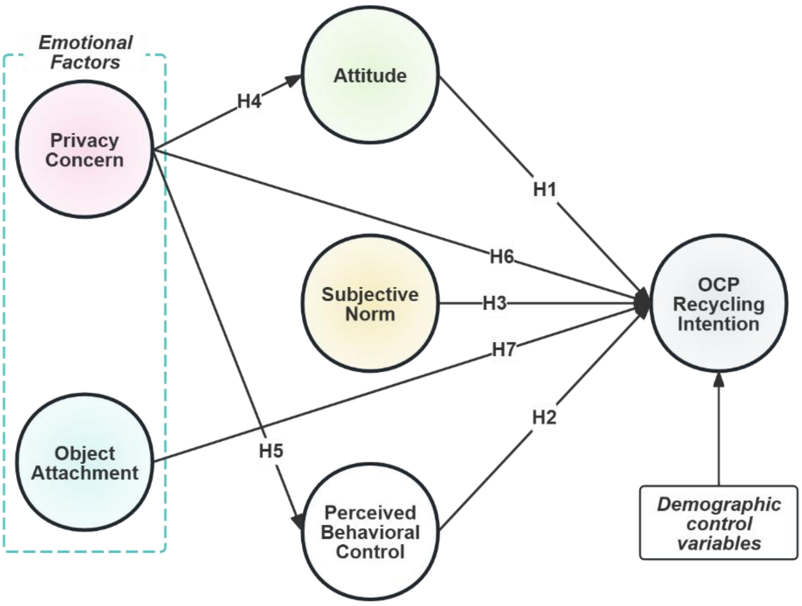
H6: PC negatively influences the IN of Chinese consumers to recycle OCP.

As stated by Dozier and Ayers (2021), the emotional bond developed with an inanimate object that can lead to feelings of loss upon its disposal. This concept is rooted in the broader theory of material possession attachment, suggesting that individuals can form strong emotional connections to their possessions (Belk, 1988; Kleine and Baker, 2004). Cell phones have transcended their basic communication functions, becoming deeply integrated into various aspects of life. Consumers personalize their phones with decorations, transforming them into extensions of themselves and expressions of personal style (Lou et al., 2022). Even when cell phones become obsolete, this emotional bond can serve as a barrier to participation in recycling processes (Welfens et al., 2016). As Brough and Isaac (2012) found, attachment to objects can hinder recycling behavior. Similarly, Trudel et al. (2016) demonstrated that OA could influence disposal decisions, with stronger attachments leading to a lower likelihood of recycling.

Moreover, the influence of OA on recycling IN can be explained through the lens of the endowment effect (Kahneman et al., 1990) and the theory of psychological ownership (Pierce et al., 2003), suggesting that individuals ascribe higher value to objects they own and feel a sense of ownership over, which can make it more difficult to part with these objects. In this study, OA as another emotional factor negatively influences OCP recycling IN, referencing Norberg and Rucker (2021), OA is defined as 'the psychological or emotional bond that individuals experience between their sense of self and an object'. Therefore, the following hypothesis is proposed:

H7: OA negatively influences the IN of Chinese consumers to recycle OCP.

Fig. 1 presents the research model of this study. To account for the effect of demographic variables, those that significantly affect the IN will be included as control variables in the proposed model.



Notes:
H4m. *PC indirectly reduces the OCP recycling IN through ATT under the model.*
H5m. *PC indirectly reduces the OCP recycling IN through PBC under the model.*

Fig. 1 The expanded TPB model of this study

2.3. Research methodology

This study employs a mixed-method approach to investigate the factors influencing consumer participation in obsolete cell phone (OCP) recycling. The research design combines quantitative data collection through a structured questionnaire with advanced analytical techniques, namely Partial Least Squares Structural Equation Modeling (PLS-SEM) and fuzzy-set Qualitative Comparative Analysis (fs-QCA). This methodological approach allows for a comprehensive examination of both the individual effects of various factors and their complex configurations in shaping OCP recycling intentions.

2.3.1. Questionnaire design

This study used an online questionnaire to explore the topics discussed earlier. The survey content was divided into three sections: I. usage and disposal of cell phone, II. Preferences for cell phone recycling, and III. Likert scale items that assess influencing factors. In this study, an OCP refers to a device that is rarely or never used for various reasons, following the definition by Zhang et al. (2021).

Before implementing the survey, the authors focused on ensuring coherence and clarity of questions. To achieve this, the study used a snowball sampling method, conducting in-depth interviews with 22 individuals, primarily comprising relatives and friends of the authors, from June 23 to July 25, 2023. These interviews yielded preliminary information on the preferences for cell phone usage, disposal, and recycling among consumers, which informs the design of the questionnaire.

Part I examines the frequency of cell phone replacement, the primary disposal method, the retention of OCP, and the reasons for not recycling OCP. Additionally, demographic data was collected prior to this part. Part II aims to indicate consumer preferences for cell phone recycling, covering factors that influence cell phone recycling participation, as well as preferences for compensation methods, recycling service providers and collection methods, and demand for data safety assurance.

Part III focuses on the factors that influence OCP recycling IN. To measure OCP recycling IN, as well as ATT, SN, PBC, PC toward OCP recycling, and OA of OCP. Respondents provided responses on a five-point Likert scale from "1 - strongly disagree" to "5 - strongly agree". As China culture is typically viewed as a high-context culture that is distinct from Western cultures, communication is strongly based on shared backgrounds and contexts (Chen, 2023), and most of the references were English-language research papers, it was essential to frame the questions clearly to prevent misinterpretation. We conducted bidirectional translations and rigorously evaluated the results to minimize inconsistencies. The last version of the construct scale questions is given in Appendix Q.

2.3.2. Data collection

Participants were recruited using the WENJUANXING online survey platform (https://www.wjx.cn), a widely recognized tool for conducting various surveys in China. According to the announcement of the platform, it boasts a diverse sample pool of more than 6.2 million registered members in different regions of China, offering rich demographic attributes. This study used a simple random sampling method, ensuring equiprobability of selection for each eligible individual. To enhance the breadth of the sample, we administered the questionnaire at various times throughout each day from November 22 to December 13, 2023. This stratified time-sampling approach aimed to minimize temporal biases and capture a diverse range of respondents. In addition, the frequency of daily survey dissemination was dynamically adjusted based on the target sample size and collection period. While this sampling method ensured randomness and reduced potential time-related biases, it is important to note that online sampling may exclude individuals without internet access or those unfamiliar with online surveys, potentially introducing some selection bias. However, the diverse nature of the WENJUANXING user base mitigates this limitation to some extent. To mitigate potential biases and improve response quality, the survey landing page prominently displayed the following information: (1) the survey is anonymous; (2) data will be used solely for academic research; (3) there are no right or wrong answers; (4) participation is voluntary and randomized; (5) individual responses will not be used to identify any participants. This study adhered to the ethical guidelines of the institutional review board (Research Ethics Review Committee, Graduate School of Natural Science and Technology, Okayama University). All survey procedures were in accordance with ethical standards.

After obtaining 91 responses on the first day, we conducted a preliminary analysis, which revealed no significant design issues, allowing us to proceed with the full-scale data collection. The sample size determination was based on the effect size definitions of Cohen (1988) and an online calculator designed by Soper (2024). For a structural equation model comprising one latent variable and five observed variables, targeting an effect size of 0.3 and a significance level of 0.05, a minimum sample size of 100 was required. Ultimately, the survey collected 677 responses, of which 621 were validated and retained for further analysis, resulting in an effective response rate of 91.73%.

2.3.3. Profile of the respondents

The geographical sources of the collected samples cover all provincial regions in mainland China, with the majority (58.13%) coming from the eastern provinces, ensures the geographical breadth of the sample. The survey captured a female majority (58.45%), and most of the participants aged between 21 and 40 years (86.95%). Most of the respondents (82.13%) had undergraduate degrees, indicating a notably high level of education, while a significant minority (8.05%) had graduate degrees. The employment rate among the respondents is high (87.76%), with diverse monthly incomes. The largest segment earns between 6,001 and 8,000 CNY (22.71%). ***Fig. 2*** presents a summary of the demographic profile. ***Fig. 3*** illustrates the regional distribution of the respondents. For both details, refer to ***Table 1***.

Table 1 Demographic profile.

Demographic variables	Item	Respondents	Percentage
Region	Eastern	361	58.13%
	Central	147	23.67%
	Western	113	18.20%
Gender	Female	363	58.45%
	Male	258	41.55%
Age	≤20	13	2.09%
	21-30	237	38.16%
	31-40	303	48.79%
	41-50	55	8.86%
	51-60	12	1.93%
	>60	1	0.16%
Education	Primary Education or below	0	0.00%
	Secondary Education	18	2.90%
	Vocational Education	43	6.92%
	Undergraduate Education	510	82.13%
	Graduate Education	50	8.05%
Profession	Student	40	6.44%
	Employed	545	87.76%
	Self-employed	34	5.48%
	Retired/Unemployed	2	0.32%
Monthly income (CNY)	≤2,000	23	3.70%
	2,001-4,000	35	5.64%
	4,001-6,000	98	15.78%
	6,001-8,000	141	22.71%
	8,001-10,000	130	20.93%
	10,001-12,000	95	15.30%
	12,001-14,000	49	7.89%
	>14,000	50	8.05%

Legend: Eastern region: Beijing, Fujian, Guangdong, Hainan, Hebei, Jiangsu, Liaoning, Shandong, Shanghai, Tianjin, and Zhejiang. Central region: Anhui, Heilongjiang, Henan, Hubei, Hunan, Jiangxi, Jilin, and Shanxi. Western region: Chongqing, Gansu, Guizhou, Guangxi, Ningxia, Qinghai, Shaanxi, Sichuan, Xinjiang, Inner Mongolia, Yunnan and Tibet.

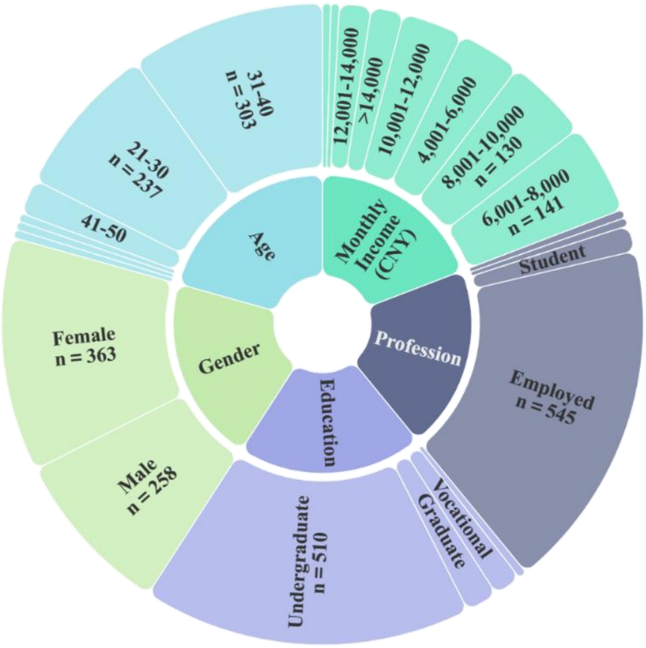


Fig. 2 Main demographic profile of the respondents

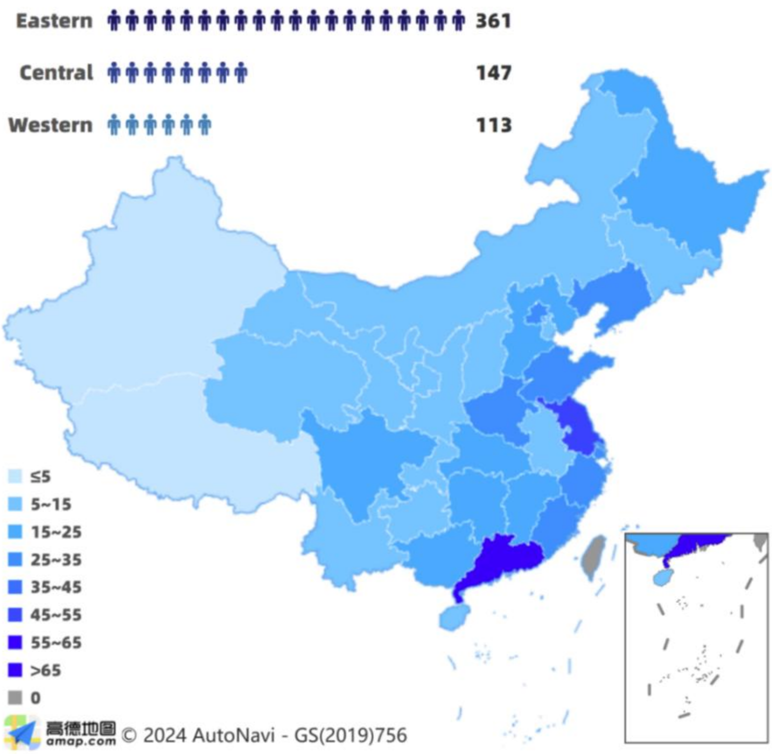


Fig. 3 Regional distribution of the respondents

2.3.4. Analytical framework

This study employs a comprehensive analytical framework combining PLS-SEM and fs-QCA to provide a nuanced understanding of the factors influencing OCP recycling IN. Initially, this study used *SmartPLS 4.0.9.6* software to construct PLS-SEM for analysis. There are several key reasons for selecting PLS-SEM: First, its suitability for exploratory research grounded in preexisting theories (Mueller and Hancock, 2018). In this study, the impacts of PC on IN were not predetermined; and OA acted as a newly introduced variable. Second, this methodology could effectively model complex relationships and reveal both direct and indirect effects between variables (Hair Jr et al., 2021; Sarstedt et al., 2023). Lastly, PLS-SEM does not impose strict requirements on data distribution or sample size (Astrachan et al., 2014; Hair Jr et al., 2021). Given the moderate sample size of 621, the findings derived from PLS-SEM are potentially more acceptable than those derived from the Covariance-Based Structural Equation Model (CBSEM). In this study, the objective of applying PLS-SEM analysis is to assess the influence of ATT, SN, PBC, OA and PC on OCP recycling IN, specifically explore whether OA influences OCP recycling IN and clarify the relationship between PC and IN within the classical TPB framework.

To complement the PLS-SEM results and address the complex, nonlinear relationships that may exist in consumer OCP recycling IN, following the identification of key factors through PLS-SEM, this study investigated their combined effects using fs-QCA, elucidating configurations conducive to high OCP recycling IN. PLS-SEM focuses on net effects and predominant patterns, fs-QCA allows us to explore the complex, nonlinear dynamics of determinants influencing human behavior (Pappas and Woodside, 2021). In fs-QCA, a "configuration" is defined as a unique combination of causal variables that interact synergistically to produce a specific outcome (Pappas and

Woodside, 2021). Additionally, this method is particularly valuable for its configurational approach, its ability to capture asymmetric causality, recognition of equifinality, and consideration of conjunctural causation (Fiss, 2011; Ragin, 2008; Woodside, 2013). Qualitative comparative analysis is applicable not only to small-N studies but also to large-N research (Ragin, 2008). Its set-theoretic approach can handle complex causality in large datasets, complementing traditional statistical methods (Greckhamer et al., 2008). The combination of these two analytical approaches provides a comprehensive examination of the factors influencing OCP recycling IN, offering both a variable-oriented perspective through PLS-SEM and a case-oriented, configurational perspective through fs-QCA.

2.4. Research output

Regarding current cell phone usage and disposal, as shown in ***Table 2***, most of the respondents replace their cell phones every 2-3 years (47.50%), while 21.10% of the participants did so every 3-4 years. The primary disposal of replaced cell phones is keeping them at home (46.38%), suggesting the potential accumulation of OCP. To date, more than 85% of the respondents have retained their OCPs. Recycling practices are significantly influenced by PC (ACS 3.84) and dissatisfaction with recycling compensation (ACS 3.43), which poses major barriers to OCP recycling participation. Fig. 4 displays a word cloud visualization of the reasons for not recycling OCP (by frequency). For details, see ***Table 3***.

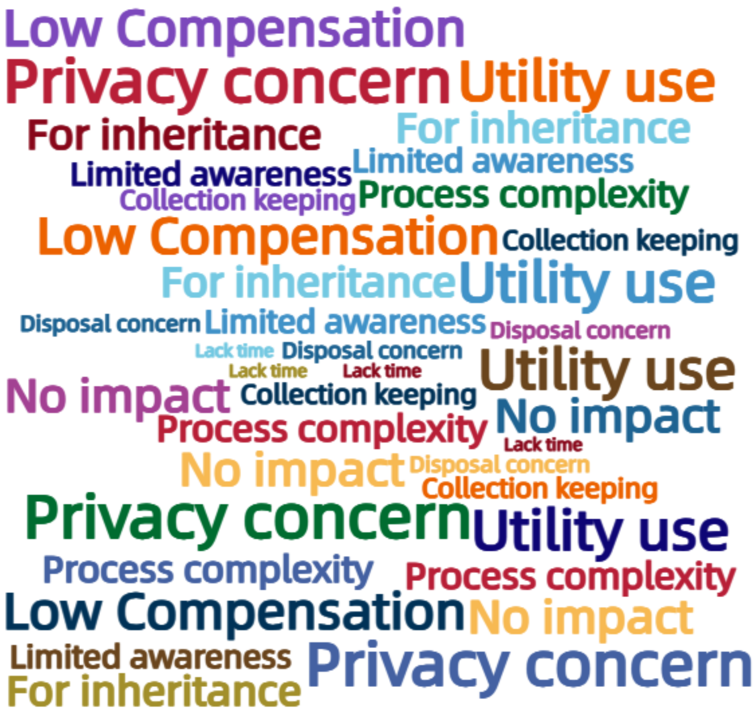


Fig. 4 Main reasons for not recycling OCP

Table 2 Usage/disposal of cell phone.

