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The formation of waste management order in urban communities under the neo endogenous development theory: Two examples from Chinese urban communities

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Introduction: China's urban community waste management (UCWM) is plagued by severe environmental pollution, resource wastage, and insufficient public participation, necessitating an urgent shift towards sustainable practices through grassroots mobilization. This study explores how urban communities can integrate external resources and endogenous dynamics to form sustainable waste management orders, guided by the Neo Endogenous Development (NED) theory.

Methods: This study collected data using the interview method and analyzed the data through NVIVO 12.0 to explore the integration of external resources and internal dynamics in forming sustainable UCWM orders in two representative Chinese urban communities in Beijing and Shanghai.

Results: The findings reveal that technology, as an exogenous force, effectively stimulates endogenous sustainable development by aggregating subjects through platform empowerment, activating grassroots resources via data interoperability, and fostering social connections and environmental awareness. The NED framework, which integrates technology empowerment, multi-stakeholder collaboration, resource activation, and value creation, demonstrates significant potential in enhancing sustainable waste management.

Discussion: These results highlight the synergistic role of technological innovation, stakeholder collaboration, and community empowerment in achieving sustainable waste management. The study underscores the replicability of NED-based waste management models in diverse socio-economic settings. Practical policy recommendations include increased government subsidies for smart devices, legislation for waste sorting responsibilities, and technology adoption tailored to community needs.

KEYWORDS

Chinese cities, urban communities waste management, neo endogenous development theory, technology empowerment, objects integration, resource activation, value creation

1 Introduction

Urban community waste management (UCWM) has become a critical challenge in China's rapidly urbanizing landscape, where traditional management methods like landfills and incineration increasingly reveal environmental limitations. Studies have documented their association with soil degradation (Meena et al., 2019), groundwater pollution (Abanyie et al., 2022), and greenhouse gas emissions exceeding World Health Organization thresholds (B. Liu et al., 2024). These systemic risks demand an urgent transition toward circular systems emphasizing organic waste valorization and closed-loop resource recovery.

This urgency intersects with two structural barriers hindering community-level implementation. China's waste classification and collection model focuses on transfer stations. However, because no waste separation facilities have been established at the transportation or final waste management stages, a large amount of useful material is not utilized, reducing the resource value of organic matter that can be used for composting and increasing the burden on landfills (Khan et al., 2022), while cost-benefit analyses show that recycling initiatives have recouped less than 50% of operational costs (Hu and Ren, 2014). Concurrently, socio-institutional gaps emerge: 61% of Beijing residents exhibit waste classification knowledge deficits (Deng et al., 2013). In a 3-year community experiment in Beijing, only about 25% of residents adopted the habit of waste classification (Tong et al., 2018). Such dual challenges necessitate frameworks reconciling technical scalability with social embeddedness.

The Neo Endogenous Development (NED) framework provides critical theoretical scaffolding for this transition. Unlike top-down modernization paradigms, NED emphasizes the dialectical synergy between external technological inputs and endogenous social capital cultivation (Gutberlet, 2018). This approach recognizes that sustainable development cannot be achieved merely through the introduction of advanced technologies or infrastructures from outside; it must also engage and strengthen local resources and capacities.

Although existing research in recognizes the complementarity between external intervention (Feng et al., 2024; Yang, Huang, and Xue, 2024) and internal resources (Rivera-Arriaga et al., 2021; Chu, Bian, and Yang, 2022) in community environmental governance, there is space for further exploration of in-depth analysis of the dynamic nature of the internal and external collaborative mechanisms. Based on this gap, this study takes the NED theory as the framework, aiming to analyze the collaborative mechanism between external technology input and endogenous community dynamics, construct a waste management order model that integrates technology empowerment, multi-agent collaboration, and community empowerment, and verify the applicability and replicability of the model in different contexts through community cases in Beijing and Shanghai, to fill the gap in the explanation of dynamic collaborative mechanisms in existing theories and provide integrated theoretical and Practical references for urban ecological governance in China and world.

The purpose of this study lies in its establishment of the NED framework for waste management in grassroots urban communities. This framework serves to broaden the scope of the NED theory's application in the realm of grassroots community environmental governance in China. Furthermore, it offers a foundation for theoretical references that can potentially inform advancements in academic research on sustainable urban governance.

2 Literature review

2.1 Multiple forces in UCWM

UCWM has mainly evolved through three distinct theoretical paradigms, each reflecting shifting understandings of agency in environmental governance.

External-Driven Model: This approach emphasizes the enabling role of external actors like governments and enterprises through policy tools and technological provision. Ostrom's (2000) institutional analysis framework establishes that external incentive mechanisms are prerequisites for grassroots environmental governance. Within this framework, Schultz et al. (1995) empirically demonstrated that government subsidies for waste sorting increased household participation rates by 23%–45%. Mmereki (2018) further developed the integrated sustainable waste management model, advocating policy standardization of waste collection systems and efficiency improvements through technological innovations like intelligent sorting equipment (e.g., the EU Zero Waste Strategy reduced landfill rates from 68% in 1995 to 4% in 2020). Esteves et al. (2021) documented that corporate-community partnerships in Brazil increased the recycling rate by 17% over 3 years, proving the effectiveness of corporate support for community pilot projects.

Community-Led Model: As research has evolved, scholars have shifted from relying on external interventions to tapping into the intrinsic resources within grassroots communities, highlighting their impact on environmental governance. Middlemiss and Parrish's (2010) four-dimensional model for building capacity for low-carbon communities underscores the importance of cultural, organizational, infrastructural, and personal capacities. Grassroots communities effectively reduce carbon footprints by transforming individual expertise into collective action (Daly, 2018). This model not only emphasizes community self-management but also broadens participation. Educational activities further empower residents by teaching waste classification skills and encouraging active engagement in environmental efforts (Dawson et al., 2021). Additionally, supporting the growth of environmental non-governmental organizations (ENGOs) and volunteer groups bridges governmental efforts with public involvement, enhancing UCWM project implementation and monitoring (Xie et al., 2022). Consequently, leveraging community strengths fosters more sustainable and inclusive environmental practices.

Symbiotic Model of Internal and External Forces: A complementary approach is the internal and external symbiotic path, emphasizing interaction and cooperation between external governmental and internal community forces. This strategy integrates top-down and bottom-up approaches for effective UCWM. Optimal grassroots governance requires the synergy of external political impulses and internal community-based spontaneous efforts to create a comprehensive system optimization. UCWM involves shifts in production and consumption patterns and policy, technology, institutional, and

business model innovations, necessitating cross-sectoral coordination (Bugge et al., 2019). Successful changes must be grounded in a deep understanding of local contexts and region-specific issues (Yukalang et al., 2018). Community-based projects mobilize resident participation and build capacity for local management and resource recycling (Wynne et al., 2018). Still, their sustainability depends on close collaboration with supportive local governments, which provide political and financial support and facilitate information and technology exchanges (Arantes et al., 2020; Xie et al., 2022).