Title	Item	Respondents	Percentage
Frequency of cell phone replacement (Year)	0-1	5	0.81%
	1-2	126	20.29%
	2-3	295	47.50%
	3-4	131	21.10%
	>4	29	4.67%
	Not sure	35	5.64%
Main disposal methods for OCP	Keep it at home	288	46.38%
	Give it to someone	77	12.40%
	Sell/Exchange	108	17.39%
	Recycle	141	22.71%
	Donate it to charity	5	0.81%
	Dispose of it as waste	2	0.32%
Retention of OCP	Yes	526	85.11%
	No	92	14.89%

Table 3 Main reasons for not recycling OCP.

Title	Item	Respondents	Percentage	ACS
*Main reasons for not recycling OCP (maximum selection of 5 items) (related to retention query, n=526)	Privacy concern (Privacy concern)	425	80.80%	3.84
	Backup or utility use (Utility use)	402	76.43%	3.66
	Dissatisfaction with recycling compensation (Low Compensation)	263	50.00%	3.43
	Retention without impacting daily life (No impact)	262	49.81%	3.06
	Retained for future inheritance (For inheritance)	195	37.07%	3.41
	Perceived complexity of the recycling process (Process complexity)	188	35.74%	3.06
	Limited awareness of OCP's recycling value (Limited awareness)	161	30.61%	3.21
	Personal collection keeping (Collection keeping)	146	27.76%	3.00
	Non-compliant (Disposal concern)	132	25.10%	2.76
	Lack of time (Lack time)	56	10.65%	2.79

Legend: Questions marked with underscores allow multiple responses, while those with asterisks require participants to rank their choices according to perceived importance. Average Composite Score (ACS) of options = (Σ Frequency × Rank Value) / total completion rate of the question.

2.4.1. Results of cell phone recycling preferences

In the context of cell phone recycling preferences, respondents prioritized data safety (ACS 3.98). Subsequently, economic incentives emerged as a significant secondary motivator (ACS 3.12). This trend indicates that improving economic incentives and strengthening data safety guarantees are essential to engage consumers in cell phone recycling initiatives. More than 85% of the participants preferred compensation by cash or transfers, highlighting a strong preference for direct financial methods. Among cell phone recycling service providers, enterprises are the most trusted, followed by government and telecom and welfare organizations, which are also deemed reliable. The home pickup service is notably favored for its convenience, reflecting the consumer’s preference for simplicity in the cell phone recycling process. More than 97% of the respondents required data safety assurance when participating in cell phone recycling. For details, refer to ***Table 4***.

Table 4 Usage/disposal of cell phone.

Title	Item	Respondents	Percentage	ACS
*Factors that influence cell phone recycling participation (ranking all items)	Security of handling residual data within recycling	621	100%	3.98
	Economic compensation from recycling	621	100%	3.12
	Post-recycling processing methods	621	100%	2.96
	Identity of recycling service operator	621	100%	2.89
	Collecting methods of cell phone recycling	621	100%	2.28
Preferences for compensation methods	Cash/Transfer	531	85.51%	
	Daily necessities/goods	13	2.09%	
	Discount on purchasing new devices	77	12.40%	
*Preferences for cell phone recycling service providers (limited to four items)	Retail repair and recycling enterprises	593	95.49%	2.88
	Government entities	498	80.19%	2.80
	Telecommunication service entities	529	85.19%	2.45
	Social welfare entities	520	83.74%	2.40
	Personal retail repair and recycling businesses	206	33.17%	1.96
*Preferences for collecting methods	Home pickup	396	63.77%	
	Mailing (Free shipping)	132	21.26%	
	Drop-off by self (Nearby)	93	14.98%	
Demand for data safety assurance	Yes	606	97.58%	
	Indifferent	13	2.09%	
	No	2	0.32%	

Legend: Questions marked with underscores allow multiple responses, while those with asterisks require participants to rank their choices according to perceived importance. Average Composite Score (ACS) of options = (Σ Frequency × Rank Value) / total completion rate of the question.

2.4.2. Results of cell phone recycling preferences

2.4.2.1. Assessment of the measurement model

Following the two-step approach recommended by Anderson and Gerbing (1988), we first assessed the measurement model to ensure reliability and validity, followed by an evaluation of the structural model to test the hypothesized relationships.

Reflective measurement is applied to all six constructs to assess their internal consistency reliability and convergent validity (Hair et al., 2019). As shown in ***Table 5***, the factor loadings for each item exceeded the standard threshold of 0.6, demonstrating the reliability of the model. Composite reliability (CR) and the Cronbach's alpha for all constructs exceeded the accepted standard of 0.70, confirming the absence of convergence validity problems with the scales used in the study.

To assess discriminant validity, the average variance extracted (AVE) for each construct exceeded the standard threshold of 0.5. Two methods were employed: the Fornell–Larcker criterion and the heterotrait–monotrait (HTMT) ratio (Henseler et al., 2015). The square root of the AVE (diagonal entries) exceeds the corresponding values of the rows and columns, and all HTMT ratios are below the recommended threshold of 0.85. The results, detailed in ***Table 6***, confirm good discriminant validity for subsequent analytical procedures.

Table 5 Measurement model.

Constructs	Items	Mean	S.D.	VIF	Loadings	Cronbach's alpha	rho a	CR	AVE
ATT	ATT1	4.03	0.813	1.614	0.912	0.763	0.772	0.894	0.808
	ATT2	4.08	0.876	1.614	0.885				
PBC	PBC1	3.65	0.983	2.048	0.875	0.855	0.860	0.912	0.775
	PBC2	3.69	1.005	2.315	0.882				
	PBC3	3.70	1.079	2.068	0.883				
SN	SN1	3.43	1.042	1.523	0.849	0.768	0.786	0.865	0.681
	SN2	3.63	1.078	1.547	0.786				
	SN3	3.66	1.001	1.656	0.839				
OA	OA1	4.06	0.940	1.765	0.860	0.813	0.847	0.887	0.724
	OA2	3.97	0.949	1.778	0.806				
	OA3	4.05	0.918	1.827	0.884				
PC	PC1	4.14	1.033	2.314	0.941	0.859	0.863	0.934	0.877
	PC2	4.14	1.032	2.314	0.931				
IN	IN1	3.72	1.041	2.058	0.931	0.835	0.837	0.924	0.858
	IN2	3.69	1.059	2.058	0.922				

Table 6 Discriminant validity (Fornell-Larckers criterion and HTMT ratio).

	ATT	IN	OA	PBC	PC	SN
ATT	**0.899**					
IN	0.606 (0.755)	**0.926**				
OA	-0.078 (0.090)	-0.196 (0.230)	**0.851**			
PBC	0.266 (0.327)	0.358 (0.421)	0.024 (0.037)	**0.88**		
PC	-0.177 (0.218)	-0.269 (0.316)	0.262 (0.313)	-0.283 (0.328)	**0.936**	
SN	0.437 (0.555)	0.579 (0.711)	0.020 (0.059)	0.347 (0.421)	-0.191 (0.230)	**0.825**

2.4.2.2. Examination of Common Method Bias (CMB)

Recognizing the potential for CMB due to self-reports (Podsakoff et al., 2003), this study used a full collinearity assessment (Kock and Lynn, 2012) and Harman's (1976) single factor tests to assess CMB.

All variation inflation factor (VIF) values remained below the threshold of 3.3. Furthermore, the Harman single factor test, conducted using SPSS, indicated that the highest variance explained by a single factor was only 31.12%, significantly below the

50% threshold. Taken together, these findings suggest that CMB did not pose a significant issue in this study.

2.4.2.3. One-way analysis of variance (ANOVA) of demographic variables

To determine the appropriate demographic variables to include as controls in our structural equation model, as well as to visualize differences in OCP recycling IN under different demographic attribute subgroups, this study conducted one-way ANOVA to assess the potential influence of demographic variables on IN. This approach aligns with recommended practices in SEM research, which stipulates that the inclusion of control variables should be empirically justified (Becker, 2005; Carlson and Wu, 2012; Williams et al., 2009).

The ANOVA results (presented in Table 7) delineate the demographic factors that exhibited statistically significant relationships with IN. The incorporation of only relevant factors into the PLS-SEM analysis aims to enhance the model's explanatory power while mitigating the risk of including extraneous variables that could potentially confound the results or diminish statistical power (Bernerth and Aguinis, 2016). Based on the ANOVA results, this study selected age, education, and monthly income that showed significant effects ($p<0.05$) on IN for inclusion as control variables in the PLS-SEM analysis.

Table 7 One-way ANOVA of demographic variables.

Demographic variables		IN	F
Region	Eastern	3.74±0.99	0.386
	Central	3.68±0.93	
	Western	3.65±0.97	
Gender	Female	3.65±0.98	3.434
	Male	3.79±0.96	
Age	≤20	2.96±1.25	3.717**
	21-30	3.62±0.93	
	31-40	3.81±0.96	
	41-50	3.76±1.05	
	51-60	3.54±1.01	
	>60	1.50±null	
Education	Secondary Education	4.11±0.61	4.254**
	Vocational Education	3.27±1.09	
	Undergraduate Education	3.74±0.96	
	Graduate Education	3.64±1.01	
Profession	Student	3.41±0.93	2.411
	Self-employed	3.91±0.93	
	Employed	3.72±0.97	
	Retired/Unemployed	2.75±1.77	
Monthly income (CNY)	≤2000	3.54±1.07	2.319*
	2,001-4,000	3.37±0.89	
	4,001-6,000	3.53±0.97	
	6,001-8,000	3.65±1.03	
	8,001-10,000	3.82±0.96	
	10,001-12,000	3.93±0.91	
	12,000-14,000	3.83±0.97	
	>14,000	3.71±0.89	

* $p<0.05$ ** $p<0.01$

2.4.2.4. Assessment of the structural model

Following the guidelines of Hair Jr et al. (2021), the validity of the structural model is confirmed using path coefficients and R^2, F^2, and Q^2 values. The R^2 for IN (0.536) exceeds Cohen's (1988) substantial threshold of 0.26, indicating strong explanatory power. Furthermore, the R^2 values for ATT and PBC are 0.031 and 0.080, respectively, both exceeding the weak effect benchmark of 0.02. All constructs show positive R^2 values, which confirms the model's predictive relevance. ATT emerges as a particularly influential predictor of IN, exhibiting the highest F^2 value of 0.259. All constructs show positive Q^2 values above zero, with IN, ATT, and PBC values of 0.450, 0.024, and 0.060, respectively, indicating significant predictive relevance. These findings support the robustness of the model's predictive capacity. Using the Hair Jr et al.'s (2021) bootstrap method with 5,000 subsamples, significant results were found: ATT ($\beta = 0.394$), PBC ($\beta = 0.117$), and SN ($\beta = 0.360$) positively affect IN, confirming hypotheses H1, H2, and H3, respectively. PC negatively affects ATT ($\beta = -0.177$) and PBC ($\beta = -0.283$), supporting H4 and H5, but does not affect IN, rejecting H6. OA negatively affects IN ($\beta = -0.161$), affirming H7.

Control variables (age, monthly income, and education) did not show significant relationships with IN ($p > 0.05$), which potentially reflect the unique nature of cell phone recycling behavior, consistent with previous research. Unlike larger durable goods, cell phone recycling decisions appear to be more influenced by awareness factors than demographic characteristics (Nduneseokwu et al., 2017; Z. Wang et al., 2016). The results of the structure model are depicted in ***Fig. 5***. Detailed results are provided in ***Table 8***. Evaluation of mediating effects, as shown in ***Table 9***, confirms that PC's effect on IN through ATT ($\beta = -0.070$) and PBC ($\beta = -0.033$) are significant, supporting H4m and H5m.

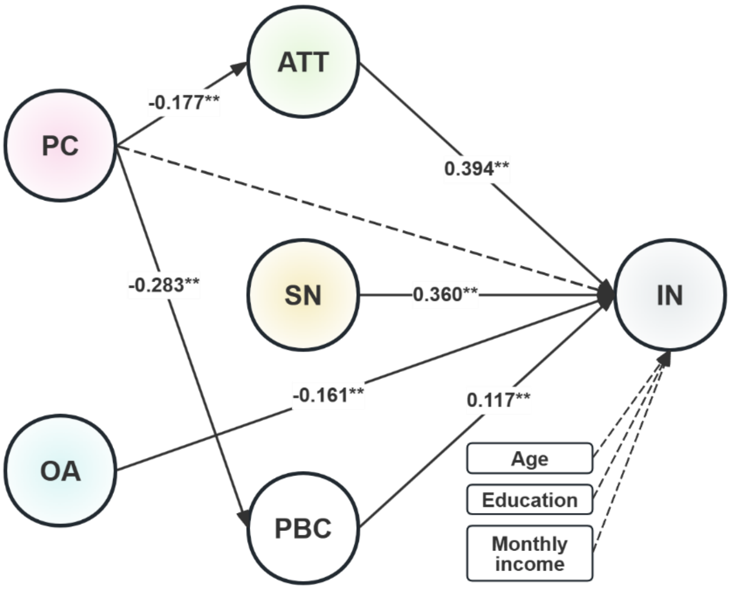


Fig. 5 Results of the structural model in PLS-SEM

Table 8 Results of the structural model.

Path	Path coefficients(β)	t. value	CI: [Low / Up]	R^2	F^2	Q^2	Decision
H1. ATT -> IN	0.394**	10.508	0.320 / 0.465	0.536	0.259	0.45	Supported
H2. PBC -> IN	0.117**	3.334	0.049 / 0.189		0.024		Supported
H3. SN -> IN	0.360**	9.827	0.361 / 0.431		0.204		Supported
H4. PC -> ATT	-0.177**	5.585	-0.237/ -0.113	0.031	0.032	0.024	Supported
H5. PC -> PBC	-0.283**	8.881	-0.284/ -0.344	0.080	0.087	0.060	Supported
H6. PC -> IN	-0.055	1.931	*-0.110/ 0.003*		0.005		*Not Supported*
H7. OA -> IN	-0.161**	5.677	-0.218/ -0.108		0.050		Supported
Age -> IN	-0.004	0.129	*-0.066/ 0.058*		0.000		*Not Supported*
Education -> IN	0.012	0.443	*-0.040/ -0.069*		0.000		*Not Supported*
Monthly income -> IN	0.001	0.017	*-0.063/ 0.063*		0.000		*Not Supported*

* p<0.05 ** p<0.01

Table 9 Assessment of mediating effect.

Path	Path coefficients(β)	t. value	CI: [Low / Up]	Decision
H4m. PC -> ATT -> IN	-0.070**	4.812	-0.099/ -0.042	Supported
H5m. PC -> PBC -> IN	-0.033**	3.051	-0.057/ -0.014	Supported

* p<0.05 ** p<0.01

2.4.3. Results of fs-QCA

2.4.3.1. Analysis of necessary conditions

Following the procedural guidelines established by Ragin et al. (2008), we initially converted ordinal data from Likert scales into fuzzy sets. This conversion involved assigning calibrated scores to represent commonly accepted thresholds for full membership (95%), maximum ambiguity (50%), and full non-membership (5%), as suggested by Ragin et al. (2008). After calibration, we constructed a truth table to capture all possible permutations of the causal conditions.

Before performing fs-QCA for configurational analysis, this study conducted a necessity analysis to determine whether any conditions are essential for high IN. Table 10 shows that the consistency scores of all variables below 0.9 indicate the absence of the necessary conditions for a high IN among the antecedent variables. This also indicates that IN is influenced by multiple interdependent factors.

Table 10 Analysis of necessary conditions.

Conditions tested	Consistency	Coverage
FATT	0.878	0.735
~FATT	0.438	0.515
FPBC	0.754	0.731
~FPBC	0.538	0.531
FSN	0.814	0.745
~FSN	0.474	0.497
FOA	0.605	0.602
~FOA	0.713	0.685
FPC	0.632	0.580
~FPC	0.680	0.712

Legend:"~" means that the condition does not exist.

2.4.3.2. Analysis of sufficient configurations

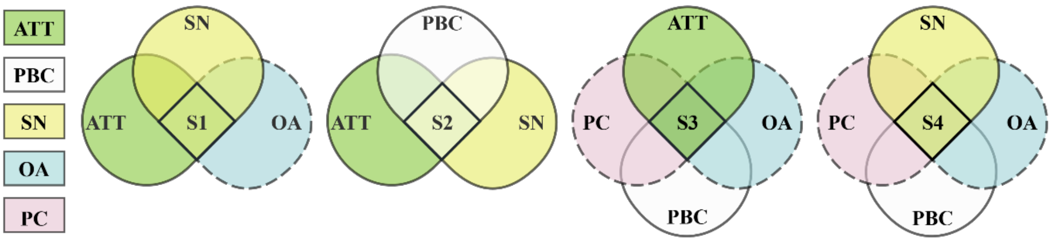
Using *fsQCA 4.1* software, the study examined the conditions that lead to high IN. The analysis used a case frequency threshold of 3. The raw consistency was established at 0.8, with a proportional reduction in inconsistency (PRI) of 0.65 (Greckhamer and Gur, 2021; Gupta et al., 2020).

The data set includes all possible combinations of five conditions, eliminating any logically redundant prime implicants. Consequently, the complex, parsimonious, and intermediate solutions were identical. The coverage of the solution is 0.766, indicating that the configurations represent a substantial proportion of high IN instances. The consistency of the solutions is 0.861, which shows a high reliability in all configurations to explain the outcome. The configurations are shown in ***Table 11*** (Initial section), where ~FOA* FATT* FSN, FATT* FSN* FPBC, ~FOA* ~FPC* FATT* FPBC, and ~FOA* ~FPC* FPBC* FSN ("~" indicates the absence of conditions) leading to high IN. The visualization of all initial solutions is shown in ***Fig. 6.*** Solution S1, which involves the absence of OA and the presence of ATT and SN, led to high IN concentrations. Solution S2 is similar to TPB, with positive SN, PBC, and ATT leading to high IN. Solutions S3 and S4 indicate that high IN can also result from the absence of PC and OA, combined with the presence of PBC & ATT or PBC & SN.

Table 11 Analysis of necessary conditions.

Conditions	(Initial) Solutions				(Robustness) Solutions			
	S1	S2	S3	S4	R1	R2	R3	R4
Object Attachment	○		○	○	○	○		○
Privacy Concern			○	○				○
Attitude	●	●	●		●	●	●	
Subjective Norm	●	●		●		●	●	●
Perceived Behavioral Control		●	●	●	●		●	●
Consistency	0.901	0.906	0.928	0.933	0.887	0.854	0.881	0.906
Raw coverage	0.560	0.617	0.454	0.433	0.416	0.448	0.514	0.337
Unique coverage	0.089	0.146	0.041	0.019	0.078	0.109	0.176	0.030
Solution consistency	0.861				0.820			
Solution coverage	0.766				0.731			

Legend: '●' Indicate the presence of causal conditions. '○'indicate the absence or negation of



***Legend**: The solid line implies the presence of conditions in the solution, and the dotted line implies the absence of conditions in the solution.*

Fig. 6 Configurations for high OCP recycling IN

2.4.3.3. Robustness test of configurations

To ensure the reliability of our findings, we adhered to the robustness testing protocol recommended by Schneider and Wagemann (2012), applying revised calibration thresholds of 75% for full inclusion and 25% for full exclusion with a PRI of 0.65, to reassess the configurations. No differences were observed between S1/S2/S4 and R2/R3/R4. However, a marked difference was observed between S3 and R1, as evidenced by the absence of PC occurring only once. The results of the robustness test are detailed in ***Table 11*** (Robustness section).

2.5. Discussion of findings

2.5.1. Cell phone usage and disposal of OCP

Cell phone usage and disposal reveal several key trends that indicate that the average lifespan of cell phones among Chinese consumers is typically less than three years, confirming the findings of previous studies (Bai et al., 2018; Liu et al., 2019), highlighting a short in-use life. This finding reinforces the concept of a ‘throwaway culture’ in modern consumer electronics, significantly impacting waste accumulation and resource efficiency (Wijetunga, 2020). After replacement, most consumers keep their OCPs at home, this behavior contributes to the increase in OCP accumulation, undermining efforts to recover valuable materials. High frequency and ACS of PC suggest that protection of privacy is paramount, potentially overriding other considerations such as environmental awareness or economic incentives. Dissatisfaction with recycling compensation, indicating a misalignment between consumer expectations and current reward systems. Furthermore, the preference for retaining OCPs as backups or for utility use aligns with the findings of Nowakowski (2019) and Wilson et al. (2017). Moreover, keeping OCP as a personal collection introduces a novel aspect that relates to the factor ‘OA’. Reasons such as ‘retention without impacting daily life’ and ‘limited awareness of OCP recycling value’ highlight a gap in consumer awareness of environmental impacts.

2.5.2. Preferences for cell phone recycling

Consumer preferences for cell phone recycling also underscore the critical role of the PC. Mishima and Nishimura (2016) assert that data safety significantly influences consumers' decisions to recycle their devices. Given the consumer demand for enhanced services, our study examined the consumer demand for data safety guarantees within recycling services. This approach contrasts with the separate data safety insurance service model mentioned by Qu et al. (2019). A significant 97.58% of the participants favored the integrated feature, suggesting that service providers should treat data safety not as an ancillary offering, but as a fundamental responsibility. The respondents' substantial interest of economic compensation suggests that adequate compensation can significantly motivate consumer participation in OCP recycling. Interestingly, consumers are interested in the post-recycling processes of recycled OCP, which may reflect a combination of PC, OA and environmental awareness. This multifaceted interest suggests that transparent and engaging communication about the recycling process could be an effective strategy to foster recycling efforts.

As a compensation method, cash/transfer is strongly preferred, reinforcing the notion that direct financial rewards significantly influence consumer OCP recycling participation (Qu et al., 2019). Furthermore, the preference of 12.40% for discounts on the purchase of new devices suggests that retailers and manufacturers could effectively promote OCP recycling through discount programs. In selecting recycling service providers, consumers prefer non-personal operators, which likely arises from the perceived risk of privacy breaches through informal collection channels or unauthorized resale (Tan et al., 2018). Finally, the strong preference of 63.77% for convenient home pickup services highlights the importance of ease and accessibility in cell phone recycling programs. Although fewer than 15% of the respondents preferred mailing or drop-off methods, the results also indicate that multiple collection methods should be available to accommodate diverse consumer preferences.

2.5.3. *Insights from PLS-SEM & fs-QCA*

According to the PLS-SEM analysis, ATT is the strongest predictor of IN, aligning with the findings of Aboelmaged (2021) and Wang et al. (2018), which emphasizes the importance of having positive beliefs and evaluations regarding OCP recycling. SN, expressed as social pressures and expectations of others, significantly impact consumer OCP recycling IN, confirming findings from Li et al. (2018) and Wang et al. (2016). However, Chang and Hung (2023) and Park and Lin (2020) reported that although SN significantly increases IN, it does not necessarily translate into actual recycling behavior. This suggests that SN should not be the primary focus when managing OCP recycling. PBC, reflecting the ease and feasibility of recycling, positively influences IN, although to a lesser extent than ATT and SN, which diverges from the findings of Berki-Kiss and Menrad (2022). This does not imply that consumer self-efficacy is irrelevant in shaping the recycling IN for OCPs. It remains imperative to improve consumer knowledge and awareness of OCP recycling benefits and to simplify the recycling process to improve its ease and feasibility (H1-H3).

OA exerts a more direct and pronounced negative impact on IN than PBC, highlighting the significant barrier posed by the sentimental value of OCP (H7). This finding aligns with previous research by Welfens et al. (2013, 2016), who suggested that strong emotional ties to objects can override cognitive assessments of recycling. However, Mulet et al. (2022) reported that OA reduces the frequency of product replacement, potentially extending the useful life of small household electrical appliances. This duality underscores the complexity of OA, revealing its varied environmental impacts in different contexts. How can consumers mitigate the negative effects of OA when encouraged to recycle their OCPs? The study by Dommer and Winterich (2021) indicated the following 3 keys. First, the digital transformation of memories (such as photos): consumers can retain access to their cherished memories without the physical object. Second, promote altruistic actions (such as donation and gifting): the altruistic satisfaction gained from helping others can help consumers relieve the feeling of loss from disposing of objects. Third, ensuring proper post-disposal: consumers with a strong attachment to their products often care deeply about their fate after disposal. Providing consumers with the assurance that their recycled products will be treated with care and used beneficially can alleviate the feelings of loss associated with the disposal of objects. Addressing these needs poses many challenges to the current management of OCP recycling in China. Furthermore, the fourth key factor is that OA can lead to an endowment effect, where consumers value their possessions more highly simply because they own them (Chatterjee et al., 2013; Kogut and Kogut, 2011). These findings suggest that improved compensation, transparent and compliant disposal processes, or the use of advanced technologies to address collection needs in the OCP recycling process could alleviate feelings of loss associated with OA, thus increasing the consumer's willingness to recycle OCP.

PC, another emotional factor in extension model, does not directly affect recycling IN (H6), consistent with the previous findings of Lyu et al. (2023). In this study, PC negatively influenced ATT and PBC (H4, H5), which subsequently indirectly affected IN through ATT and PBC (H4m, H5m). This finding suggests that PC can subtly undermine IN by influencing people's perceptions of the recycling process and their confidence in participating. Although the path coefficient for PC is not exceptionally high, the mechanism through which it influences consumer decision making in OCP recycling highlights the critical importance of maintaining privacy security during cell phone recycling. Zhang et al. (2021) noted that consumer trust in formal recycling channels can ensure data safety. This perception underscores that policies must prioritize the establishment of stringent data safety measures, especially within informal recycling sectors. By ensuring that consumer privacy is protected through both formal and informal cell phone recycling processes, receptiveness to OCP recycling initiatives is likely to improve.

The fs-QCA results reveal multiple pathways leading to high OCP recycling IN, complementing and extending the PLS-SEM findings. Four main solutions emerged from the initial solutions, each offering unique insights into the complex interplay of factors influencing OCP recycling IN. Solution S1 indicates that the presence of ATT and SN, combined with the absence of OA, leads to high IN. This suggests that positive ATT towards recycling and SN, coupled with low OA to the OCP, create a favorable condition for recycling IN. Solution S2 presents a more comprehensive pathway, where ATT, SN, and PBC are all present. This configuration aligns closely with the TPB, emphasizing the importance of these three key factors in driving recycling intentions. Interestingly, Solution S3 introduces PC as a relevant factor. Here, the presence of ATT and PBC, combined with the absence of OA and PC, leads to high IN. This configuration suggests that when individuals have low PC, they may be more inclined to recycle if they also have positive ATT, feel capable of recycling, and have low attachment to the product. In solution S4, SN and PBC are present, while OA and PC are absent. This pathway indicates that SN and PBC can drive recycling IN even in the absence of strong ATT, as long as OA and PC are low. Robustness solutions (R1-R4) largely confirm these patterns. Despite its less frequent appearance in the fs-QCA robustness results which may echo the fact that it as an indirect influence factor of IN in PLS-SEM. But it is undeniable that PC remains a significant influence factor of OCP recycling IN. Abbreviately, fs-QCA reveals how TPB factors interact with OA and PC to create multiple pathways to high recycling IN. These findings highlight the complex roles of OA and PC as emotional factors in OCP recycling decisions and underscores the significance of such factors in the study of pro-environmental behaviors (Beery and Wolf-Watz, 2014; Berki-Kiss and Menrad, 2022; Lam et al., 2022).

Milestone 2. Digital Transformation of Obsolete Cell Phone Recycling Management System Based on Blockchain Featuring the NFT Incentive Mechanism

3.1. Research background and objectives

Recent advancements in digital technologies have created novel opportunities for enhancing management strategies. The ongoing digital transformation, characterized by the integration of big data, artificial intelligence (AI), Internet of Things (IoT), digital twins, and blockchain, is revolutionizing diverse industries (Kraus et al., 2022). These technologies have the potential to enhance production efficiency, improve process safety, optimize resource recovery, and reshape business strategies (Abiodun et al., 2023; Calderon-Monge and Ribeiro-Soriano, 2024; Yaqub and Alsabban, 2023; J. Zhang et al., 2023). Among these technologies, blockchain has emerged as a particularly potent tool for resource management and supply chain traceability, leveraging its core attributes of decentralization, transparency, and immutability (Zhang et al., 2024), which also holds promise for optimizing OCP recycling management systems (OCP RMS).

The efficacy of any recycling system is fundamentally contingent on consumer engagement. Our previous research (Du et al., 2024) has demonstrated that consumers' attitudes (ATT), perceived behavioral control (PCB), subjective norms (SN), and privacy concerns (PC) regarding OCP recycling, in conjunction with their object attachment (OA) to OCPs, significantly influence their recycling intention (IN) and behavior. Furthermore, well-designed incentive mechanisms play a pivotal role in fostering participation in electronic waste recycling initiatives (Wang et al., 2021). To address these behavioral factors, this study investigates innovative incentive approaches, particularly Non-Fungible Tokens (NFTs), as a potential strategy to enhance consumer interest in OCP recycling. NFTs, which function as blockchain-verified digital certificates of ownership for unique assets, have garnered substantial attention across diverse markets, including art, collectibles, and gaming (Ante et al., 2023; Chalmers et al., 2022; Yilmaz et al., 2023). The decentralized nature of blockchain technology underpinning NFTs ensures the provenance and authenticity of each asset without requiring a centralized authority (Wu et al., 2023). The unique attributes of NFTs, particularly their capacity to represent ownership of both digital and physical assets, present novel opportunities for preserving the sentimental value of physical OCPs while potentially stimulating consumer interest in recycling. This approach offers the recycling sector an opportunity to enhance its innovative image and engage in indirect economic activities (Bao and Roubaud, 2022; Bellagarda and Abu-Mahfouz, 2022; Król and Zdonek, 2023). Thus, the integration of NFTs into recycling programs may create a mutually beneficial scenario, incentivizing both consumers and businesses to engage in recycling efforts, thereby potentially enhancing OCP recycling management.

Despite the demonstrated potential of digital technologies in resource management, systematic research on effectively combining blockchain and NFT technologies for OCP recycling management remains limited. This study aims to address this research gap by designing and evaluating a blockchain-based OCP RMS, thereby translating theoretical insights into a concrete proposal. The study seeks to answer the following key questions: 1. How to design OCP RMS framework based on blockchain and NFT technologies? 2. What are the potential opportunities and challenges of digital transformation in OCP RMS, and how can development strategies be formulated to address them? 3. What is the level of consumer acceptance for this novel recycling system, and what factors influence this acceptance? 4. How effective are NFTs as an incentive mechanism in the OCP recycling market? To address these questions, the study employ a multi-method approach: (1) Design Science Research (DSR) to construct an innovative recycling system framework; (2) Strengths, Weaknesses, Opportunities, Threats (SWOT)-Analytic Hierarchy Process (AHP) analysis to evaluate the feasibility and strategic priorities of digital transformation in OCP RMS; and (3) Contingent Valuation Method (CVM) to explore consumer acceptance and market potential of the blockchain-based OCP RMS characterized by novel NFT-based recycling incentives. The structure of this paper is organized as follows: Section 2 reviews relevant literature as background. Section 3 introduces research methods. Section 4 presents the framework design and empirical analysis results. Section 5 discusses the research findings and implications. Section 6 summarizes the results and limitations.

3.2. Related work

To lay the groundwork for this study, we present the challenges and opportunities in OCP recycling through briefly reviewing relevant prior research as follows.

3.2.1. Sustainability of OCP recycling

The sustainability of OCP recycling is a multifaceted issue that intertwines environmental, economic, and social dimensions, reflecting the holistic nature of sustainability challenges in contemporary waste management. The concentration of toxic components in mobile devices has escalated in recent years, exacerbating environmental and health concerns (Singh et al., 2019). The production of cell phones involves substantial resource extraction, resulting in an "ecological rucksack" of approximately 75 kg of resources per device (Welfens et al., 2016). Consequently, non-recycled OCPs contribute significantly to resource depletion and environmental degradation. Moreover, informal recycling frequently occurs outside regulated frameworks, resulting in hazardous practices that potentially harm both human health and the environment (Chi et al., 2011; Li et al., 2017). Stakeholders, particularly regulators, face significant challenges in tracking the lifecycle information of cell phones and ensuring compliance with environmental regulations. Consequently, the transition from informal practices to well-regulated operations remains a critical challenge.

Consumer behavior plays an important role in the effectiveness of OCP recycling efforts. Research (Prabhu N and Majhi, 2023; Welfens et al., 2016) indicates that many individuals tend to retain OCPs rather than recycle them, often due to insufficient awareness and acceptance of recycling programs. This phenomenon, termed "hibernation," reflects a broader challenge in promoting sustainable disposal practices among consumers (Inghels and Bahlmann, 2021). From an economic perspective, the implementation of subsidies and tax incentives has demonstrated a positive influence on recycling rates by enhancing the financial attractiveness of the process for consumers (Wang et al., 2021, 2022). Furthermore, the establishment of comprehensive industrial chains for processing OCPs in various countries has illustrated the potential for economic benefits through recycling, encompassing resource recovery and job creation (Li et al., 2017).

Policies mandating the collection and recycling of electronic devices are also crucial for establishing structured approaches to managing obsolete devices (Kumar et al., 2017). Extended Producer Responsibility (EPR) policies, which require manufacturers to take responsibility for the entire lifecycle of their products, including post-consumer waste, have been implemented in various regions to encourage recycling (Wang et al., 2011). However, the effectiveness of these policies also depends on consumer compliance and the availability of accessible recycling channels (Wang et al., 2017). In China, the lack of well-designed formal collection systems and the prevalence of informal recycling practices pose significant barriers to effective e-waste management (Tan et al., 2018). Enhancing the infrastructure for e-waste collection is posited to yield improved outcomes (Cao et al., 2018; Y. Zhang et al., 2019).

3.2.2. Blockchain-based digital transformation in management practices

Digital transformation is fundamentally reshaping management paradigms. A significant consequence of digital transformation is the advent of blockchain technology, which is revolutionizing supply chain management. Blockchain technology offers a decentralized and transparent ledger system that enhances traceability and accountability in supply chains, thereby mitigating issues related to trust and security (Saberi et al., 2019; Treiblmaier, 2018; Y. Wang et al., 2019). The integration of blockchain technology into waste management systems has demonstrated considerable potential.