2.2 Technology-driven waste management

Cases of Digital Technology Application: Digital technology and biotechnology applied to waste management have significantly enhanced treatment efficiency, reduced pollution, and delivered a myriad of social benefits. These technological innovations have optimized the resource recovery process, thereby fostering the development of a circular economy. For instance, an IoT-based system constantly monitors waste discarded from smart garbage cans and accurately monitors waste collection in terms of resource management and services provided to the community. As a result, such a system could effectively change the way people manage waste and optimize economic and physical resources (Pardini et al., 2020). Artificially intelligent sorting systems and advanced robots can optimize recycling by reducing manual labor and increasing material recovery in recycling facility rates (Lakhouit, 2025). Furthermore, composting or anaerobic digestion can help households obtain biofertilizers, which in turn increase their motivation to separate organic waste (Meena et al., 2019). Biological treatment of municipal waste is the most rational of the various approaches to waste management in terms of cost, potential and generation of non-toxic products. However, these technologies can only be successfully implemented if they are supported by national and local governments (Banerjee and Arora, 2021). In addition, in China, AI-driven route optimization and IoT-enabled real-time monitoring deployed in Beijing resulted in 25% fewer garbage collection trips and 30% fewer garbage overflow incidents (Yao et al., 2024). Moreover, there is a waste management system developed based on the WeChat small program. Users can take pictures of garbage on site and directly check the garbage classification standards, with a picture recognition accuracy of 80% (Chen et al., 2023). These examples demonstrate how technology is transforming the traditional waste management industry, reducing waste at its source and enhancing resource utilization.

Mechanism of Technological Intervention: The mechanism of action of technological intervention in waste governance is multifaceted. Firstly, it transcends spatial and temporal constraints, lowering participation costs (He et al., 2024). Secondly, it enhances the diversity and synergy of governance bodies (Castro et al., 2017). Finally, technology reshapes the governance process, facilitating the integration of top-down resources with public participation (Imran et al., 2024). Technology is not only embedded in the development of ecological and environmental problems, but also has a broad impact on the entire chain of ecological governance. From concept to practice, from tool selection to process design, and even to goal setting and structural optimization, technology profoundly influences governance practices. It also serves as a mediator, regulating the interactive interface between ecology and technology and promoting the modernization and transformation of governance systems and capacities (Mukherjee et al., 2021).

Challenges of Organic Waste Utilization: Organic waste utilization represents an environmental technology that offers both economic and ecological benefits. However, there exists an inherent contradiction between technological progress, economic growth, and ecological and environmental protection (Lavee, 2007). Despite the transformative impact of intelligence on traditional waste management paradigms, environmental governance issues persist, such as neighborhood campaigns and environmental protests stemming from the inappropriate distribution of treatment facilities (Huang and Yang, 2020). Intergenerational injustice due to unsustainable processing and unequal access resulting from the digital divide are also concerns (Martínez-Peláez et al., 2023). New technologies have introduced novel challenges, including the impact and changes to the organic waste recycling model, resource use, and psychological identity associated with the rise of digital and smart technologies (MacKenzie and Julia Christensen, 2015). While technological advancements present numerous opportunities for waste management, they also necessitate the employment of diverse strategies and continuous adaptation and improvement of existing management systems to address complex and evolving realities.

2.3 Shortcomings of extant studies and the NED theory in UCWM

While extant studies have explored the theoretical paradigms and practical paths of UCWM in a multidimensional way, there are still obvious shortcomings. First, although extant studies emphasize the complementarity between external interventions and internal resources, most of them treat the two as parallel or static elements and have insufficient analysis of the dynamics and coordination of "internal and external synergy mechanisms" This dynamic analysis would include, in particular, how to achieve the organic integration of policy tools and endogenous community dynamics through institutionalized design. For instance, while technology-driven solutions enhance efficiency, they frequently overlook socio-cultural embeddedness, leading to superficial resident participation and an inability to address entrenched barriers to behavioral change. Secondly, while extant theoretical frameworks encompass the technological, institutional, and community dimensions, they often adopt a compartmentalized perspective and lack integrated theoretical tools to elucidate the interactions of multiple actors in complex urban systems.

The NED theory represents an innovation in the field of waste management by offering a unique approach that diverges from both traditional exogenous and endogenous development models. In contrast to Ostrom (2000), which emphasizes the exogenous model of reliance on external intervention and top-down policies, NED emphasizes the empowerment of local communities through resident-driven advocacy and knowledge-sharing. This bottom-up

approach ensures that waste management practices are tailored to each community's specific needs and contexts, fostering greater ownership and sustainability. Moreover, traditional endogenous models focus primarily on leveraging internal resources. In contrast to Middlemiss and Parrish's (2010) model of community autonomy, NED integrates strategic external linkages and adaptive technologies to enhance transparency and community agency. Additionally, NED incorporates social innovation through educational programs that promote collective ownership and circular living, thereby creating a holistic ecosystem where environmental, technological, and social dimensions co-evolve. By harmonizing these elements, NED addresses the limitations of existing models. It provides a replicable blueprint for transforming urban neighborhoods into resilient, self-sustaining hubs, thus redefining the landscape of waste management governance.

3 Organic waste management and endogenous development of urban communities: an analytical framework

3.1 The concept of NED theory

The evolution of development models in modern societies has followed a typical trajectory from exogenous growth to endogenous development, culminating in the emergence of the NED Theory. This progression not only reflects profound changes in socio-economic structures but also signifies a deepening understanding of the dynamics and mechanisms of development. In the early stages of social development, economic growth was primarily driven by external factors such as the exploitation of natural resources, labor force expansion, and technology importation. However, this model, reliant on external resource inflows, has led to issues like resource depletion, environmental pollution, and increased social inequality over time. Moreover, it has fostered a high degree of dependency on external conditions, which can adversely affect local economic development when these conditions change.

With the rising concern for sustainability, an "endogenous" stage of development emerged, emphasizing knowledge, technological, and institutional innovation as key drivers of long-term economic growth (Grossman and Elhanan, 1994). The Dag Hammarskjold Consortium underscored the importance of promoting regional development from within, advocating for the cultivation of indigenous, cultural, and human resources within villages to propel economic growth and rural transformation through internal forces (Cardoso and Nerfin, 1977). This perspective is widely recognized in academic circles. However, the endogenous development model may lead to an over-reliance on internal resources and traditional management methods (Abdallah, 2025a). As a result, the update of advanced technology lags, and it is difficult to cope with the growth of the number of practical development problems and the complexity of the type. Its emphasis on local self-management is easy to form a closed system, and it lacks an effective linkage mechanism with external resources and subjects (Abdallah, 2025b). In addition, under the endogenous development model, the community has limited fundraising capacity, which makes it difficult to undertake continuous investment in publicity, team building and infrastructure maintenance. At this time, if the cultivation of residents' awareness of development or the management ability of community self-government organizations is insufficient, the system may become a mere formality, and it is difficult to achieve the systemic goal of grassroots development.

Reflecting on traditional exogenous and endogenous development models, Ray (2006) introduced the NED Theory, aiming to reconcile the tensions between the two and provide a more integrated and coordinated approach to regional development. Rooted in the core ideas of the endogenous development model, the NED Theory underscores the autonomy of local communities and the utilization of internal resources. However, it also acknowledges the necessity of external support and collaboration. The NED Theory posits that truly endogenous development is rare in practice and advocates for a hybrid model that transcends the limitations of purely endogenous or exogenous approaches. It emphasizes the dynamic interactions between local areas and their broader political, institutional, market, and natural environments (Adamski and Gorlach, 2007; Gkartzios and Scott, 2014).

The NED Theory extends beyond the economic realm, encompassing social inclusion, environmental protection, and the enhancement of population quality of life. It promotes a holistic view that not only integrates different sectors but also facilitates collaboration among various levels, such as local governments, ENGOs, and national governments, to support local development (Gkartzios and Scott, 2014). Furthermore, the NED Theory underscores the significance of power relations between local and supra-local domains, advocating for cooperative relationships that facilitate stakeholder participation in decision-making processes (Shucksmith, 2009).

The core concepts of the NED Theory include:

1. Integrated Development Perspective: Moving away from the constraints of the traditional bottom-up endogenous development model towards an integrated view that values the uniqueness and autonomy of local communities while recognizing the need for external support to foster local development.
2. Community-Based Empowerment Strategy: Advocating for the empowerment of local communities through appropriate external interventions rather than relying solely on external assistance or prescriptive measures.
3. Open and Supra-Local Practices: Unlike the previously closed localism confined to specific geographical areas, the NED Theory promotes considering local development within a broader context (Ward et al., 1995).
4. Structural "Up-and-Down Linkage" and "Internal and External Symbiosis": Emphasize leveraging favorable conditions, such as policy concessions and financial subsidies from various government levels and external institutions, while maintaining local autonomy. They also promote horizontal linkages among various social organizations, enterprises, and individuals to foster a collaborative development pattern.

The NED Theory is inherently aligned with constructing UCWM orders. Firstly, the urban community is a relatively fixed

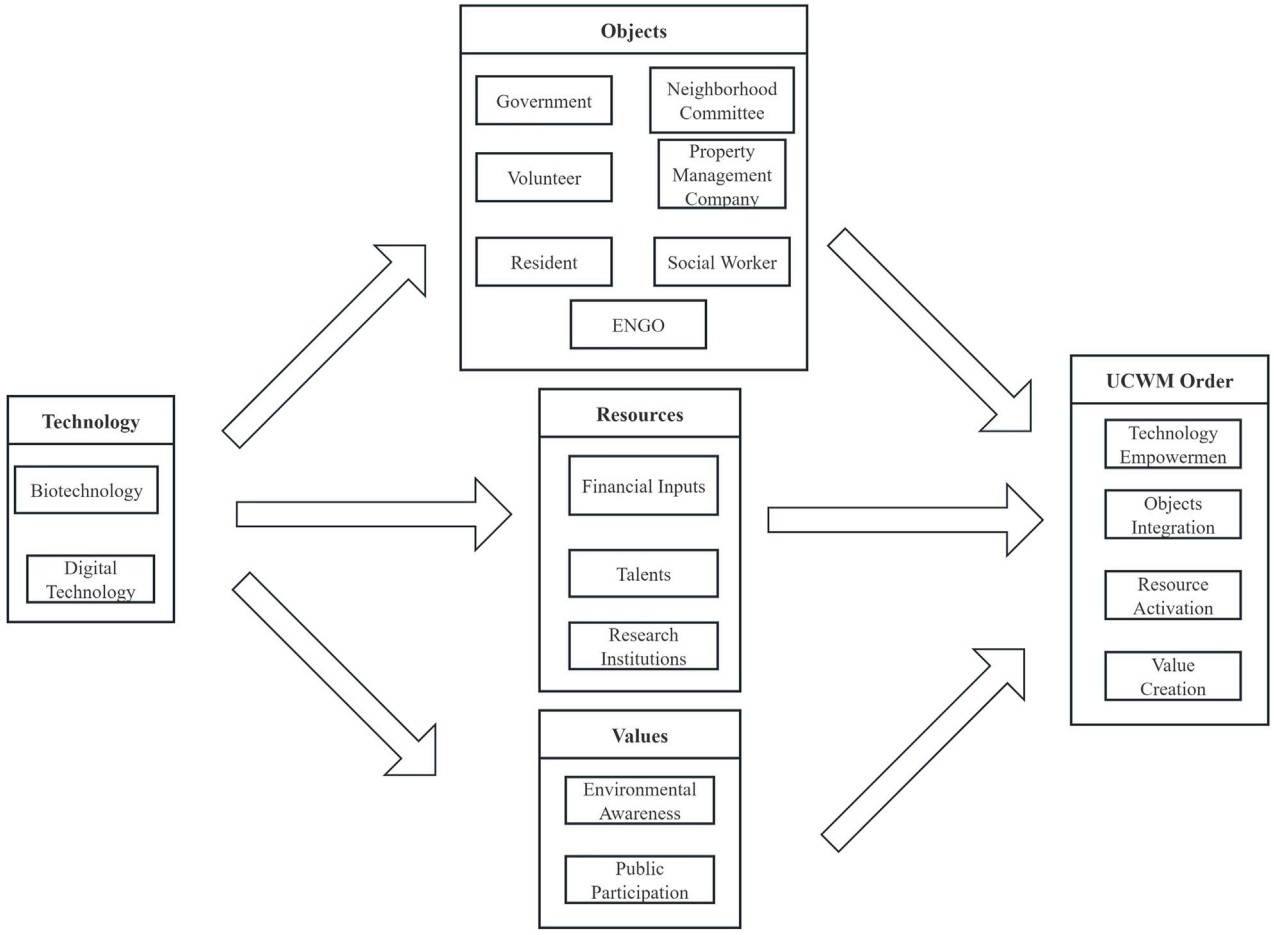

FIGURE 1
The NED framework for UCWM.

spatial field at the grassroots level. Secondly, the integrative development perspective advocated by the NED Theory aligns with the objective of UCWM, which necessitates national-level support to motivate grassroots communities and engage residents as active participants in waste management initiatives. Thirdly, the NED Theory's emphasis on embedding external resources and activating internal resources aligns with the technical foundation provided by the waste management order construction and the characteristic resources of local communities. Lastly, the NED Theory's focus on value enhancement and development is consistent with the vision of a UCWM order that fosters community cohesion and sustainable bottom-up development.

3.2 Framework construction: NED framework for UCWM mode

Integrating biotechnology, digital technology, and UCWM is forging a novel social order and environmental governance paradigm in urban areas. This study proposes an explanatory framework for UCWM based on the analytical perspective of the NED Theory, utilizing waste management models from two grassroots communities in Beijing and Shanghai, China. This framework comprises three modules: external drivers, endogenous development forces, and order construction, and encompasses four essential elements: technology, objects, resources, and values. The theoretical framework is shown in Figure 1.

1. Technology Empowerment: Technology, especially digital platforms and biotechnology applications, plays a key role in UCWM. Digital technologies such as IoT, smart trash cans, and smartphone apps are helping to improve the efficiency of waste management and attract community residents to participate in UCWM. Biotechnology, such as bio composting, turns waste into organic fertilizer for residents to reap the benefits. These technologies have helped to improve waste classification and transshipment practices at the grassroots level. The integration of these technologies is both an external resource and an enabling medium, enhancing the functional role of urban community elements and revitalizing the vitality of the community.
2. Objects Integration: Establishing a UCWM system relies on the collaborative engagement of various stakeholders, including neighborhood committees, governments, grassroots community cadres, social workers, ENGOs and residents.

TABLE 1 The structural framework and research process.

Process/ Reaearch Step	Description/Activities	
Research Design	· Identify the key issues related to lawn research · Reveal the goals, methods used in the related research and a research gap · Selected two Chinese urban communities	Research goal and research questions ⇩
Premise for Conducting Reaserch	· Preliminary list for research gaps and suggestions how they can be covered by the current research · Developing concept, thinking models and NED framework in UCWM	Literature review about multiple forces and technology-driven in UCWM in SCOPUS, ISI Web of Sciences, Google Scholar ⇩ Key issues identified as the main sections of the research
Analysis	· Using qualitative research methods:semi-structured interviewes, participant observation, and text document analysis · NVIVO12.0 Analysis Interview Data · Comparative analysis of two communities	⇩ Analysis of two case study evidence ⇩ Analysis of the relevant publications and documents
Dicussion	· Comparing findings with the existing concepts and results · Reflect (test) the research questions · More deep dicussion about NED and UCWM · Future directions for research on sustainable UCWM	⇩ Discuss the findings in the case study ⇩
Conclusion	· Summary of Central Viewpoints · Propose policy recommendations by sub entities · Disclaimer limitations · Future research prospects	Contribution to the knowledge base

Digital platforms enable eco-digital urban communities to facilitate real-time information sharing, promoting effective aggregation, collaboration, and virtual interaction among participants. This collaborative environment is crucial for the successful implementation and sustained operation of waste management initiatives.