Blockchain technology facilitates real-time tracking of waste from generation to disposal, ensuring that all stakeholders, including consumers, waste management entities, and regulatory bodies, have access to reliable data regarding waste handling processes (Bułkowska et al., 2023; Gopalakrishnan et al., 2021; Jiang et al., 2023). For instance, smart contracts can automate transactions and compliance checks, reducing delays and conflicts that often arise in waste management processes (Wahab et al., 2023). By leveraging blockchain technology, waste management entities can establish a transparent and immutable record of waste transactions, facilitating regulatory enforcement and ensuring proper waste processing (Bułkowska et al., 2023; Scott et al., 2023). Moreover, the potential of blockchain technology to facilitate a circular economy is particularly significant. Castiglione et al. (2023) propose a framework that leverages blockchain technology to achieve a circular economy within sustainable waste management systems. These innovations not only enhance waste management practices but also contribute substantially to broader sustainability objectives. Gopalakrishnan et al. (2021) conducted a cost analysis of a blockchain-based solid waste management traceability system, revealing that such systems can optimize costs while streamline solid waste management. This economic viability is crucial for encouraging the adoption of blockchain in waste management. Despite the promising benefits, Jiang et al. (2023) identify several barriers to the widespread adoption of blockchain technology, such as system errors, insufficient practices and data safety challenges. By addressing key challenges and leveraging the potential of blockchain, stakeholders can improve waste management practices and contribute to a more sustainable future.

3.2.3. OCP retention tendency and NFT collection

While economic compensation addresses the physic asset perspective of OCPs, consumer retention is also influenced by various psychological and behavioral factors, complicating effective electronic waste management (Prabhu N and Majhi, 2023). The divestment concept proposed by Poppelaars et al. (2020) offers a framework for understanding consumer separation from products, emphasizing both physical and psycho-emotional aspects of this process. Recent research suggests that individuals frequently develop strong emotional attachments to their cell phone devices, viewing them as extensions of their identity and personal history (Du et al., 2024; Lou et al., 2022). These implications can result in consumers retaining OCPs longer than necessary, either by incorporating them into personal collections or allowing them to "hibernate" at home.

An NFT is defined as "a unique digital identifier that cannot be copied, substituted, or subdivided, that is recorded in a blockchain, and that is used to certify authenticity and ownership (as of a specific digital asset and specific rights relating to it)" (Merriam-Webster dictionary, 2023). This technology ensures the authenticity and provenance of digital items, making it particularly appealing to collectors and investors (Wu et al., 2023; Wu and Liu, 2023). Collectors frequently seek to acquire NFTs both for their intrinsic value and for the status they confer within social circles (Ante et al., 2023). This aligns with findings in behavioral psychology, indicating that emotional connections to objects significantly influence purchasing decisions and collecting behaviors (Yap et al., 2020). For instance, NFTs encourage consumer participation by offering unique experiences and rewards. Brands such as Louis Vuitton, Gucci, and Coca-Cola use NFTs to engage consumers through interactive games or exclusive digital collectibles, enhancing brand loyalty and consumer engagement (Taylor, 2023). In China, the rapid digital transformation and increasing interest in innovative technologies have created fertile ground for the adoption of NFTs (He et al., 2022). In the OCP recycling sector, the innovative use of NFTs in sustainable practices has the potential to enhance companies' images by demonstrating their commitment to transparency, collaboration, and environmental responsibility (Compagnucci et al., 2024).

3.3. Methodology

This study employs a multi-faceted methodology to explore the design, feasibility, and development strategies for the digital transformation of OCP RMS.

DSR serves as the foundational methodological framework for this study, given its capacity to address complex socio-technical challenges and generate innovative solutions (Gregor and Hevner, 2013; Hevner et al., 2004). The digital transformation of OCP RMS inherently involves intricate interactions between technological innovation, environmental sustainability, and economic viability. DSR's holistic approach allows for a nuanced exploration of these interconnected elements. Moreover, DSR's emphasis on bidirectional interaction between theory and practice (Peffers et al., 2007; Sein et al., 2011) aligns with our objective of developing an academically rigorous and practically implementable sustainable digital OCP RMS.

To formulate strategic development recommendations for digital transformation, this study combines SWOT analysis with AHP. SWOT analysis provides a comprehensive assessment of internal strengths and weaknesses and external opportunities and threats (Gürel, 2017; Helms and Nixon, 2010), while AHP offers a systematic method for quantifying expert judgments and prioritizing strategies (Mu and Pereyra-Rojas, 2016; Saaty, 2008). The main advantages of combining SWOT with AHP include overcoming the limitations of traditional SWOT analysis in quantitative assessment and providing more precise strategic priorities (Kurttila et al., 2000). This combination also allows for effectively integrating opinions from multiple experts, thereby enhancing the scientific rigor and reliability of decision-making, especially for complex cross-domain issues (Görener et al., 2012).

To assess consumer acceptance of blockchain-based digital OCP RMS and explore willingness to pay (WTP) for OCP NFT (defined as a unique NFT-based OCP recycling certificate in the proposed OCP RMS), we employed the Contingent Valuation Method (CVM). CVM is widely applied in environmental economics and consumer behavior research, and is particularly suitable for evaluating the market potential of emerging technologies and services (Breidert et al., 2015; Carson, 2012). Additionally, CVM can quantify consumer value assessments of specific attributes or functions, a crucial aspect in understanding the appeal of NFT collection schemes and economic incentives for environmentally friendly behavior (Bateman and Großbritannien, 2002; Hanemann, 1991).

In summary, the DSR method provides structured guidance for the overall research, ensuring the practical applicability of the research outcomes. The AHP-SWOT analysis offers a systematic approach to strategy formulation, balancing multiple interests while considering long-term sustainability. The CVM survey component primarily assesses the market potential of NFT-based novel compensation.

3.4. Demonstration

The research flow comprises four main phases: theoretical knowledge, design principles, design solutions, and evaluation of solutions, as illustrated in ***Fig. 7***. The SWOT-AHP analysis involving expert assessment and the consumer-focused CVM survey were conducted concurrently throughout the study period. To present the research findings coherently, the following structure is adopted: Section 4.1 elucidates the theoretical foundations and design principles and proposes and delineates solutions. Section 4.2 reports the demonstration and results of the SWOT-AHP analysis. Section 4.3 details the survey implementation and results from the consumer CVM component.

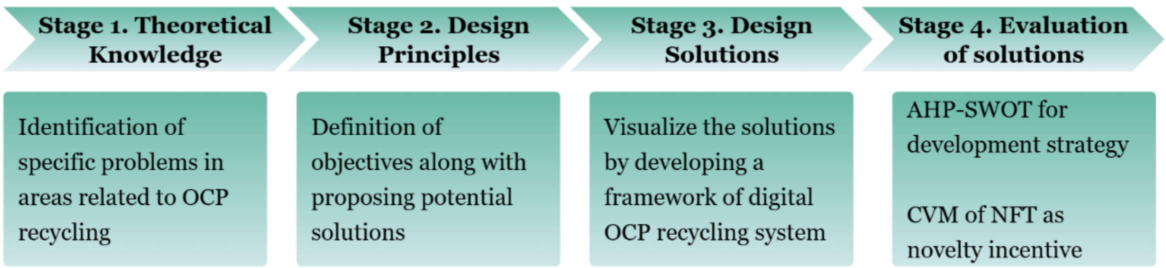


Fig. 7 Research flow of this study.

The DSR methodology consists of six activities: problem identification, solution objective definition, design and development, demonstration, evaluation, and communication (Peffers et al., 2007). After identifying challenges through a review of existing OCP recycling management research, we developed a potential solution framework, drawing insights from blockchain-based management systems across various fields (Boumaiza and Maher, 2024; Ciriello et al., 2023; Lin et al., 2024; Wahab et al., 2023). The refined research process (***Fig. 7***) aligns with the problem-solution-evaluation pathway described by vom Brocke and Maedche (2019) and incorporates the four phases outlined by Romme and Dimov (2021). The core objective of this section is to present the design and demonstration of the blockchain-based OCP RMS framework.

As presented in Section 3.2, the challenges in OCP recycling are apparent at both the systemic management and participatory levels. From a systemic management perspective, inefficiencies in information exchange, risks of non-compliant processing, and inadequate systems significantly hinder recycling management efficiency. At the participatory level, insufficient recycling incentives, inadequate public communication about recycling processes, privacy concerns, and emotional attachment to OCPs contribute to low consumer engagement. In response to these identified problems, the study established key design criteria guided by problem-oriented principles: enhancing data utilization efficiency and transparency, promoting multi-stakeholder collaboration and standardization in the recycling process, and establishing diverse compensation mechanisms.

To address these challenges and meet the design principles, this study proposes a blockchain-based OCP RMS, drawing inspiration from blockchain-based management systems in data management (Yaqoob et al., 2022), supply chain (Venkatesh et al., 2020), and waste management (Lin et al., 2024). The proposed OCP RMS architecture comprises four layers: data, blockchain, application, and service (Fig. 2), each addressing specific aspects of the identified challenges. The data layer forms the foundation, managing information related to recycled OCPs, transaction details, disposal information, and regulatory data. It utilizes distributed storage technologies to ensure data integrity and accessibility. The blockchain layer, comprising consensus mechanisms, smart contracts, transaction processing, and state storage, ensures system transparency and security. The consensus mechanism validates transactions, while smart contracts automate and enforce predefined rules and agreements among participants. The application layer provides functional modules including user management, OCP valuation, recycling transactions, reward distribution, OCP NFT recycling certificate generation, secure disposal process management, compliant disposal reporting, and data analysis. The service layer directly interfaces with various users and stakeholders, offering key services such as recycling transactions, process supervision, information sharing, and recycling incentives (including credit evaluation of recycling stakeholders).

The system's core users include consumers, transactors, manufacturers, remanufacturers, regulators, and system maintainers. Primary activity flows encompass commercial transactions in OCP recycling (e.g., transactions between users and recyclers, recyclers and remanufacturers) and regulatory activities throughout the entire process (e.g., maintaining a commercial credit environment, overseeing sustainable compliant processing). This integration of various stakeholders promotes more efficient collaboration and information sharing, addressing the current fragmentation in the recycling ecosystem (Schmelz et al., 2019). Notably, the application layer's reward distribution and NFT certificate generation modules introduce novel incentive structures to encourage consumer participation (França et al., 2020; Poongodi et al., 2020). Additionally, the compliant disposal reporting and secure process management modules facilitate better oversight and enforcement of recycling regulations. (Akram et al., 2021). By providing transparent valuation processes and secure transactions, the system aims to address consumer concerns regarding fair compensation and data privacy.

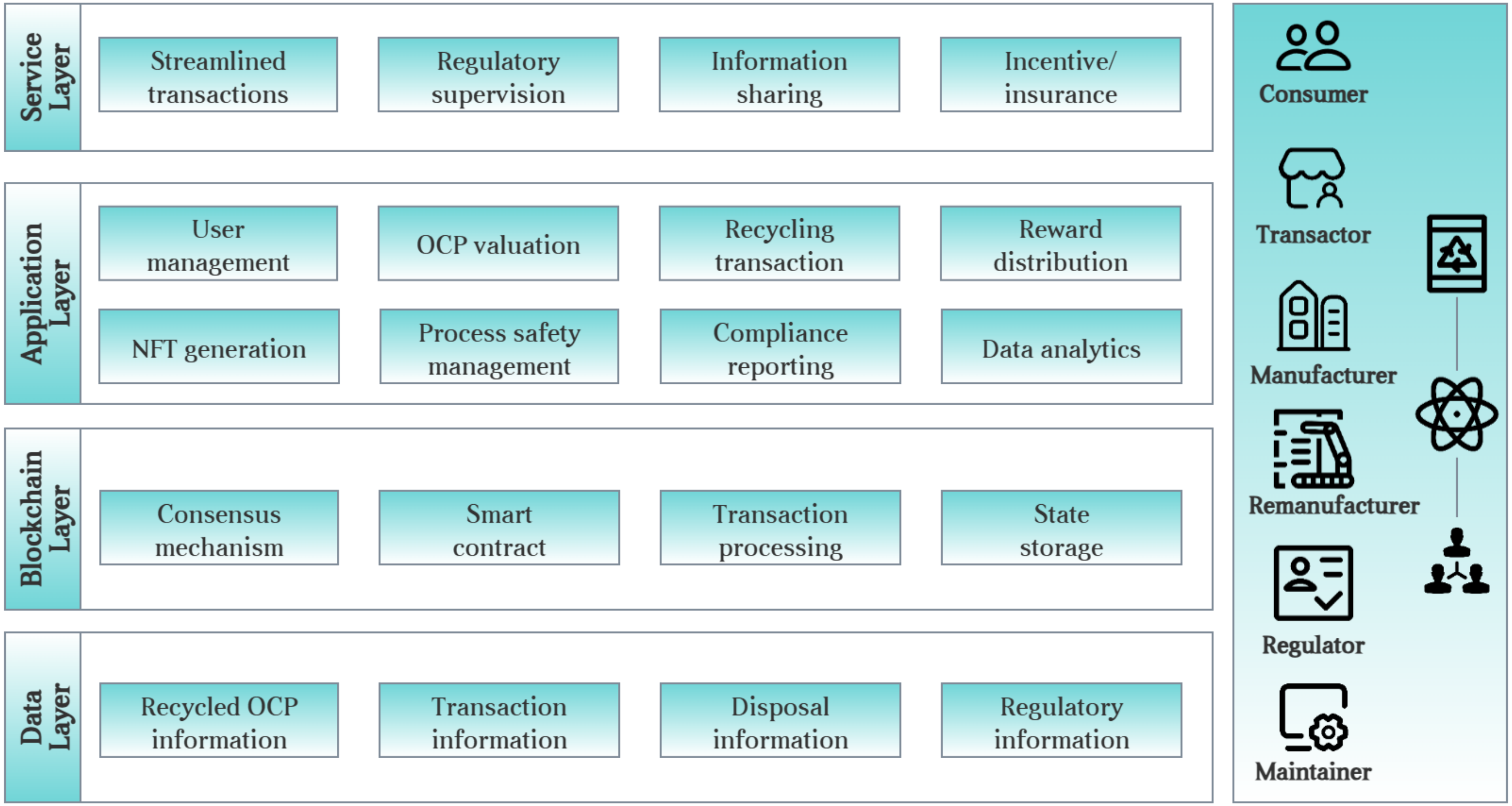


Fig. 8 Framework of digital OCP RMS.

3.5. Multi-evaluation of solution

To thoroughly evaluate the proposed OCP RMS and analyze its potential impact, we employed a multi-faceted approach combining SWOT-AHP analysis and a consumer survey based on the CVM. This comprehensive evaluation provides insights into the strategic implications of implementing the system and assesses consumer acceptance and willingness to pay for the innovative NFT-based incentive mechanism.

3.5.1. SWOT-AHP of digitalization in OCP RMS

This section aims to evaluate the potential of digital transformation in OCP RMS through a combination of quantitative and qualitative methods. We use an AHP to construct a four-by-four SWOT matrix for efficiency assessment, determining the optimal recommended development path through prioritization of factors and their subordinate items.

3.5.1.1. SWOT of digital OCP RMS

To assess the SWOT factors influencing the digital transformation of OCP RMS, we employed a systematic literature review combined with expert consultation. The literature review process began with constructing a multidimensional, interdisciplinary keyword matrix. This matrix encompassed relevant topics, including digital transformation strategies, blockchain technology applications, emerging technologies in management (e.g., Big data, NFTs, IoT, digital twins, AI), sustainable development, e-waste management innovation, supply chain digitalization, and innovative management methodologies. Extensive searches using these keywords across major academic databases such as Web of Science, Scopus, IEEE Xplore and Google Scholar.

Selected literature underwent in-depth analysis, from which we extracted information highly pertinent to our research framework.

From March 8th to 15th, 2024, we conducted interviews with 22 experts from diverse backgrounds, including academics in environmental science, information management, and circular economy; industry specialists in electronic devices; and environmental protection government officials. The primary objectives of these interviews were to: (1) evaluate and refine the description of each SWOT factor/item, (2) clarify and streamline collected items based on experts' feedback, and (3) conduct a voting process to select core items. The SWOT factors, collected items, and voting results are presented in ***Table 12***.

Table 12 SWOT factors/collected items for the digital transformation of OCP RMS.