3. Resource Activation: Urban communities possess abundant resources including organic waste, financial inputs, talents, research institutions and so on. These resources are particularly suitable for UCWM. The convergence of digital and biotechnologies has been instrumental in activating these resources, offering environmental professionals new research avenues and technical challenges that stimulate innovation and reinforce social responsibility. By leveraging these resources, communities can enhance their waste management capabilities and promote sustainable development.
4. Value Creation: Developing a community spirit of mutual aid and fostering a positive neighbourhood environment is critical for the sustainability of waste management practices. Digital technologies strengthen environmental awareness, while biotechnologies increase resident participation in waste management and enable direct fertilizer production from waste treatment. The proliferation of digital social media has also enhanced the frequency and convenience of resident interactions, fostering a collective identity and sense of community belonging.

In summary, the NED framework for UCWM mode integrates external drivers, endogenous development forces, and order construction through the four elements of technology, objects, resources, and values. This framework not only provides a comprehensive approach to waste management but also aligns with the goals of fostering community cohesion and sustainable development.

4 Materials and methods

The research process of this study is shown in Table 1.

4.1 Research site

The two cases selected for this study are located in Beijing and Shanghai, China. The exact locations of the two communities are shown in Figure 2. Beijing and Shanghai, two megacities central to

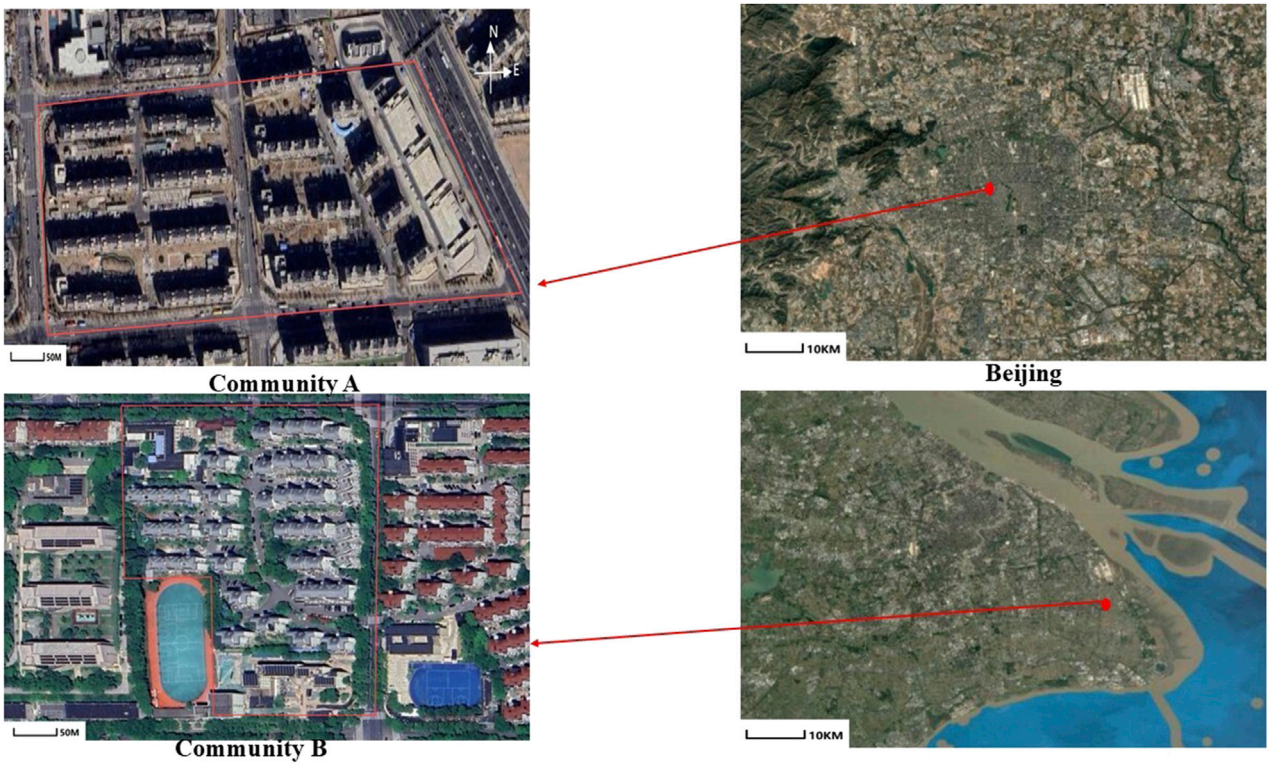

FIGURE 2
Maps of XS &PS.

TABLE 2 The basic information of community XS&PS.

Community	XS	PS
Region	North China plain	Near the mouth of the Yangtze River
Department city	Beijing	Shanghai
Size (km2)	0.0988	0.0769
Community Features	High-end urban commercial	Older urban
	housing neighbourhoods	workers' neighbourhoods

China's socio-economic landscape, exemplify contrasting urban identities yet share critical waste management pressures. Beijing (16,410.54 km^2), the nation's political core, and Shanghai (6,340.5 km^2), its financial hub, differ markedly in spatial and functional priorities. However, both confront escalating waste volumes reflective of their dense populations and consumption patterns: Beijing generates 26,000 tons of household waste daily (1.2 kg/capita), while Shanghai produces over 30,000 tons (0.82 kg/capita). These disparities in *per capita* output highlight distinct urbanization dynamics—Beijing's larger land area accommodates dispersed waste infrastructure, whereas Shanghai's compact geography intensifies disposal pressures. To address these challenges, both cities prioritize waste sorting initiatives, circular economy technologies, and recycling rate optimization, forming a strategic backdrop for examining community-level interventions.

Within these urban contexts, the XS and PS communities offer contrasting yet complementary microcosms for analysis. The XS Community in central Beijing comprises 64 middle-class intellectual households residing in a high-end commercial housing complex. Its waste management strategies, developed through collaborations with external social organizations, emphasize technological innovation and policy compliance. Conversely, the PS Community in Shanghai—a 76,900 m^2 neighborhood established in 1982 with 1,818 households—prioritizes social mobilization through partnerships with local governments and ENGOs, leveraging its elderly-dominated demographic to institutionalize waste separation practices. This deliberate selection of cities and communities ensures methodological diversity: XS reflects top-down, expertise-driven approaches typical of Beijing's politically anchored governance, while PS exemplifies Shanghai's grassroots, socially embedded problem-solving. Together, they enable a robust

exploration of how NED theory reconciles systemic external support with localized agency in urban sustainability transitions. The basic information of the two communities is shown in Table 2.

4.2 Criteria for case selection

Both communities were chosen to represent the NED model for four reasons.

4.2.1 Governance structure and collaboration mechanisms

The two communities selected for the case study have established a multi-level waste management framework covering government leadership, residents' autonomy, and social organization participation, as well as a regular consultation mechanism. This innovative translation of the NED theory into institutional practice is a significant contribution to the field.

4.2.2 Indicators of practice effectiveness and resource recycling

The waste management level of the selected case communities was evaluated through three indicators: the effectiveness of waste reduction at source, the utilization rate of resources, and the level of harmless disposal. The two urban communities are at an advanced level among similar communities in terms of waste generation reduction, the accuracy of recyclables sorting, the scale of recycling of renewable resources, the proportion of application of resource transformation technologies such as composting of food waste, and rate of specialized collection and compliant disposal of domestic waste.

4.2.3 Institutional and cultural support standards

First, both Beijing and Shanghai have local regulations or community conventions to support waste management. Secondly, urban residents in Beijing and Shanghai generally have a high level of education and environmental awareness. This heightened level of participation facilitates the implementation of waste management practices at the community level, supporting the development and refinement of NED models. Thirdly, the two selected communities implemented regular training on waste classification, interactive publicity activities, and the establishment of teams of environmental volunteers to enhance residents' participation in waste management.