SWOT factors	Collected items	Vote	References
Strength	*CS1: Transparency, traceability, and data efficiency*	15*	(Bułkowska et al., 2023; Cole et al., 2019; Kouhizadeh and Sarkis, 2018; Kshetri, 2018; Saberi et al., 2019; Treiblmaier, 2018; Venkatesh et al., 2020; Y. Wang et al., 2019)
	CS2: Enhance trust and responsibility	9	
	CS3: Improve collaboration and streamline management	11*	
	CS4: Optimize incentive mechanisms	9	
	CS5: Resource utilization efficiency	11*	
	CS6: Reduce risk of non-compliant handling	8	
	CS7: Enhance environmental image and social responsibility	10*	
Weakness	*CW1: Initial construction costs and investment*	9*	(Akanfe et al., 2024; Beck et al., 2016; Gopalakrishnan et al., 2021; Hunhevicz et al., 2022; Kouhizadeh and Sarkis, 2018; Kshetri, 2018; Lin et al., 2024; Okorie et al., 2022; Popoola et al., 2024; Sedlmeir et al., 2020; Strebinger and Treiblmaier, 2024; Wahab et al., 2023; Xiao et al., 2024; Xu et al., 2019; Yli-Huumo et al., 2016; Zheng et al., 2017)
	CW2: Technical complexity and system integration	8	
	CW3: System energy consumption	4	
	CW4: Technical standards development	7	
	CW5: Social acceptance	9*	
	CW6: Operational costs	10*	
	CW7: Blockchain privacy technology challenges	9*	
Opportunity	*CO1: Sustainable development trends and related policies*	8*	(Ahmed et al., 2024; Böhmecke-Schwafert, 2024; Boumaiza and Maher, 2024; Bravo-Núñez et al., 2024; Brouard, 2024; Chen and Wang, 2024; Ding et al., 2024; Giganti et al., 2024; Kotiranta et al., 2024; Murimi et al., 2023; Nuttah et al., 2023; Prajapati et al., 2022; Ressi et al., 2024; Rivera et al., 2024; Sánchez-García et al., 2024; Šilenskytė et al., 2024; Sipthorpe et al., 2022; Soori et al., 2024; Swinkels, 2024;
	CO2: International collaboration on e-waste management	5	
	CO3: Environmental market potential and carbon credits	10*	
	CO4: NFT consumer market potential	6	
	CO5: Emerging technology integration opportunities	6	

	CO6: Smart city development	6	Ullah et al., 2023; Wolf et al., 2022; Zalan and Toufaily, 2024; Zou et al., 2024)
	CO7: ESG develop trends	5	
	CO8: Cross-industry collaboration demands	7	
	CO9: Increasing consumer environmental awareness	8*	
	CO10: Global digitalization trends	9*	
Threat	CT1: Market competition from traditional recycling	9*	(Bułkowska et al., 2023; Caldarelli, 2024; Chalmers et al., 2022; Chhina et al., 2024; Du and Wang, 2024; Flick, 2022; Gao et al., 2024; Liu et al., 2024; Mulligan et al., 2024)
	CT2: Technological barriers and digital divide	4	
	CT3: Public misunderstanding	9*	
	CT4: System security concerns and external privacy risks	7*	
	CT5: Regulatory policy changes	9*	
	CT6: Incomplete legal and regulatory framework	5	
	CT7: New types of fraud risks	5	
	CT8: Resource price fluctuations affecting system stability	7	

Legend: Asterisked (*) items were included in the AHP analysis based on experts' voting and comprehensive review.

3.5.1.2. AHP within SWOT

AHP was employed to complement SWOT analysis with quantitative data. ***Table 13*** presents the hierarchical structure of the SWOT-AHP analysis, detailing the pairwise comparisons required at each level.

Table 13 SWOT factors/collected items for the digital transformation of OCP RMS.

Hierarchy	Details
1st Objective	Strategic priorities/ recommendations for digital transformation of OCP RMS
2nd SWOT factors (6 Pairwise comparisons)	(S:W), (S:O), (S:T), (W:O), (W:T), (O:T)
3rd Specific items of SWOT (24 Pairwise comparisons)	S: (S1:S2), (S1:S3), (S1:S4), (S2:S3), (S2:S4), (S3:S4) W: (W1:W2), (W1:W3), (W1:W4), (W2:W3), (W2:W4), (W3:W4) O: (O1:O2), (O1:O3), (O1:O4), (O2:O3), (O2:O4), (O3:O4) T: (T1:T2), (T1:T3), (T1:T4), (T2:T3), (T2:T4), (T3:T4)

Legend: Pairwise comparisons are based on Saaty's 1-9 scale method.

To strengthen the evaluation rigor, we expanded the expert panel to 31 participants. From March 22nd to 28th, 2024, experts evaluated the relative importance of elements at both factor and item levels using a pairwise comparison matrix. The scoring format is presented in Tables 14 and 15.

Table 14 Pairwise comparison matrix (SWOT Group as a sample).

Item	More important than								Equal	More Important than								Item
	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	
S	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	W
S	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	O
S	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	T
W	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	O
W	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	T
O	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	T

Table 15 Scoring guidelines for SWOT-AHP pairwise comparison.

Related precautions	Details of precautions
Explanation of scale	Extremely Important (9): Reflects the highest level of importance difference. Very Strongly Important (7): Clearly indicates a strongly higher importance. Moderately Important (5): Indicates a moderate level of higher importance. Slightly Important (3): Indicates a slightly higher level of importance. Equally Important (1): Indicates no difference in importance. Intermediate values (2,4,6,8) can be utilized to express the importance levels that fall between the principal scale points.
Consistency requirement	It is crucial to maintain the consistency of each pairwise comparison. If A is determined to be more important than B and B is more important than C, then A must be more important than C (e.g. if A>B and B>C, then A>C). Any inconsistency renders the questionnaire invalid.
Selection rules	Only single selections are permitted for each pairwise comparison. Multiple or skipped selections will invalidate the questionnaire.
Tips	Before starting the pairwise comparisons, it is recommended to first consider all four items within a group (e.g., S1, S2, S3, S4 for Strength) as a whole. Mentally rank these items to get an overall sense of their relative importance. Take your time with each comparison. Rushed decisions may lead to inconsistencies.

The AHP implementation involved constructing pairwise comparison matrices for each hierarchical level based on Saaty's 1-9 scale (Saaty, 1990). These matrices captured expert assessments on the relative significance of factors, structured as equation (1):

$$A = (a_{ij}) = \begin{bmatrix} 1 & \frac{w_1}{w_2} & \cdots & \frac{w_1}{w_n} \\ \frac{w_2}{w_1} & 1 & \cdots & \frac{w_2}{w_n} \\ \vdots & \vdots & \cdots & \vdots \\ \frac{w_n}{w_1} & \frac{w_n}{w_2} & \cdots & 1 \end{bmatrix} \quad (1)$$

Relative priority of each indicator was determined through eigenvalue analysis. To validate consistency of expert judgments, the Consistency Ratio (CR) was calculated as equation (2):

$$CR = \frac{\frac{\lambda_{max} - n}{n - 1}}{RI} \quad (2)$$

Where λ_{max} is the maximum eigenvalue of the matrix, n is the matrix order. Matrices with CR values below 0.1 were considered acceptably consistent, ensuring reliability (Kurttila et al., 2000). For matrices failing to meet this consistency threshold, experts revised their judgments to improve coherence.

Following consistency verification, geometric means of each matrix layer were used as factors and item weights. Overall priorities were calculated by multiplying factor weights with item weights. Strengths (S) emerged as the most important factor with a priority of 0.485, followed by Opportunities (O) at 0.281, Threats (T) at 0.122, and Weaknesses (W) at 0.113. The top-ranked item overall was S2, followed by S1, S3, and O2. The results are visualized in ***Fig. 9*** and presented in ***Table 16***.

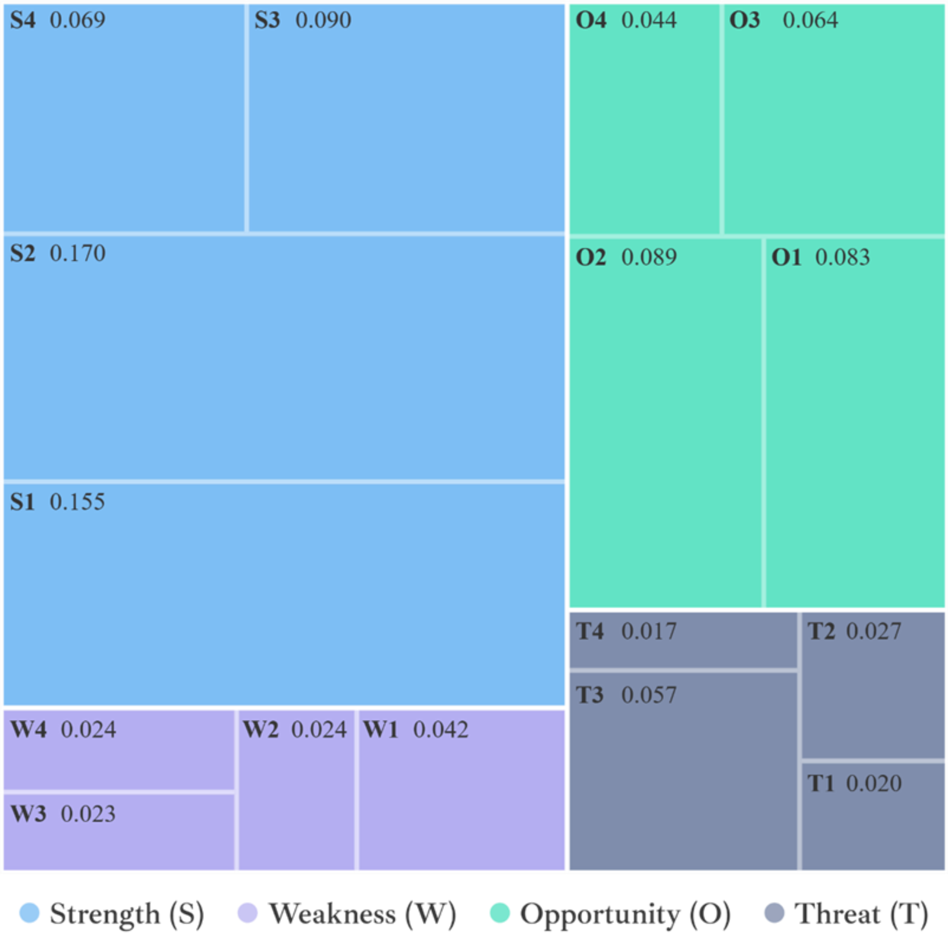


Fig. 9 SWOT-AHP results.

Table 16 SWOT-AHP comprehensive analysis results.

SWOT factor	CR	Factor priority	Factor ranking	Item	CR	Item priority	Overall priority weight	Item ranking
Strength (S)	0.074	0.485	1	S1: Transparency, traceability, and data efficiency	0.017	0.320	0.155	2
				S2: Improved collaboration and streamlined management		0.351	0.170	1
				S3: Resource utilization efficiency		0.186	0.090	3
				S4: Enhanced environmental image and social responsibility		0.143	0.069	6
Weakness (W)		0.113	4	W1: Initial construction costs and investment	0.03	0.375	0.042	10
				W2: Social acceptance		0.209	0.024	12
				W3: Operational costs		0.206	0.023	14
				W4: Blockchain privacy technology challenges		0.209	0.024	13
Opportunity (O)		0.281	2	O1: Sustainable development trends and related policies	0.022	0.296	0.083	5
				O2: Environmental market potential and carbon credits		0.318	0.089	4
				O3: Increasing consumer environmental awareness		0.228	0.064	7
				O4: Global digitalization trends		0.158	0.044	9
Threat (T)		0.122	3	T1: Market competition from traditional recycling	0.003	0.167	0.020	15
				T2: Public misunderstanding		0.225	0.027	11
				T3: System security concerns and external privacy risks		0.470	0.057	8
				T4: Regulatory policy changes		0.138	0.017	16

3.5.2. Estimation of NFT incentive solution's efficiency under blockchain-based digital OCP RMS

3.5.2.1. Consumer survey design and data collection

To assess consumer acceptance of blockchain-based OCP RMS and explore willingness to pay (WTP) for OCP NFT (defined as a unique NFT-based OCP recycling certificate recording recycled OCP information and transaction tracking), this study implemented a two-stage questionnaire survey. The questionnaire comprised four main sections: personal attributes, OCP recycling practices, five-point Likert scale questions from our previous study (Du et al., 2024), and CVM questions (For detailed scale questions and scenarios, see SI). A two-stage survey approach was adopted to mitigate starting point bias in CVM (Chien et al., 2005), gather reasons for non-acceptance, and enhance academic rigor by reducing design-related errors. The first stage CVM employed an open-ended bidding method to determine a reasonable starting price range for OCP NFT, providing a foundation for the second stage's Double-Bounded Dichotomous Choice (DBDC) valuation, aiming for more accurate estimation (Harinath and Rhodes, 2004).

The CVM part presented two scenarios: 1) inquiring whether consumers would be willing to recycle low-value OCPs for free in exchange for OCP NFT, and 2) asking if consumers would accept both OCP NFT and economic compensation lower than conventional recycling offers. Consumers unwilling to participate were considered not in the market, and their reasons were also explored. For willing participants, DBDC questions determined specific WTP intervals. ***Fig. 10*** presents a detailed flowchart of the CVM question process.

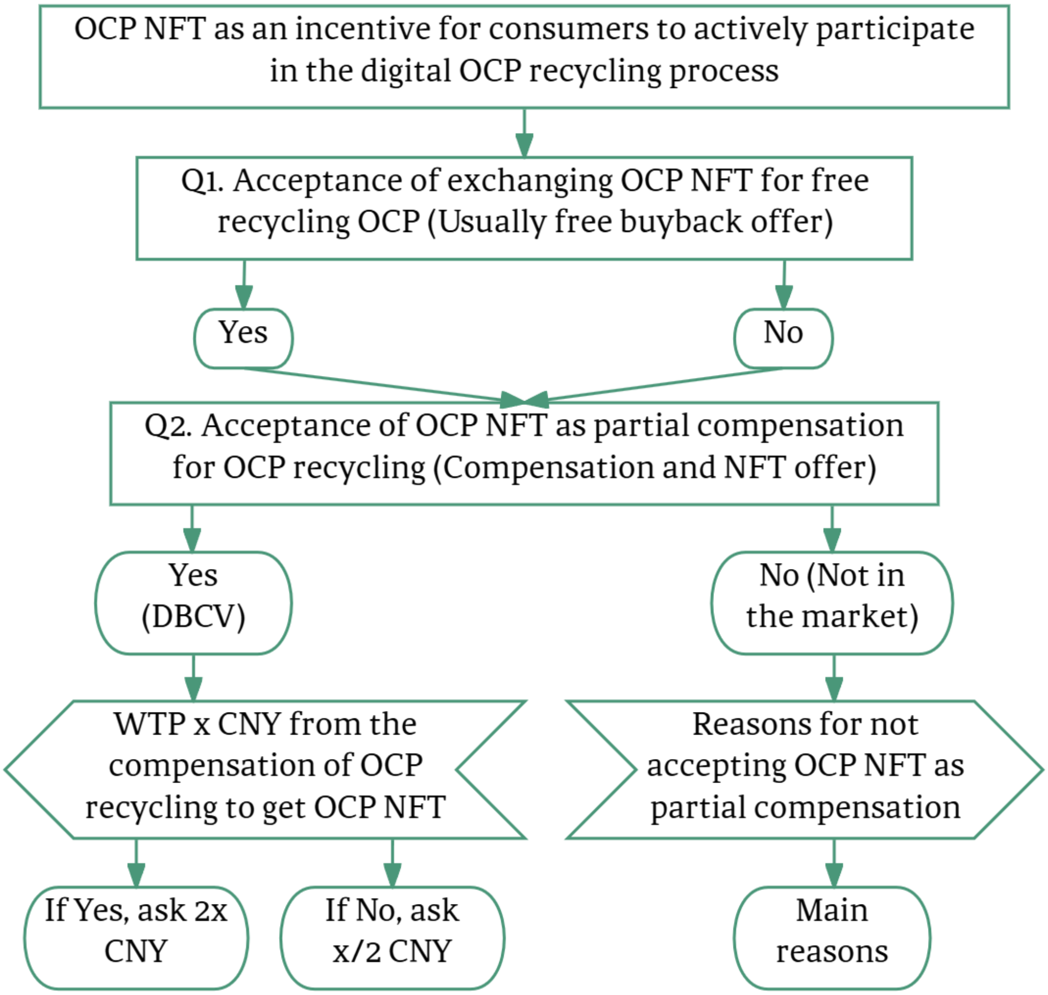


Fig. 10 CVM questions' flow of consumer acceptance for two scenarios and WTP for OCP NFT

The survey was conducted through the Wenjuanxing platform, which boasts a sample pool of 6.2 million users and is widely recognized in commercial and scientific research fields in China (https://www.wjx.cn). A simple random sampling method was employed to ensure equal probability of selection for all users in the sample pool. The survey distribution frequency was dynamically adjusted based on time periods and target numbers to enhance sample diversity and the representativeness of research conclusions. The survey process adhered strictly to ethical standards, providing a comprehensive explanation of the study's purpose, participant freedom, and informed consent at the outset of the questionnaire.

The first stage of the survey was conducted from February 10-18, 2024, targeting 100 questionnaires and yielding 96 valid responses. The results validated the questionnaire design, categorized the main reasons from respondents who were not in the market, and determined the starting price for the DBDC as 50 CNY (based on a mean value of 46.28 CNY and a median value of 50 CNY).

The second stage of the survey was carried out from March 13-30, 2024, collecting a total of 1,372 questionnaires, of which 1,298 were deemed valid, resulting in a 94% validity rate. ***Fig. 11*** illustrates the personal attributes of the respondents. The survey covered all provincial-level administrative regions in mainland China, with a higher proportion of respondents from eastern regions. Gender distribution was relatively balanced, and age was primarily concentrated in the 20–40 range. Regarding education level, most participants hold a bachelor's degree or higher. Monthly income was predominantly distributed in the 6,001-10,000 CNY range.