4.2.4 Innovation and sustainability

The two case communities have expanded waste management coverage and ensured its effectiveness by adopting innovative technologies, such as bio-waste treatment technology and IoT monitoring systems. Over the past 3 years, the rate of waste reduction has continuously increased, accompanied by a sustained capacity for self-management.

Unlike most studies, which use NED primarily to analyze rural development issues (Georgios et al., 2021; Qu and Zollet, 2023), this research uses two urban communities that have achieved some success in waste management for a more in-depth analysis. This approach aims to address the lack of application of NED theory in urban grassroots governance, particularly with regard to environmental governance and waste management. The relatively mature governance structures of the XS community in Beijing and the PS community in Shanghai, along with their resource base and organizational capacity, can more clearly demonstrate the 'activation of endogenous dynamics by external technological inputs' mechanism of NED theory. These communities also have a policy reference value. Additionally, while qualitative research methods such as ethnography and in-depth interviews require a long immersion period, the dual case study strikes a balance between depth and a comparative perspective. This approach achieves an optimal balance between in-depth contextual understanding and comparative logical rigor. This avoids the limitations of single cases and the superficiality of multiple cases, making it an ideal approach for exploring complexity and developing a meso-theory.

4.3 Methods, procedures and data analysis

This study utilizes a qualitative research methodology, which involves the examination of how urban communities develop NED models of waste management and the exploration of the logic underlying this dynamic process. In contrast to quantitative methods, qualitative research can prioritize the context of the study, thereby facilitating a more in-depth exploration of the underlying reasons for a phenomenon and a more nuanced understanding of the implications of the researchers' explanations of their actions. Furthermore, qualitative methods facilitate a deeper comprehension of the underlying motivations and processes behind actions among different subjects.

This study utilizes a multi-case, in-depth analytical framework to select two urban communities for empirical investigation. The survey methodology consisted of three methods: semi-structured interviews, participant observation, and text document analysis. Semi-structured interviews and participatory observation were conducted in the field between September 2021 and September 2023. The following methods were used to conduct the survey. We interviewed ten people in each community. Twenty people were interviewed in two communities in total. First, five key people including community managers, ENGO representatives, community sanitation workers, and resident opinion leaders involved in waste management from each community were interviewed. The interviews focused on conflicts, negotiation mechanisms, and the logic of role interaction in waste classification practices. Each interview lasted 60–90 min and was conducted in closed offices. The remaining five interviewees are community residents. We first obtained a family roster from the community, and then selected one household based on sampling criteria for age group and family structure, including core families (consisting of parents and unmarried children), main families (three or more generations living together, including grandparents, parents, and children), single family (with only one resident), empty nest families (where only one parent or one parent resides after the children leave home as adults), and DINK families (where both spouses have no children). We believe that different types of households are crucial for residents' awareness of waste classification and environmental participation (Nainggolan et al., 2019). Second, with the consent of the residents, we randomly entered the homes of five residents in each community to observe their management of

TABLE 3 Nodes and code information of thematic analysis.

Node	Code	Case
Technology	Digital Technology	"You can see how to handle garbage on WeChat mini program."
	Biotechnology	"Earthworms have decayed all those leaves."
object	Government	"There are many supportive policies."
	Volunteer	"Elderly people often do volunteer guidance."
	Resident	"Everyone is enthusiastic and enthusiastic."
	ENGO	"WK has introduced us with foreign technology."
	Neighborhood Committee	"The neighborhood committee has done a lot of publicity."
	Property Management Company	"The property service is very good."
	Social Worker	"Social workers have organized environmental protection activities."
Resource	Financial input	"A lot of money was invested above."
	Talent	"Many experts provide guidance."
	Research Institution	"Universities and research institutes have provided community guidance."
value	Environmental Awareness	"Creating a good environment is crucial."
	Public Participation	"Many people come to garbage classification."

TABLE 4 Basic elements of NED in two cases.

Dimensions of NED Theory	XS	PS
Technology	· Application of the "City Brain"system · IoT trash bins + centralised data platform for real-time monitoring	· Intelligent waste sorting monitoring platform · Intelligent recycling bins + WeChat mini programme to track recycling revenue
Objects	· Middle-class residents · Property management company · WK ENGO · Government	· Elderly volunteer · Social workers · Neighbourhood committee · AIFEN ENGO · Government
Resource	· WK's Technical and Financial Support · Leveraged nearby university research resources	· WK's Technical and Financial Support · Community talents
Value	· The model of "participation learning practice" · Cultural atmosphere of sustainable development	· Improved compliance with waste separation policies · Strengthened community cohesion

household waste. We also visited the community's waste management process and facilities, participated in environmental protection activities and attended their seminars. Thirdly, this study collected a large number of government policy documents from different levels and minutes of meetings held by communities, property management, ENGOs, and residents. This integration is used to reveal the differences between institutional design and grassroots practice, thereby elucidating the adaptation gap. This integration is used to reveal differences between institutional design and grassroots practice, thereby elucidating the adaptation gap.

All interviews were audio-recorded and subsequently transcribed verbatim with the interviewees' consent. Two rounds of coding were used to analyze the transcripts using NVIVO 12.0 software. The coding process was carried out in two iterative rounds. In the first round, open coding was applied to identify initial codes directly from the data, allowing for the emergence of patterns grounded in participants' narratives. In the second round, axial coding was used to categorize and refine these codes into higher-order conceptual themes aligned with the NED framework, including technology, object, resource, and value. To ensure the reliability of the coding process, two researchers independently coded a sample of transcripts (35% of the total data). Inter-coder reliability was assessed using Cohen's Kappa coefficient, which yielded a value of 0.82, indicating substantial agreement (Landis and Koch, 1977). Two coders discussed data saturation and coding differences, and modified different coding rules and code definitions until consensus was reached on all coding materials. Nodes and code information of thematic analysis can be seen in Table 3.

To maintain the confidentiality of the interviewees, the interview transcripts were anonymously organized, and all information was used for scientific documentation. This study improved the reliability and validity of the findings by cross-referencing interviews and observational and textual evidence through triangulation (Bylund and Norman, 1972).

5 Case studies

Each dimension of the NED theory in both of the case studies is summarized in Table 4. It systematically outlines how the principles of the NED theory manifested within each case, enabling a clear comparison of the similarities and differences in their application.

5.1 XS communities: The NED model for waste management in new urban neighborhoods

The Beijing XS Community is a waste management pilot project run by the WK Public Welfare Foundation. Initially, a group of residents who were highly aware of and committed to waste classification moved into the community and suggested to the property management company that waste classification be implemented within the community. At the time, Beijing was one of China's first pilot cities for waste sorting and the government was encouraging the public to participate in waste classification initiatives to advance the implementation of policies. In response to this call and to address residents' requests, the XS took its first steps towards waste sorting. It has integrated waste classification into its daily management system and continuously improved its storage and transportation infrastructure. As a result, waste classification has become a stable preliminary step in the community's waste management process. The daily workflow involves residents reducing waste at source and sorting it properly, followed by the property management team collecting the classified waste on schedule. Adhering to the principle of 'daily collection and daily clearance, classified transportation', different types of waste are transported to transfer stations or waste treatment facilities for further processing.