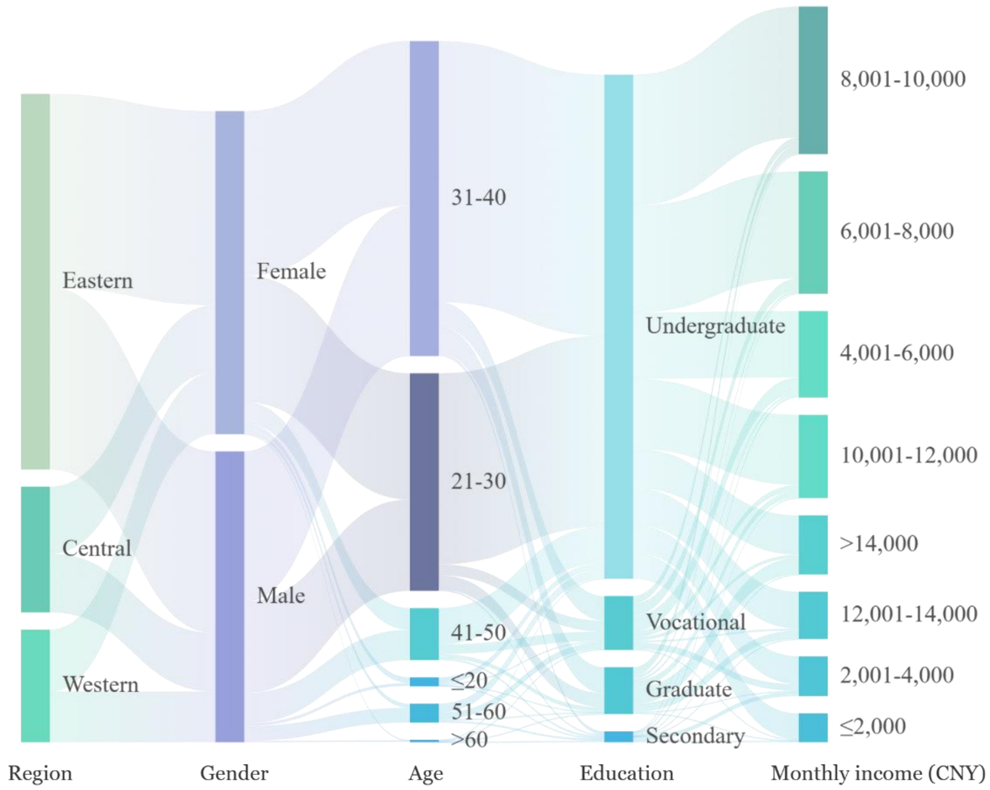


Fig. 11 Distribution of respondents' personal attributes.

By investigating consumers' OCP disposal practices and expected compensation for OCP recycling. The initial question assessed whether the respondent's current cell phone was their first, identifying those with potential OCP disposal experience (only 12 respondents claimed this). The subsequent question explored general disposal behaviors, including recycling and non-recycling (gifting, donating, reselling), as alternatives to retention or waste disposal. The third question focused on participation in formal recycling services, encompassing trade-in programs offered by platforms, companies, or institutions. The final question addressed informal recycling practices, including second-hand transactions or exchanges with individuals or non-institutional dealers. Respondents (n = 1,286) were classified into five groups based on their past disposal practices, incorporating both formal and informal recycling experiences. ***Fig. 12*** illustrates these findings. Approximately one-third (30.94%) of consumers reported no prior OCP disposal experience. Of those with disposal experience, the largest group engaged in both formal and informal recycling methods. This category was closely followed by respondents who solely used formal disposal channels. A small fraction (7.78%) of respondents chose only alternative disposal methods, such as gifting, donating and reselling. (Group: informal-n, formal-n).

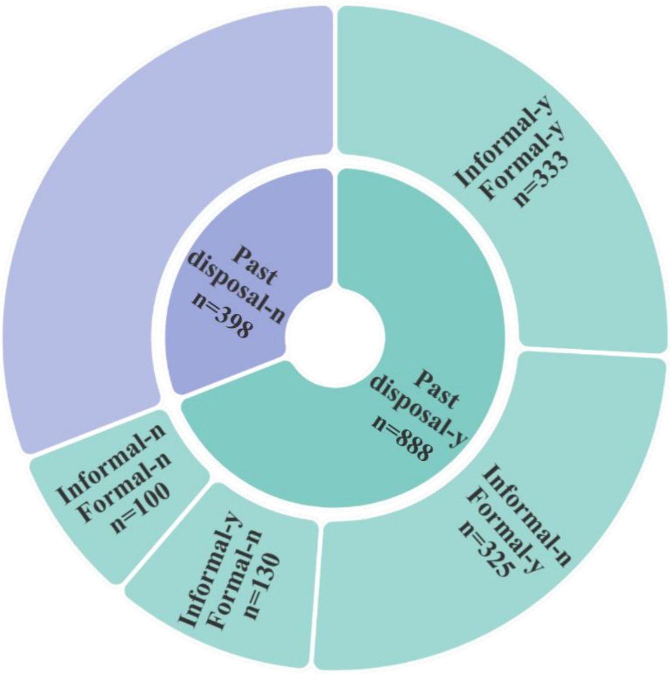


Fig. 12 Respondents' past disposal behavior of OCPs.

To gauge consumers' OCP recycling compensation expectations, the survey categorized OCPs into three conditions: functional, partially functional, and totally broken. Respondents were asked about their expected compensation as a percentage of the OCP purchased price for each category. ***Fig. 13*** illustrates the results. For functional OCPs, over half of the consumers expected compensation exceeding 30% of the purchase price. For partially functional OCPs, more than half of the respondents considered compensation between 10-20% of the purchased price acceptable. For totally broken OCPs, only a small fraction of respondents expected compensation above 10% of the purchased price.

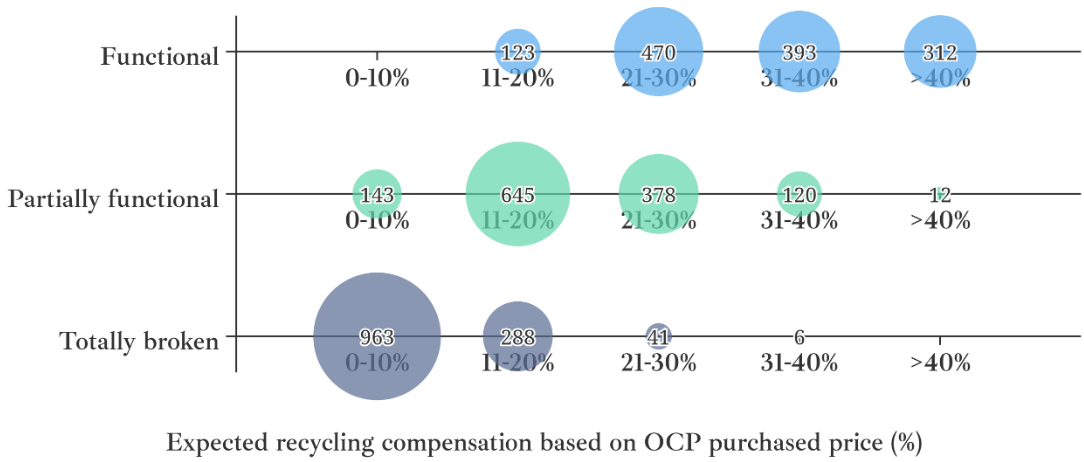


Fig. 13 Respondent's expected compensation for OCP recycling by conditions.

3.5.2.2. Consumer's acceptance of novelty compensation and WTP

In exploring consumer acceptance of blockchain-based OCP RMS and WTP for OCP NFT in the CVM part, ***Table 17*** presents detailed descriptive results. In Scenario 1, 73.11% (n=949) of respondents were willing to accept free recycling in exchange for OCP NFT, indicating a general openness to NFTs as digital collections/recycling certificates in recycling initiatives. Scenario 2 showed increased acceptance, with 83.98% (n=1,090) willing to accept OCP NFT as partial economic compensation. This significant increase (10.87%) suggests that combining NFTs with traditional economic incentives enhances consumer acceptance. For the 208 respondents who were not in the market, a multiple-choice survey revealed the main barriers: 75.96% (n=158) preferred tangible rewards over digital assets, 49.52% (n=103) lacked understanding of NFT technology and its benefits, and 44.23% (n=92) were concerned about NFT market stability and long-term value.

Table 17 Consumer's acceptance for two scenarios and WTP.

Title	Item	Frequency	Percentage
Exchange OCP NFT for free recycling OCP.	Yes	949	73.11 %
	No	349	26.89 %
OCP NFT as partial compensation for OCP recycling.	Yes	1090	83.98 %
	No	208	16.02 %
Reasons for not accepting OCP NFT as partial compensation. (n=208)	Preference for tangible rewards over digital assets.	158	75.96 %
	Insufficient understanding of NFT technology and its potential benefits.	103	49.52 %
	Concerning the stability and long-term value of the NFT market.	92	44.23 %
	Apprehensions regarding the security of digital assets.	75	36.06 %
	Uncertainty about the widespread acceptance and practical use of NFTs.	42	20.19 %
	Environmental concerns related to the energy consumption of blockchain technology.	30	14.42 %
WTP was assessed using DBDC method, with an initial bid of 50 CNY, followed by two sequential WTP questions. (n=1090)	0-25 CNY (response no-no)	90	8.26%
	25-50 CNY (response no-yes)	103	9.45%
	50-100 CNY (response yes-no)	369	33.85 %
	Above 100 CNY (response yes-yes)	528	48.44 %

Legend: Question marked with underscores allow multiple responses.

Through DBDC questions, the 1,090 participants with WTP for OCP NFT were categorized into four groups: 48.44% (n=528) WTP over 100 CNY, 33.85% (n=369) WTP 50-100 CNY, 9.45% (n=103) WTP 25-50 CNY, and 8.26% (n=90) WTP 0-25 CNY. This distribution indicates that a vast majority (82.29%, n=897) were willing to accept a reduction of 50 CNY or more in economic compensation for OCP NFT, reflecting substantial consumer interest in OCP NFT as a novel recycling compensation combined with economic incentives.

Likert scale questions were used to measure consumers' ATT, PBC, SN, PC towards OCP recycling, OA to OCP, and OCP recycling IN, the results are presented in ***Table 18***. As illustrated in ***Fig. 14***, the mean value of IN was 3.671 (SD = 1.041), indicating a moderate level. ATT had the highest mean value of 4.101 (SD = 0.823). OA and PC had mean values of 4.129 (SD = 0.799) and 4.141 (SD = 0.954), respectively. This reflects their potential to significantly inhibit recycling behavior. SN (M = 3.521, SD = 1.057) and PBC (M = 3.610, SD = 1.029) indicated possible correlations between social pressure, perceived ability, and IN.

Table 18 Descriptive statistics, and reliability and validity analysis.

Constructs	Items	Mean	S.D.	Loadings	Cronbach's alpha	CR	AVE
ATT	ATT1	4.035	0.795	0.813	0.730	0.731	0.577
	ATT2	4.166	0.850	0.845			
PBC	PBC1	3.632	0.956	0.826	0.832	0.834	0.626
	PBC2	3.613	1.032	0.857			
	PBC3	3.586	1.098	0.841			
SN	SN1	3.535	1.030	0.834	0.787	0.791	0.558
	SN2	3.415	1.113	0.833			
	SN3	3.612	1.028	0.720			
OA	OA1	4.102	0.827	0.813	0.751	0.751	0.502
	OA2	4.112	0.773	0.810			
	OA3	4.174	0.796	0.813			
PC	PC1	4.132	0.920	0.838	0.829	0.830	0.620
	PC2	4.149	1.013	0.867			
	PC3	4.141	0.929	0.849			
IN	IN1	3.642	1.029	0.793	0.802	0.802	0.669
	IN2	3.700	1.053	0.811			

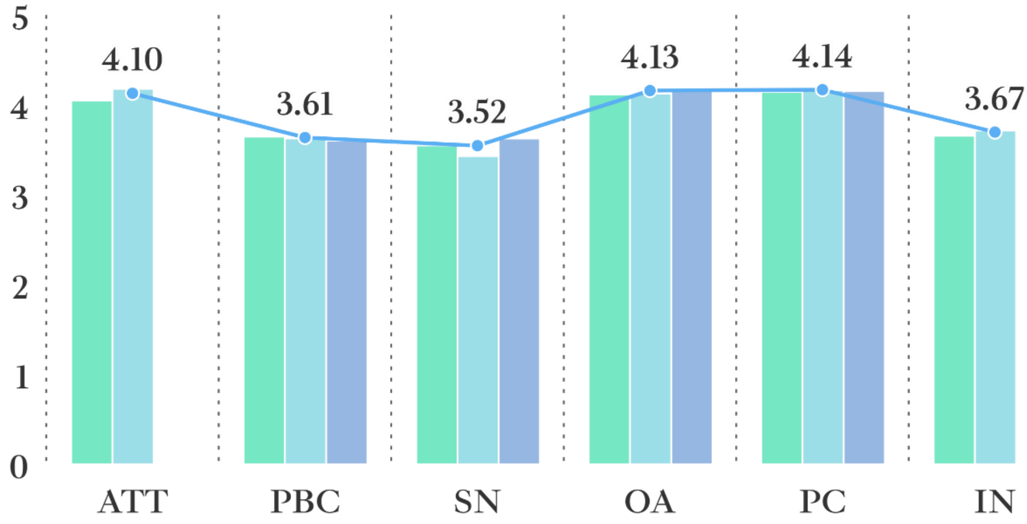


Fig. 14 Constructs and items mean distribution. (Note: Bars represent individual item scores; Line represents construct mean scores.)

Before assessing whether this mechanism also affects consumer acceptance of blockchain-based OCP RMS and WTP for OCP NFT. Reliability analysis showed Cronbach's α values above 0.7 for all constructs, indicating good internal consistency. Exploratory factor analysis yielded a KMO value of 0.822 and a significant Bartlett's test of sphericity ($p < 0.001$), supporting the appropriateness of factor analysis. Confirmatory factor analysis further validated the scale's construct validity. All item factor loadings exceeded 0.7, Composite reliability (CR) values were above 0.7, and average variance extracted (AVE) values exceeded 0.5, demonstrating good convergent validity. For discriminant validity, as shown in ***Table 19***, the square root of AVE for each construct was greater than its correlation coefficients with other constructs, confirming good discriminant validity (Chin et al., 1997). And the content validity could be ensured by using validated classic scales from previous study.

Table 19 Discrimination validity. (Pearson's correlation & AVE square root).

	ATT	PBC	SN	OA	PC	IN
ATT	**0.759**					
PBC	0.314**	**0.791**				
SN	0.408**	0.340**	**0.747**			
OA	-0.010	0.038	0.032	**0.709**		
PC	-0.177**	-0.167**	-0.158**	0.189**	**0.787**	
IN	0.547**	0.376**	0.534**	-0.125**	-0.243**	**0.818**

Legend: * p<0.05 ** p<0.01

To explore the influence of these factors on consumer acceptance of blockchain-based OCP RMS and WTP for OCP NFT, a hierarchical regression model was employed after conducting preliminary data observations and basic tests, including independence tests and residual analysis. In hierarchical regression, two regression models were developed: Model 1 included only control variables, while Model 2 incorporated all construct factors as independent variables. This resulted in six sets of analysis results across two models.

Table 5 presents the hierarchical regression results. Multicollinearity was not a concern, as all variables showed tolerance values above 0.3 and the maximum Variance Inflation Factor (VIF) was 1.853, well below the common threshold of 10 (Gebremariam et al., 2020).

Table 20 Hierarchical regression results of consumer acceptance for two scenarios and WTP for OCP NFT.

	Model 1			Model 2			Co-linear statistics	
	Acceptance 1	Acceptance 2	WTP	Acceptance 1	Acceptance 2	WTP	Tolerance	VIF
Step 1. Control variables								
Age	-0.014	-0.035*	0.031	-0.004	-0.027*	0.037	0.891 (0.902)	1.123 (1.109)
Gender	0.018	0.014	-0.005	0.019	0.014	0.009	0.944 (0.943)	1.060 (1.061)
Region	-0.030	-0.018	0.023	-0.023	-0.013	0.021	0.986 (0.988)	1.015 (1.013)
Education	-0.008	-0.024	0.096	-0.001	-0.019	0.090	0.878 (0.904)	1.139 (1.106)
Monthly Income	0.031**	0.022**	0.063**	0.019**	0.012*	0.047**	0.826 (0.837)	1.211 (1.195)
Step 2. Independent variables								
IN				0.032	0.029*	0.068	0.540 (0.592)	1.853 (1.689)
PC				-0.010	-0.003	-0.028	0.892 (0.911)	1.121 (1.098)
OA				0.151**	0.097**	0.214**	0.924 (0.946)	1.082 (1.057)
SN				0.101**	0.092**	0.091*	0.666 (0.725)	1.502 (1.379)
PBC				0.044**	0.017	0.071*	0.801 (0.827)	1.248 (1.209)
ATT				0.021	0.019	0.062	0.665 (0.722)	1.504 (1.384)
R^2	0.016	0.014	0.024	0.161	0.136	0.075		
Adjusted R^2	0.013	0.010	0.019	0.154	0.128	0.066		
$\triangle R^2$	0.016	0.014	0.024	0.144	0.122	0.051		
sig.	p=0.001	p=0.003	p=0.000	p=0.000	p=0.000	p=0.000		

Legend: * p<0.05 ** p<0.01; n of two scenarios=1298, n of NFT WTP=1090, thus the co-linear statistics are reported according to two sets of data.