A key turning point occurred when the WK Foundation selected XS Community for its flagship Waste Management Program, which introduced crucial external technical and financial resources. Drawing inspiration from Bangalore's "gadfly treatment + vermicomposting" model, the community adapted this innovation to suit local conditions. This model utilizes Hermetia illucens, commonly known as black soldier fly larvae, to facilitate the conversion of kitchen waste. The process integrates leaf litter composting with organic matter composting within a vermicomposting system, thereby creating a balanced ecological cycle. The gadfly, a type of carrion fly, has larvae capable of consuming food waste up to 200,000 times their body weight. After feeding for 7–8 days, the larvae transform into protein-rich worms, which serve as valuable feed for poultry and fish, offering significant economic benefits. The odorless droppings produced by the larvae can also be directly integrated into composting as organic matter. Additionally, the seasonal garden waste that accumulates every autumn in Beijing, which poses challenges for the gadfly process, was addressed through aerobic composting in perforated fermentation boxes. The fertilizer is used separately for urban greening and green plants in residents' homes. This hybrid approach highlights NED's emphasis on tailoring external solutions to fit local ecological and infrastructural contexts.

The implementation of the 2020 Haidian District of Beijing Urban Brain System marked another significant milestone in line with NED principles. This system utilized IoT (Internet of Things) -enabled waste bins, transport vehicles, and a centralized data platform to enable real-time monitoring and traceability. Crucially, this technology was not imposed top-down but instead served as a tool to enhance community agency. Both residents and property managers could access data to optimize waste sorting accuracy, while local authorities used the insights to allocate resources efficiently (e.g., dispatching cleanup crews via GPS). This integration of community participation with smart governance highlights NED's focus on co-designing systems that unite local actors and institutional authorities.

In addition to improving infrastructure, the XS Community prioritizes social innovation and integrates sustainability into everyday life. The community brings together multiple stakeholders, including ENGOs, property management companies and research institutions, to collaborate on planning and executing activities, thereby fostering a collaborative environment among diverse participants. Over the past 3 years, the community has organized the 'Zero Waste Day' initiative, comprising activities such as creating plant-printed eco-friendly shopping bags, playing waste sorting games, making DIY comfrey ointment, and holding a flea market for exchanging used items. Furthermore, community gardening and nature education workshops transform environmental practices into collective activities. During the second-hand goods exchange market, the community collaborates with local second-hand trading platforms to provide residents with convenient exchange channels. Nature education workshops invite university experts and scholars to deliver lectures, enhancing the professionalism and authority of the activities. These social innovation initiatives establish a 'participate-learn-practice' model, fostering a cultural atmosphere of sustainable development within the community.

The efficacy of the NED model is evident in XS Community's several key outcomes: a 30% reduction in household waste, annual savings of 114.88 tons of CO_2 equivalent (roughly the carbon offset of planting 1,149 trees), and the establishment of a self-sustaining organic waste loop that converts food scraps into soil enhancers for community green belts. Residents report heightened environmental awareness and a strong sense of pride in their "zero-waste" identity. These outcomes underscore the NED model's strength in aligning ecological goals with socio-economic resilience. By internalizing waste management as a collective responsibility, supported by adaptive technology and cross-sector partnerships, the XS community provides a replicable model for urban sustainability.

In the XS community, there is a heavy reliance on advanced technologies such as IoT infrastructure and smart governance platforms, which have raised concerns about technological exclusion. Residents with limited digital literacy, such as the elderly or new immigrants, may struggle to participate meaningfully, creating a digital divide within the community. On the other hand, these systems depend on ongoing technical support and financial maintenance, and community residents have questioned whether the significant investment in related technologies is sustainable and worthwhile.

5.2 PS communities: A NED model of waste management in older urban neighborhoods

The PS community's experience in waste management offers a valuable illustration of how local institutions, working in

collaboration with strategic external interventions, can effectively address urban sustainability challenges. Initially, the adoption of waste classification practices was threatened by resistance, especially from time-pressed young tenants. However, the community capitalized on endogenous social capital. In August 2016, the PS community established a team of 21 community volunteers for the implementation of waste classification, one-third of whom were members of the community's Communist Party. The supervision and code-sweeping duty work for waste classification is carried out according to a shift system. The PS Community also carries out various kinds of waste management-themed activities, such as solid waste base visits, waste classification knowledge contests, and community-used bike replacement, to continuously improve the knowledge, participation, and cohesion of waste classification among the community residents. In addition, in 2019, the PS community invited a community theatre group to perform a situational comedy on the correct classification of refuse. The entire community committee also performs a publicity song on the correct classification of waste with children in the community. These events serve to illustrate the NED model's emphasis on community-driven leadership, thereby transforming waste classification from a policy mandate to a shared social norm. This mobilization, which is rooted in the community, has two notable outcomes: improved compliance with waste classification policies and strengthened community cohesion. The former is indicative of the NED model's emphasis on utilizing internal relational assets to catalyze systemic change, while the latter is a reflection of the community's capacity for collective action.

With the support of both policy and digital technologies, PS Community has collaborated with AIFEN, an ENGO, to introduce professional services for waste management. In particular, the community has made bold strides in food waste treatment. By constructing a glass greenhouse and implementing edible landscaping, PS Community is converting food waste into organic fertilizer for growing flowers and vegetables, beautifying the environment while also meeting the residents' needs. To manage pet waste, the community installed a "vermicomposting tower" in the greenhouse, where earthworms decompose organic waste into fertilizer, thus enhancing resource recycling. Vegetables and fruits such as eggplants, cucumbers, squash and peppers are harvested and given to elderly people living alone. Additionally, PS Community has implemented several initiatives to motivate residents and ensure effective waste separation. For instance, a "green account" mechanism encourages residents to separate waste properly in exchange for points. Every Thursday morning, the community designates a "Community Greening Consultation Day," where community gardeners address residents' questions about maintaining green spaces. The community also regularly updates its WeChat public account with information on green public service activities and waste management, producing a series of short videos to promote environmental protection and create a participatory atmosphere for sustainable development.

On 31 July 2019, the Shanghai Municipal Domestic Waste Management Regulations came into effect. The Jing'an District, where the PS Community is located, has established an intelligent waste classification monitoring platform. The platform provides an intuitive overview of waste classification data, resource utilization, and the routes of waste collection and transport vehicles, offering valuable insights for governmental decision-making. Additionally, Jing'an District set up a 24-h recycling service point near the PS Community, where residents can sort and deposit recyclables using smart recycling bins. Residents can track their recycling proceeds via the WeChat applet.

After years of sustained effort, the PS Community has significantly improved its waste classification efficiency, reducing contamination of dry waste bins. The average daily reduction in household waste per household reached 417.45 g, which is 166.80% of the previous amount. The community has also developed special green eco-spaces, such as greenhouses, herb gardens, and vegetable plots, through food waste composting and edible landscaping projects. Residents frequently engage in environmental education activities within these eco-spaces, which have become key components of the community's green ecosystem, connecting broader community greening efforts with individual garden projects at residents' doorsteps.

In the PS community, it can be observed that waste management was initially met with resistance and non-cooperation from residents of different ages and occupations. The composition of the urban community is relatively complex and heterogeneous, making it challenging to unify everyone's thinking. Additionally, the most active residents and primary volunteers in the PS community are elderly. While they are enthusiastic and have the time, their capabilities are limited. The question of how to leverage the influence of the elderly to encourage more young people to participate in community waste management is a concern shared by all.

5.3 Cross-case analysis

The significant disparities in governance, participation, use of technology, and results in two communities can be seen in Table 5. This research focuses on analyzing the practices of the XS and PS communities in the course of studying UCWM. From a governance perspective, the XS community adopts a property management-led model. It is drawing on international experiences and adapting them to local contexts in order to establish its governance logic. The PS community, on the other hand, is led by a residents' committee that leverages the community's internal social capital to drive waste management efforts. The two communities' governance approaches differ due to variations in their initiating entities and resource dependencies. In terms of participation, the XS community focuses on middle-class residents, aiming to influence the community's waste management culture through their involvement. The PS community prioritizes elderly residents, leveraging their community integration and time advantages to establish a unique participation system. In the recycling and reuse phase, XS uses a biological conversion model involving black soldier fly larvae and earthworm composting. The resulting fertilizer is used for urban greening and resident gardening. PS creates a greenhouse ecosystem in which kitchen waste is used to cultivate vegetables and support elderly residents living alone. PS also sets up earthworm composting towers to process pet waste, achieving distinct resource circulation pathways.

Regarding incentive mechanisms, XS fosters an environmental protection atmosphere through social innovation activities, using

TABLE 5 Comparative Table: XS and PS communities.

Dimension	XS	PS
Governance	· Property management-led · Drawing on foreign models and adapting them to local conditions	· Led by neighbourhood committees · Driven by endogenous social capital
Participation	· Focusing on middle-class residents	· Focusing on elderly residents
Recycling	· Biological transformation mode: black soldier fly larvae and earthworm compost · Fertilizer is used for urban greening and residential gardening	· Greenhouse ecosystem: Using kitchen waste to fertilize and grow vegetables, serving elderly people living alone · Earthworm composting tower for treating pet feces
Excitation	· Implicit motivation: Creating an environmentally friendly atmosphere through social innovation activities · Ecological Value Driven: Sustainability from Organic Waste Recycling	· Explicit incentive: "Green Account" points redemption · Community service linkage: Points can be exchanged for green consulting and other services
Results	· A 30% reduction in waste, resulting in annual carbon emissions reductions of 114.88 tonnes.	· The average daily reduction in household waste per household reached 417.45 grams, which is 166.80% of the previous amount.

implicit incentives and ecological value to encourage participation among residents. PS uses a 'green account' points redemption system with explicit incentives, where points can be exchanged for community services such as landscaping consultations. The difference in incentive approaches stems from different interpretations of what motivates residents to participate. In terms of outcomes, XS achieved a 30% reduction in waste, as well as annual carbon emission reductions of 114.88 tons. PS achieved an average daily reduction in household waste of 417.45 g per household, which is a 166.80% increase on previous levels. These results demonstrate the effectiveness of the two models in waste management.

6 Discussion

6.1 Multivariate elements of UCWM in the NED model

The integrated operation of technology, objects, resources, and values constitutes the foundational logic of sustainable UCWM under the NED framework. Each element contributes a distinct yet interdependent function in shaping environmental governance at the grassroots level. More importantly, it is their mutual reinforcement—rather than their attributes—that forms the core mechanism enabling resilient, adaptive, and inclusive waste governance systems.

6.1.1 Technology empowerment

The NED theory emphasizes a holistic strategy that harnesses both internal and external resources, particularly emphasizing the pivotal role of external dynamics in motivating and empowering community members (Bosworth et al., 2016). This theory posits that by introducing external stimuli and support, the inherent vitality of the community can be effectively activated, thereby fostering a sustainable development model. The two cases analyzed in this study exemplify how the application of digital technology and biotechnology has catalyzed grassroots communities. This stimulates innovation in waste management models and heightens residents' enthusiasm for participating in community environmental management.

Digital technology is reshaping the UCWM system with the advent of a digital governance platform integrating information collection, processing, analysis, and waste management research and evaluation. This integrated approach significantly enhances governance efficiency. On the one hand, the government establishes a unified digital governance platform to achieve real-time sharing of environmental information, enabling all stakeholders to participate in governance based on comprehensive information. This transparency fosters trust among parties and encourages broader public participation. On the other hand, the introduction of digital technology provides residents with diverse channels for participation, enriching community communication (Galassi at al., 2021). It enables the public to engage more conveniently in environmental protection activities, receive the latest community news instantly, provide feedback and suggestions to relevant authorities, and proactively participate in various environmental initiatives. This shift not only strengthens residents' sense of belonging and ownership but also paves the way for more efficient and democratic community governance.

The integration of biotechnology further empowers the objectives, environmental settings, contents, and methods of waste treatment, leading to a transformative change in the entire system (Farid et al., 2023). This transformation is not solely driven by the functional attributes of the technology itself or the cognitive differences among individual residents but rather results from a complex and dynamic interplay between the two. Firstly, the introduction of biotechnology alters residents' perceptions and expectations regarding waste treatment. It not only improves treatment efficiency and mitigates pollution risks but also prompts a reevaluation of waste value and its role in the broader ecological cycle (Xu et al., 2019). Secondly, changes in residents' perceptions play a crucial role in this process. As public environmental awareness rises and technology diffusion education deepens, more community members begin to comprehend and embrace new waste management methods. They are willing to alter their daily habits, practice waste separation, and actively participate in localized waste management initiatives. This societal response, in turn, spurs the adoption and development of more innovative technologies and solutions (Coccia, 2019). The interaction between biotechnology

applications and residents' environmental behaviors constitutes a continuous evolutionary process, reinforcing each other.

In the context of transforming UCWM models, community consensus and acceptance of human-technology integration and technological innovation are crucial for fostering grassroots practice innovation. They also serve as a significant impetus for communities to shift from traditional waste management towards an ecological and intelligent approach. Firstly, community consensus and acceptance pave the way for adopting new technologies. When community members understand and appreciate the value of novel waste management technologies, they are more likely to actively participate in their implementation. This creates a positive feedback loop: as more residents engage in environmental practices, the effectiveness and tangible benefits of the technology become more evident, which further attracts more participants. Secondly, community support is essential for ensuring the sustainability of technological innovations. If residents can recognize the long-term environmental and social benefits of new technologies and are willing to accept their potential risks, these innovations are more likely to be practically adopted. Lastly, residents' sense of identity strengthens community cohesion. Residents build stronger trust and connections by collaborating on environmental actions and forming a tighter social network. This social network is vital for addressing new challenges that may arise from future innovations. By fostering greater collective action and individual responsibility, the community as a whole becomes more resilient and adaptable (Zahra and Shohibuddin, 2025).

The deeper integration of technology embedding and ecological management in urban communities, as advocated by the NED theory, is critical for advancing waste management systems. Digital technology facilitates efficient information sharing and public participation, while biotechnology transforms waste treatment processes and enhances residents' environmental awareness. The synergistic effect of these technological advancements, combined with community consensus and support, fosters sustainable waste management models that contribute to ecological and socio-economic wellbeing.

6.1.2 Objects integration

Objects are central operational agents in UCWM. Rather than viewing governance as the product of abstract systems or isolated technologies, focusing on these actors reveals the social mechanisms that mediate implementation. Objects provide both legitimacy and structure: residents' participation confers social acceptance, while government and ENGO involvement ensures regulatory and professional support (Lu and Sidortsov, 2019). Critically, these actors act as translators, mediating between top-down policies or technical tools and everyday behavior. Their capacity to interpret, adapt, and embed technological solutions into local routines determines whether interventions succeed or remain symbolic. Moreover, objects form the relational infrastructure of governance: their coordination shapes whether UCWM systems become fragmented or synergistic. When properly aligned, these actors create a collaborative governance ecosystem where each contributes specific capacities—governments offer authority and funding, community organizations facilitate communication and execution, ENGOs introduce technical expertise, and residents anchor behavioral change (Natasha, 2019). Thus, object integration is not merely administrative; it is foundational for building trust, aligning goals, and transforming waste management from externally imposed systems into endogenous, collectively sustained practices.