In model 1, control variables exhibited differentiated effects. Monthly income showed significant positive impacts across all three dependent variables (β range: 0.022 to 0.063, $p<0.01$ or $p<0.05$), indicating that economic capacity is a universal factor influencing consumer participation in proposed programs. Age only demonstrated a negative effect on Acceptance 2 (β=-0.035, $p<0.05$), potentially reflecting older groups' cautious attitudes towards emerging technologies (Demiris et al., 2004; Jeng et al., 2022). Model 2, which introduced extended TPB variables, significantly improved explanatory power. The incremental R-squared ($\triangle R^2$) values were 0.144 (Acceptance 1), 0.122 (Acceptance 2), and 0.051 (WTP), highlighting the importance of adding these factors. OA showed the strongest and most consistent positive influence across all three scenarios (β range: 0.097 to 0.214, $p<0.01$), emphasizing the central role of consumers' emotional connections to OCPs. SN was also significant in all three cases (β range: 0.091 to 0.101, $p<0.01$ or $p<0.05$), underscoring the importance of social influences in such decision-making.

However, IN only showed a weak positive influence in Acceptance 2 (β=0.029, $p<0.05$), suggesting that general recycling intentions may not directly translate into acceptance of blockchain-based OCP RMS and WTP for OCP NFT. PBC significantly influenced Acceptance 2 (β=0.044, $p<0.01$) and WTP (β=0.071, $p<0.05$) but was not significant for Acceptance 1, possibly reflecting differences in perceived complexity across schemes. Lastly, PC and ATT did not show significant effects in any of the models.

3.5.2.3. Non-parametric WTP Analysis for OCP NFT.

Following hierarchical regression analysis, the Kaplan-Meier-Turnbull nonparametric approach was used to calculate consumers' WTP for OCP NFTs, based on both theoretical considerations and empirical observations. This method was chosen for its distribution-free nature, robustness to outliers, and tendency to yield conservative estimates (Carson et al., 1992; Carson and Hanemann, 2005). This method was chosen over parametric estimation techniques, which necessitate a priori assumptions about the WTP distribution and rely on maximum-likelihood methods that produce consistent estimates only when the specified probability distribution is accurate (Maganga et al., 2021).

The analysis was conducted using the 'DC choice' package (version 0.2.0) in *R software*, the data preparation, computation, and result presentation adhered to the procedures outlined in the 'DC choice' package's manual (DC choice, 2023) and study by Aizaki et al. (2022). As presented in ***Table 21***, the Kaplan-Meier mean WTP estimate was 65.37 CNY (8.99 USD), which represents a cautious lower bound for consumer valuation. The Spearman-Karber mean WTP estimate was 78.26 CNY (10.77 USD), with a median WTP in the interval of 50-100 CNY. The proposed empirical survival function sheds further light on consumers' WTP for OCP NFTs. As illustrated in ***Fig. 15***, at a bid of 50 CNY, the survival probability was 0.82. At 100 CNY, the survival probability fell to 0.48. The gradual decrease in survival probability between these thresholds indicates consumers with varying pricing sensitivity, while still suggesting a sizable market for OCP NFTs as a novelty compensation method.

Table 21 Non-parametric estimates of consumer WTP for OCP NFT.

Estimator	Point Estimate	Interval Estimate	
		Lower Bound	Upper Bound
Kaplan–Meier	65.37		
Spearman–Karber	78.26		
Median	-	50	100

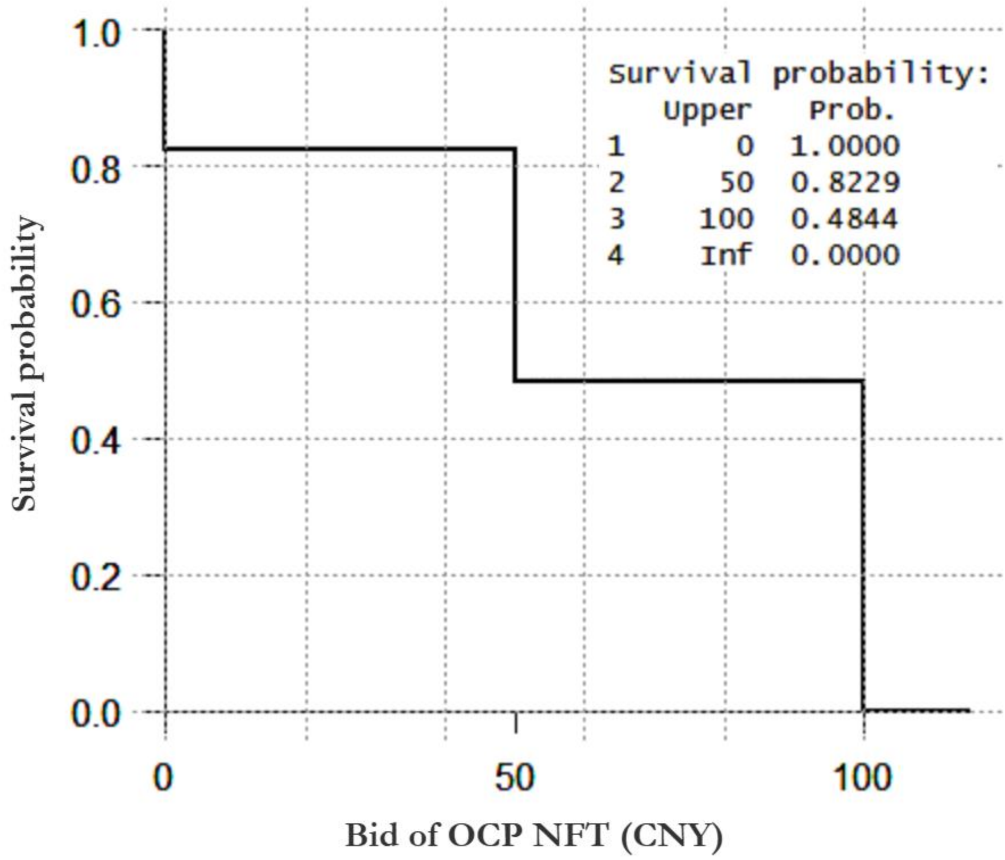


Fig. 15 The Kaplan-Meier Turnbull estimation of OCP NFTs' WTP.

3.6. Discussion

3.6.1. Proposed OCP RMS & digital transformation strategy recommendations

The application of DSR methodology enhances the study's rationale and practicality. By integrating theoretical knowledge, design principles, demonstration, and evaluation into a coherent framework, this study avoids merely advocating for blockchain technology applications and instead provides a solution based on actual needs, ensuring both a theoretical foundation and practical value, thus contributing to the OCP recycling information systems literature. Specifically, the adoption of problem-oriented design principles effectively maps out the existing issues in OCP recycling management, highlighting not only management-level challenges such as low coordination efficiency, data loss, and policy implementation difficulties, but also emphasizing consumer participation issues, including low recycling participation rates, mainly caused by compensation dissatisfaction and retention tendencies. Frantz Schneider et al. (2024) noted that in e-waste management, information barriers between manufacturers, recyclers, consumers, and regulatory bodies often lead to improper resource allocation and inefficient processing. This problem-oriented system can address this issue through the transparency and real-time data sharing capabilities of blockchain technology. Moreover, consumer participation challenges, such as unsatisfied compensation and hoarding (Du et al., 2024), are addressed in our OCP RMS through the use of OCP NFT as recycling certificates.

The OCP RMS employs a four-layer architecture comprising data, blockchain, application, and service layers, which builds upon and refines commonly referenced blockchain architectures that typically include data, network, consensus, incentive, contract, and application layers (Yuan et al., 2016; R. Zhang et al., 2019). The data layer directly addresses the problem of source recycling data loss by ensuring the integrity and accessibility of information on recycled OCPs, transactions, and compliance. This is particularly important in addressing the data tracking difficulties in e-waste management pointed out by Wang et al. (2013). For example, through blockchain technology, each recycled phone can be assigned a unique identifier, enabling full tracking from collection to final processing. This not only improves system transparency but also provides a valuable data foundation for subsequent circular economic analysis. The blockchain layer's consensus mechanism and smart contracts provide a foundation for building trust among stakeholders. In particular, as highlighted by Lin et al. (2024), the application of smart contracts addresses the inefficient information exchange and compensation mechanisms in the recycling industry. For instance, through preset smart contracts, the system can automatically calculate compensation amounts based on the model and condition of recycled OCPs and execute payments when specific conditions are met. This greatly improves transaction efficiency and reduces human intervention and potential disputes. The diverse modules in the application layer, especially the OCP valuation module, help alleviate consumer concerns about fair compensation by combining multi-dimensional data such as phone usage duration, brand, model, and functional integrity to provide more accurate and fair valuations. The dedicated service layer improves the system's flexibility and user-centricity, consistent with Iansiti et al.'s (2017) emphasis on considering multi-stakeholders' rights in blockchain business applications. For example, regulatory bodies and even consumers can monitor the recycling process in real-time through this layer to ensure compliance, while consumers can easily participate in recycling activities and view the environmental impact of their contributions through user-friendly interfaces. This aligns with Bressanelli et al. (2020)

emphasis on stakeholder collaboration being crucial to the success of e-waste management. A notable innovation is the integration of a diversified compensation structure through OCP NFT generation. By creating potentially appreciating digital assets tied to recycling actions, offers a unique solution to raise consumers' OCP recycling participation interest. From an environmental perspective, OCP RMS has the potential to reduce the environmental impact of electronic waste by streamlining processes and ensuring proper disposal under all stakeholders' collaboration and oversight. Tracking devices throughout their lifecycle could provide valuable data for life cycle assessments and widen the lens of circular economy creative initiatives (Konietzko et al., 2020). In addition to serving as collection or recycling participation certification, the potential for NFTs to appreciate adds an interesting economic dimension to recycling activities. NFTs’ marketing potential may attract a broader range of participants (Ali et al., 2023).

While the framework design explains how to optimize OCP recycling, the implementation feasibility and focus areas still need to be clarified for stakeholders. This combined SWOT-AHP approach enables us to answer two key questions: "What are the potential opportunities and challenges of digital transformation in obsolete cell phone recycling management systems? How to formulate development strategies?"

The SWOT-AHP results indicate that strengths (weight 0.485) and opportunities (0.281) are the most significant factors in the digital transformation of OCP RMS. This suggests that a strategy leveraging existing strengths to capitalize on emerging opportunities could be most effective. Specifically, the top-ranked strength—improved collaboration and streamlined management (S2, weight 0.170)—aligns well with the identified opportunities in environmental market potential and sustainability trends. For instance, Kayikci et al. (2022) demonstrated how blockchain technology can enhance cooperation in circular supply chains. The second-ranked strength—transparency, traceability, and data efficiency (S1, weight 0.155)—further supports this potential. Lin et al. (2024) proposed a blockchain-based construction recycling traceability system that showcases how immutable records of waste flows can be created, addressing issues of illegal disposal and ensuring compliance with environmental regulations. This strength directly addresses the growing demand for accountability in waste management, as highlighted by the high-ranking opportunity of sustainability trends and related policies (O1).

While the analysis emphasizes strengths and opportunities, it also reveals significant challenges that must be addressed for the successful digital transformation of OCP RMS. The most prominent threats identified are system security issues and external privacy risks (T3). This aligns with recent cybersecurity research in the context of digital supply chains. Yeboah-Ofori and Islam (2019) emphasized that digital supply chains are increasingly vulnerable to cyber-attacks, necessitating robust security measures for any digital recycling system. The transparency and traceability advantages (S1) also require carefully balancing privacy and transparency, a challenge noted in blockchain applications (Y. Wang et al., 2019). Recent advancements in privacy-preserving technologies offer potential solutions to this challenge. For example, Raj et al. (2024) proposed a novel approach combining blockchain with homomorphic encryption for secure, private data sharing in supply chains. Adapting such technologies for OCP recycling could address security threats (T3) while maintaining the benefits of transparency and traceability. The analysis also identifies initial construction costs and investments (W1) as the most significant weakness. This aligns with broader findings on digital transformation in the circular economy. However, innovative approaches to mitigate this weakness are emerging. Lo and Medda, (2020) explored the potential of tokenization and Initial Coin Offerings (ICOs) to fund circular economy projects. Such approaches combined with related company interests could potentially be applied to OCP recycling, leveraging environmental market potential (O2) to offset initial costs.

Although SWOT-AHP analyses focus on digital transformation based on blockchain, the integration of other digital technologies can improve the identified strengths and address the weaknesses. For example, the concept of digital twins has significant potential to improve resource utilization efficiency (S3). Barth et al. (2023) demonstrated how digital twins can optimize waste management processes in smart cities, and the approach can be applied to OCP recycling to improve efficiency and reduce operational costs (W3). In addition, the integration of devices on the Internet of Things (IoT) can further enhance transparency and tracking (S1). Henaien et al. (2024) proposed a real-time IoT-based solid waste monitoring system that could be adapted to track individual waste components during the recycling process. This granular tracking could provide new opportunities for environmental markets (O2), particularly in enhancing producers' responsibility and circular economic initiatives.

Based on the discussion above, several strategic recommendations can be formulated for industry and regulatory stakeholders regarding the digital transformation of OCP RMS:

1. Prioritize the development of collaborative platforms that leverage the strength in improved collaboration (S2) to address the fragmented nature of the recycling industry.

2. Implement comprehensive transparency and traceability systems using blockchain and advanced technologies, capitalizing on the strength in transparency and traceability (S1) while addressing security concerns (T3).

3. Develop tech-driven resource optimization systems to enhance resource utilization efficiency (S3) and reduce operational costs (W3).

4. Explore innovative financing models to mitigate the weakness of initial construction costs (W1) while leveraging environmental market potential (O2).

5. Establish robust cybersecurity frameworks to address the threat of system security issues (T3), incorporating advanced encryption and access control measures.

6. Develop adaptive regulatory frameworks to create flexible policies that can accommodate the rapid pace of technological innovation (O1) while addressing the potential for regulatory challenges (T1).

7. Implement public education and engagement programs to address the weakness in social acceptance (W2) and build trust in digital recycling systems.

3.6.2. Consumer participation and potential of incentive mechanisms

The findings from the consumer survey reveal a nuanced picture of consumer behavior regarding OCP recycling. While existing studies often focus on recycling participation rates and the retention of OCP, our findings indicate that approximately 60% of consumers have experience with various disposal methods, including recycling, gifting, and donating. Highlights the need for a comprehensive understanding of "participation" in OCP recycling management. The broader perspective suggests that consumers may be more environmentally responsible than previously thought (Inghels and Bahlmann, 2021; Qu et al., 2019). Results of formal and informal recycling program participation reveal that the largest proportion of consumers have engaged in both types of programs. This finding challenges the notion that formal programs can simply replace informal ones as a management strategy, echoing the study by Umair et al. (2015). The significantly lower participation in formal-only recycling compared to informal-only recycling underscores the relative underdevelopment and lower acceptance of formal programs. This disparity may be attributed to differences in convenience and compensation value, echoing the findings of S. Zhang et al. (2023) regarding the gap between recycling intentions and waste recycling participation. The investigation into consumer expectations for compensation reveals a complex landscape that poses challenges for economically viable recycling programs. Results show that compensation expectations vary significantly based on device functionality, with most consumers accepting minimal compensation for totally broken devices. However, for obsolete but functional devices, a substantial number of consumers expect compensation of 21-30% or more of the purchased price. An examination of trade-in programs offered by major cell phone manufacturers and retailers reveals that these programs typically offer minimal compensation or even free recycling for older models or slightly damaged devices that are still functional. This industry-wide approach, while economically viable for businesses, often falls short of meeting consumer expectations, and highlights a key challenge in the OCP recycling ecosystem. This discrepancy suggests the need for innovative approaches to value creation in recycling programs.

The introduction of OCP NFTs as a compensation mechanism for e-waste recycling represents an innovative approach to addressing these challenges. This method not only responds to Konietzko et al.'s (2020) call for innovative circular economy implementation but also extends Helmefalk and Rosenlund's (2020) research on waste management gamification. For the free exchange program, consumers with stronger object attachment, higher subjective norms, and more positive perceived behavioral control were more willing to accept OCP NFTs as recycling compensation. The NFT-based partial compensation program was positively influenced by object attachment, subjective norms, and recycling intentions, but the effect of perceived behavioral control was no longer significant. For WTP of OCP NFT, object attachment had the most prominent influence, followed by subjective norms and perceived behavioral control. The findings indicate high consumer acceptance of OCP NFTs, with 73.11% willing to exchange them for free and 83.98% accepting partial compensation. The WTP distribution further validates that over 80% of respondents agree to reduce 50 CNY or more for OCP NFT. Analysis of personal attributes suggests that younger, higher-income groups are likely the primary target audience for this project. The study further indicates that this demographic is more likely to show interest in digital assets. Object attachment emerged as a strong driver of consumer participation in the project, influencing both participation willingness and WTP levels. This innovative solution echoes the recommendation for technological innovations to mitigate emotional influence in previous research (Du et al., 2024). By transforming physical devices into digital collectibles, the OCP NFTs project successfully shifts consumer emotional attachment from physical to digital assets, thereby promoting recycling behavior. Subjective norms were confirmed to not only drive general recycling behavior but also promote consumer willingness to participate in and pay for innovative projects. This finding aligns with Truc's (2024) research, emphasizing the importance of social influence in promoting environmentally friendly behavior. It suggests that OCP recycling projects can expect positive participation if a favorable participation atmosphere is created. Perceived behavioral control significantly influenced participation willingness in free exchange scenarios but had a weaker impact on WTP for digital collectibles. This result suggests potential consumer concerns about the complexity of innovative projects, consistent with Ajzen's (1991) theory of planned behavior. It also indicates the need for simplified processes and clear instructions in future recycling project designs to enhance consumer understanding and participation experience.

The estimated average WTP for OCP NFTs (65.37 CNY using Kaplan-Meier and 78.26 CNY using Spearman-Karber) provides a quantitative basis for understanding the potential of OCP NFT as a recycling certificate. These figures fall within the range of expected compensation for functional devices, suggesting that OCP NFTs could bridge the gap between consumer expectations and economically viable recycling programs. But it also raises important questions about the economic sustainability of such digital incentive systems. While these innovative approaches may potentially alleviate recyclers' monetary burdens, it remains uncertain whether such elevated valuations can be maintained in real-world implementations or if they are primarily driven by initial marketing strategies. While digital incentives may attract tech-savvy consumers, they could create new barriers for less technologically adept populations, aligning with Yap et al.'s (2021) observations on technology consumption and consumer vulnerability. In conclusion, OCP NFTs as a compensation mechanism for OCP recycling show potential, particularly in addressing collection needs and diversifying compensation structures, but require careful consideration of economic viability, technological accessibility, and alignment with diverse consumer expectations.

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Bridge of Two Milestones

4.1. Linkages and complementarity of two studies

This dissertation presents two interconnected studies that explore different facets of OCP recycling management systems, forming a complementary relationship that addresses both consumer behavior and technological innovation. The first study delves into the factors influencing consumer participation in OCP recycling, utilizing TPB as its foundation while incorporating emotional factors such as OA and PC. This research provides a robust theoretical framework and empirical support for understanding the complex dynamics of consumer recycling behavior in the context of OCPs.

The second study shifts focus on the digital transformation of OCP recycling management systems, proposing an innovative framework that leverages blockchain technology and NFTs. This research not only addresses some of the key issues identified in the first study, such as privacy concerns and object attachment, but also offers novel approaches to increase recycling participation and efficiency.

The linkage between these two studies is multifaceted and synergistic. Firstly, the privacy concerns identified as a significant barrier in the first study are directly addressed in the second study through the implementation of blockchain technology, which enhances data security and transparency in the recycling process. Secondly, the issue of object attachment, discovered to be a major hindrance to recycling intentions in the first study, is innovatively addressed in the second study through the use of NFTs as digital collectibles. This approach provides a unique solution that allows consumers to maintain a digital connection to their devices while still participating in the recycling process. Lastly, both studies emphasize the critical importance of improving recycling convenience and optimizing compensation mechanisms, with the second study proposing concrete technological solutions to these challenges identified in the first study.

Moreover, the methodological approaches in both studies complement each other, with the first study employing a combination of PLS-SEM and fs-QCA for a nuanced understanding of consumer behavior, and the second study utilizing DSR and SWOT-AHP for a comprehensive evaluation of the proposed digital transformation. This methodological diversity provides a holistic view of the OCP recycling ecosystem, from individual consumer behavior to system-level management strategies.

4.2. Integrated contributions

The integration of these two studies contributes significantly to the field of e-waste management and circular economy practices, particularly in the context of OCP recycling. From a theoretical perspective, this research expands the TPB by incorporating emotional factors into the explanatory framework for OCP recycling behavior. This extension addresses a crucial gap in the TPB, which traditionally focuses primarily on rational decision-making processes. By demonstrating the substantial influence of emotional factors, particularly object attachment's direct and strong negative impact on recycling intentions, this research highlights both the applicability and limitations of the TPB in explaining pro-environmental behaviors.

Furthermore, the research provides a more nuanced understanding of OCP recycling decision-making, revealing that privacy concerns negatively influence both attitudes and perceived behavioral control. This finding extends previous work on privacy in sustainable consumption and applies it specifically to cell phone recycling. The examination of privacy concerns and object attachment as potential barriers to OCP recycling intentions improves our understanding of the practical and psychological obstacles individuals face when engaging in such pro-environmental behaviors.

The second study contributes to the literature on digital transformation in e-waste management by proposing an innovative OCP recycling management system framework that integrates blockchain and NFT technologies. This framework demonstrates how digital transformation can significantly improve the transparency and efficiency of the entire OCP recycling process, thereby better coordinating the sustainable management of growing e-waste. The application of the DSR approach to the digital transformation of OCP recycling provides a systematic framework that bridges theoretical construction with practical application, offering a replicable and scalable research model for studying digital transformation in e-waste management.

Methodologically, the research makes several important contributions. The first study innovatively combines PLS-SEM and fs-QCA methods, offering a more comprehensive understanding of OCP recycling participation. This combination addresses calls for more sophisticated analytical techniques in environmental psychology research. The second study employs the Design Science Research (DSR) approach, providing a systematic framework for digital transformation research in the context of e-waste management. The use of the SWOT-AHP method for objective quantitative assessment overcomes the limitations of traditional SWOT analysis subjectivity, providing more targeted development strategies based on quantitative results.

In terms of practical contributions, the research provides specific recommendations for improving OCP recycling management. These include enhancing recycling convenience, optimizing compensation mechanisms, implementing stringent data safety measures, and leveraging technological innovations to mitigate the negative impact of object attachment. The proposed use of NFTs as recycling certificates represents an innovative incentive mechanism that could potentially satisfy consumers' object attachment through digital collectibles while promoting recycling participation.

The research also yields several important policy recommendations. It emphasizes the need for supportive policy frameworks and standardization efforts to facilitate the digital transformation of OCP recycling management systems. The studies highlight the importance of enhancing public education and raising awareness about recycling processes and their benefits. Additionally, the research underscores the critical need for continuous technological advancement and skill development in the OCP recycling industry to keep pace with digital innovations and evolving consumer behaviors.

4.3. Limitations

Despite the significant contributions of this research, several limitations must be acknowledged. The first study is constrained by its narrow sample range, which may limit the generalizability of the findings to broader populations or different cultural contexts. The use of original scales for measuring object attachment, combined with scales from various studies for other factors, could introduce measurement errors that may affect the reliability of the results.

The second study focuses primarily on system design and hypothetical scenarios without operational data, potentially limiting the full anticipation of implementation challenges in real-world settings. The sample size and representativeness in the SWOT-AHP analysis and Contingent Valuation Method (CVM) survey may introduce some bias, affecting the generalizability of the strategic recommendations and market potential assessments.

Additionally, the proposed technological solutions, while innovative, are still in the early stages of application in waste management. This presents uncertainties in practical implementation, including potential technical challenges, regulatory hurdles, and user adoption issues that may not be fully anticipated in the current research.

Both studies lack long-term effect evaluation due to the nature of the research, which limits the assessment of the system's sustainability and continuous consumer behavior over time. The rapid pace of technological advancement also presents a challenge, as newer technologies may emerge that could impact on the proposed solutions or render certain aspects obsolete.

Furthermore, the focus on the Chinese context in the first study and the hypothetical nature of the digital transformation in the second study may limit the direct applicability of the findings to other geographical or economic contexts. Cultural differences, varying regulatory environments, and different levels of technological infrastructure could all influence the effectiveness and feasibility of the proposed recycling strategies and digital transformation initiatives.

Conclusion

5.1. Summary of key research findings

This dissertation presents two interconnected studies on OCP recycling, offering valuable insights into consumer behavior and digital transformation in recycling management systems. The first study reveals that while TPB predictors reliably forecast OCP recycling intentions, object attachment significantly reduces intention, exceeding the influence of perceived behavioral control. This finding highlights the crucial role of emotional factors in recycling behavior, extending beyond traditional rational decision-making models. Privacy concerns were found to indirectly affect intention by influencing attitude and perceived behavioral control, underscoring the importance of data security in recycling programs.

The fs-QCA analysis identified key conditions for high OCP recycling intentions, including the presence of positive attitude, supportive subjective norms, and high perceived behavioral control, along with the absence of strong object attachment and privacy concerns. This nuanced understanding of the interplay between various factors provides a more comprehensive picture of what drives recycling behavior.

The second study proposes an innovative OCP recycling management system framework integrating blockchain and NFTs. This digital transformation demonstrates significant potential to address management-level challenges such as low coordination efficiency, data loss, and policy regulatory difficulties. Simultaneously, it offers solutions to consumer participation issues, including privacy concerns and retention tendencies identified in the first study.

The Contingent Valuation Method results confirmed the market potential of OCP NFTs as a novel recycling compensation/certification mechanism, suggesting consumer readiness for innovative, technology-driven recycling incentives. The SWOT-AHP analysis offered comprehensive strategic recommendations for OCP recycling management system digital transformation, identifying key factors such as global digitalization trends, environmental market potential, social acceptance, and system security issues. This analysis provides a roadmap for implementing digital transformation in OCP recycling systems, balancing opportunities with potential challenges.

Together, these findings provide a holistic view of the OCP recycling landscape, from individual consumer motivations to system-level management strategies, offering a foundation for developing more effective and sustainable recycling programs.

5.2. Directions for future research

Future research should address the limitations identified in both studies while building upon their findings to further advance the field of OCP recycling and e-waste management. For the first study, efforts should be made to increase the sample size and diversify the demographics of participants. This expansion should include not only a broader Chinese population but also varied cultural contexts in different geographical regions to evaluate the cross-cultural validity of the proposed theoretical model. Such comparative studies could reveal how cultural factors influence recycling behaviors and attitudes, potentially leading to more tailored recycling strategies for different regions.

Further exploration of factors influencing consumer decisions to participate in OCP recycling is needed. This could include investigating the role of other emotional factors beyond object attachment, such as environmental guilt or pride in pro-environmental behaviors. Additionally, longitudinal studies tracking changes in recycling behavior over time could provide insights into how attitudes and behaviors evolve, particularly in response to new recycling initiatives or educational campaigns.

For the second study, future research should explore the potential synergies between multiple digital technologies in OCP recycling. This could involve investigating how the integration of Internet of Things (IoT) devices with blockchain systems could enhance tracking and verification in the recycling process, or how artificial intelligence and machine learning could be used to optimize recycling logistics and predict consumer behavior patterns.

Longitudinal studies examining the long-term environmental and economic impacts of digitalized management initiatives would be particularly valuable. These studies could assess the actual effectiveness of blockchain-based systems and NFT incentives in increasing recycling rates and improving resource recovery over time. They could also evaluate the scalability and cost-effectiveness of these technologies as they mature and are implemented on larger scales.

Additionally, investigating the implementation challenges of digital transformation in management system initiatives across different geographical and economic contexts could provide insights into their scalability and adaptability. This could include studying how different regulatory environments impact the adoption of blockchain-based recycling systems, or how varying levels of technological infrastructure affect the feasibility of implementing such systems in developing versus developed countries.

Future research should also focus on developing more robust and comprehensive models that integrate behavioral insights with technological innovations to create sustainable and efficient OCP recycling systems. This could include exploring the long-term effects of NFT-based incentive mechanisms on consumer behavior, investigating how gamification elements could be incorporated into digital recycling systems to increase engagement, and examining the potential for integrating circular economy principles more deeply into OCP lifecycle management.

Finally, as privacy concerns were identified as a significant factor, future studies should delve deeper into developing and testing enhanced data protection measures in digital recycling systems. This could involve research into advanced encryption methods, decentralized identity management systems, or novel approaches to anonymous but verifiable recycling transactions.

By pursuing these research directions, future studies can build upon the foundation laid by this dissertation, contributing to the development of more effective, sustainable, and user-friendly OCP recycling systems that address both the technological and human aspects of e-waste management.

Appendices

Appendix Q

➢ATT toward OCP recycling. (Ajzen, 1991; Zhang et al., 2020)

ATT1. Recycling OCP contributes to society.

ATT2. The responsibility for recycling OCP should be shared.

➢PBC of OCP recycling. (Ajzen 2006)

PBC1. Participating in OCP recycling requires minimal effort.

PBC2. It is easy for me to participate in the recycling of my OCP.

PBC3. I am confident in my ability to actively participate in OCP recycling.

➢SN of OCP recycling. (Ajzen 2006)

SN1. I receive encouragement from family and friends to recycle my OCP.

SN2. I receive encouragement from government initiatives and the public media to recycle my OCP.

SN3. Most of the people who are important to me support the recycling of OCP.

➢OA of OCP.

OA1. I feel like my OCP is part of my past life.

OA2. I associate my OCP with memories from the time I used it.

OA3. I associate my OCP with experiences from the time I used it.

➢PC of OCP recycling. (Smith et al., 1996)

PC1. I am concerned about potential privacy breaches during OCP disposal.

PC2. I am concerned about the potential misuse of privacy information during the disposal of OCP.

*PC3. I am anxious about my personal information to be extracted from my OCP even after I've attempted to delete it. (*PC3 was added in survey of Milestone 2)

➢OCP recycling IN. (Ajzen 2006; Lam et al. 2022)

IN1. I intend to recycle my OCP afterwards.

IN2. I am willing to participate in the recycling of OCP.

Supplementary information (SI)

With the fast progress of cell phone technology, the problem of electronic waste has become more serious. Untreated electronic wastes precious resources while also polluting the environment significantly. According to research, many consumers keep obsolete cell phones owing to object attachment or love for certain brands and models, which further reduces recycling rates. To solve this issue, we suggest a novel blockchain-based recycling management system feature Non-Fungible Tokens (NFTs).

Digital collectibles (NFTs) are virtual artworks or collectibles created using blockchain technology. They have qualities like uniqueness, indivisibility, immutability, verifiability, and scarcity. In our initiative, each discarded phone is converted into a one-of-a-kind digital collectible that includes information such as the phone's model and use history. These digital items will be created via the blockchain, assuring their validity and exclusivity. For example, the Hangzhou Asian Games issued a digital torch collectible "Eternal Flame" priced at 39 CNY, restricted to 20,000 copies, and transferable after 180 days of possession. When it first became available, it quickly sold out. Another prominent example is the Goujian sword digital collectible, which costs 19.9 CNY and was created in partnership with the Hubei Provincial Museum and Alibaba. Ten thousand copies sold out in 3 seconds, with over 600,000 individuals bidding for them. Currently, important digital collecting platforms include Alipay's Jingtan, Taobao's Ali Auction, and Digital Collection China.

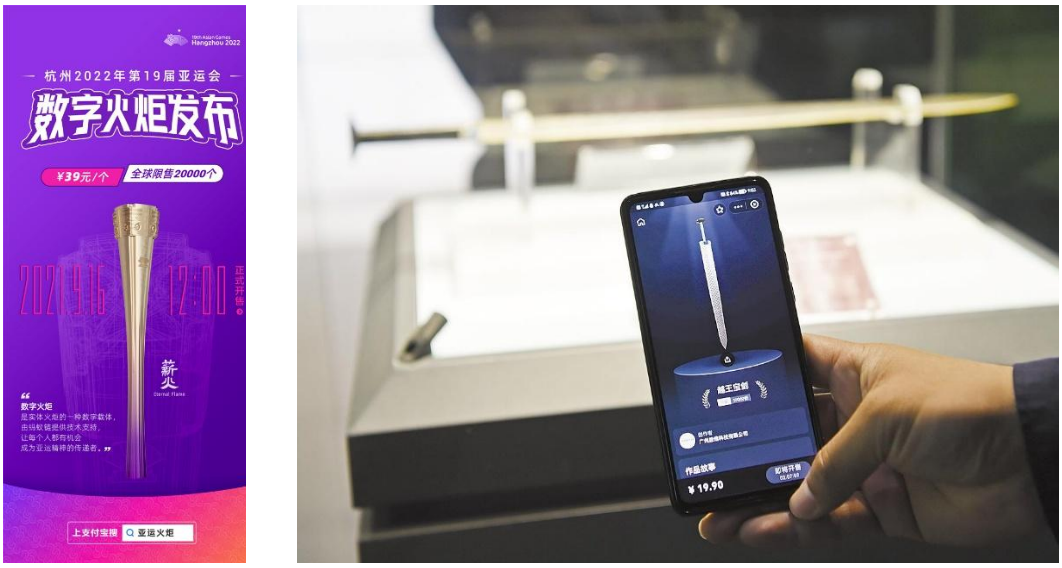

Fig. A1. Illustrative representation of the "Eternal Flame" digital torch collectible from the Hangzhou Asian Games and the digital collectible of the Goujian sword. (“Digital copies of famous sword sell out in seconds,” 2022; Sina Sports, 2021)

Our recycling program operates as follows: Consumers can submit recycling applications through designated recycling platforms. Digital collectibles (OCP NFT) will be distributed to consumers' NFT applications within a specified period after recycling is completed. Consumers can view, display, and potentially sell or transfer these digital collectibles on NFT application platforms.

Fig. A2. Conceptual illustration of OCP recycling participation and OCP NFT acquisition. (The left panel shows a hand holding an obsolete cell phone with a recycling symbol, representing participation in recycling. The right panel depicts the acquisition of an OCP NFT recycling certificate, symbolized by a digital representation of recycled OCP.)

This blockchain-based recycling management system makes the entire process transparent and traceable. Consumers, as major players in the system, may follow their recycling transactions and procedures in real time using blockchain technology. NFTs, which are unique identifiers produced using blockchain technology, serve as both electronic receipts for recycling and unique digital collectibles based on obsolete cell phones. Participating in this program not only allows you to acquire rare digital treasures, but it also helps to safeguard the environment. The purpose of this study is to analyze consumer approval of this new recycling approach, as well as the economic compensation difference that customers are ready to accept in exchange for digital collectibles. Your involvement will enable us to improve the recycling program, raise electronic product recycling rates, and contribute to the circular economy.

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