6.1.3 Resource activation

Resources encompass not only material inputs such as space, tools, and funding but also intangible community assets—local knowledge, volunteer labor, time, and social networks. In UCWM, mobilizing these endogenous resources is essential to bridge implementation gaps that external interventions alone cannot address (Zucaro and Agostinho, 2025). Activated internal resources foster autonomy and resilience, allowing communities to manage systems sustainably without overreliance on external subsidies (Osborne et al., 2021). More importantly, they generate local ownership: when residents contribute knowledge and labor, they shift from passive recipients to active co-producers of governance. This participation reinforces commitment and legitimacy. Resource-rich communities also exhibit greater adaptive capacity. They are more capable of absorbing new technologies, adjusting to policy shifts, and refining practices through iterative learning. Rather than viewing resources as static inputs, they function as dynamic assets that multiply over time through use, coordination, and trust-building. This aligns with the principles of NED, which emphasize empowering communities from within. Ultimately, sustainable UCWM depends not just on financial or technical inputs but on recognizing and cultivating the often-overlooked capacities already embedded in community life. Activating these resources transforms UCWM from a compliance-driven obligation into a resilient, co-managed system rooted in local agency.

6.1.4 Value creation

Values—such as environmental awareness, civic responsibility, reciprocity, and trust—constitute the normative foundation of sustainable urban governance (Knox-Hayes et al., 2021; Morrow and Davies, 2022). They shape internal motivations that go beyond rule-following, enabling communities to engage in self-regulation and collective action even in the absence of external enforcement (Kramer et al., 2024). When governance is underpinned by shared values, policies and technologies are not perceived as external impositions but as expressions of a community's ethical commitments and collective aspirations. Values provide the moral legitimacy that justifies behavioral change, anchoring abstract principles—like sustainability or zero-waste living—in daily practices and social rituals (Tavanti, 2023). Without this normative grounding, even the most technically sound waste systems can face indifference, resistance, or rapid decline in participation. Conversely, when environmental values are actively cultivated through education, storytelling, or symbolic recognition, waste management becomes integrated into community identity. Residents begin to view participation not merely as compliance, but as contributing to a shared social good. Such value-driven engagement enhances durability, equity, and cohesion within governance systems (Liu et al., 2025). Ultimately, values do not simply support governance—they transform it, turning waste management from a logistical challenge into a cultural project rooted in pride, purpose, and collective belonging (Garnett et al., 2017).

6.1.5 The synergy among these elements

Importantly, the synergy among these elements is what ensures system coherence and long-term sustainability (Song et al., 2025). For example, technologies can amplify values when they visualize environmental impact or gamify civic behavior; objects can activate resources by coordinating volunteer networks or leveraging local expertise; and strong value systems can legitimize new technologies and institutional roles, smoothing their integration. This interdependence creates positive feedback loops, where success in one domain strengthens performance in others. In this sense, waste governance becomes more than a technical or administrative challenge; it evolves into a complex socio-technical ecosystem governed by mutually reinforcing forces. Recognizing this ecosystemic nature is essential for designing scalable and context-sensitive urban waste management systems. Policies or interventions that target only one element in isolation—such as deploying technology without stakeholder engagement or promoting behavioral change without infrastructure—are unlikely to succeed. Effective strategies must therefore be integrative, adaptive, and co-produced.

6.2 Challenges and solutions of NED in UCWM

The application of the NED theory to UCWM in China presents several notable challenges, particularly concerning multi-stakeholder coordination, resource distribution, public participation, and technology promotion.

One of the primary challenges lies in the coordination and cooperation among different stakeholders, including governments, enterprises, and residents. Each stakeholder often holds distinct goals and priorities, leading to potential conflicts and inefficiencies in policy implementation (Bridges and Guo, 2024). The government prioritizes the overall effectiveness of policy implementation and societal benefits (Whitsel et al., 2024). On the other hand, residents are more concerned with daily convenience and environmental quality. To establish a communication and decision-making mechanism for managing refuse in urban communities, it is necessary to integrate institutional and technological means and promote shared governance through multi-party consultation and transparent processes. The regular organization of residents, properties, enterprises, and the government to jointly negotiate policy options is paramount. The utilization of a combination of online and offline communication methods (e.g., community APP, suggestion box) to collect timely feedback is equally crucial. The establishment of incentive mechanisms (points exchange, honor selection) to enhance the motivation to participate in the process and ensure the implementation of the closed-loop management of the "collection of problems - implementation tracking - results announcement" is also essential. The efficacy of this model is further enhanced by its integration of data-driven tools and flexible consultation, ensuring a balance between scientific governance and community consensus.

The unequal distribution of resources poses another significant challenge. Financial, technological, and human resources are often limited, making it difficult to ensure a fair and reasonable allocation (Henderson and Loreau, 2021). This issue is particularly acute in older urban neighborhoods, where infrastructure is relatively weak, and the cost of introducing and updating technology is high. The uneven distribution of resources not only hinders waste management efficiency but may also exacerbate social equity concerns, as less advantaged communities may lack access to essential waste management services. To enhance the fairness of resource allocation, urban communities must prioritize investments in facilities and infrastructure in disadvantaged communities (Daniel Beltsazar Jacob and Ni Made Utami Dwipayanti, 2022). Such investments are crucial for ensuring the equitable distribution of resources for waste management. Additionally, communities should prioritize the improvement of infrastructure, such as waste separation bins and sewage pipes, by strengthening routine maintenance. Furthermore, communities should promote intelligent recycling equipment and volunteer supervisory programs. Mechanisms to enhance the convenience of waste classification and implement targeted policies to narrow regional gaps, such as customizing collection and transportation programs according to regional characteristics. At the same time, it establishes a dynamic demand monitoring mechanism to mobilize participation through incentives such as point rewards and service redemptions. The implementation of such incentives, including point rewards and service redemptions, has been instrumental in mobilizing participation, thereby establishing a closed-loop management system that encompasses "demand response, resource deployment, and effect assessment" to ensure balanced coverage of facilities and services.

Low motivation among residents represents another obstacle to the successful implementation of NED-driven waste management models. The enhancement of the community outreach of the NED model necessitates the cultivation of environmental awareness and a sense of community responsibility among residents over an extended period. The formation of a collective consensus within a community regarding waste separation and organic treatment has been demonstrated to engender a "herd mentality" among individuals. When integrated with local cultural traditions, such as the utilization of the community's "social acquaintance" characteristics to establish a mutual evaluation mechanism, it has the potential to fortify residents' sense of ecological and moral responsibility. Secondly, the content of education has been demonstrated to directly impact residents' understanding of classification standards and environmental values (Tjakraatmadja et al., 2021). For groups with a low level of education, more intuitive training methods should be employed. For example, environmental awareness brochures could be replaced with "classification cards and explanations in the vernacular."

Lastly, the issue of technology promotion and acceptance cannot be overlooked. Advanced waste management technologies, while potentially transformative, may be unfamiliar to the general public, leading to cognitive barriers. Moreover, such technologies' high initial investment and maintenance costs can be prohibitive for economically disadvantaged communities. Successfully promoting these technologies necessitates a nuanced understanding of community-specific conditions, coupled with a progressive promotion strategy that takes into account residents' acceptance and adaptability. Simultaneously, economic incentives

that align with the requirements of residents should be implemented. Material incentives (e.g., points redemption) are more efficacious for low-income groups, while higher-income groups prioritize convenience services (e.g., door-to-door recycling appointments).

In conclusion, the application of NED theory to waste management in Chinese urban communities faces multifaceted challenges, encompassing stakeholder coordination, resource distribution, public participation, and technology promotion. Addressing these challenges requires a comprehensive approach that involves enhancing inter-stakeholder communication, ensuring equitable resource allocation, fostering public engagement, and adopting a community-centric strategy for technology promotion. By doing so, it is possible to overcome the obstacles hindering the successful implementation of NED-based waste management models, ultimately contributing to more sustainable and resilient urban environments.

7 Conclusion

Against the backdrop of the escalating phenomenon of direct incineration and landfill of waste and the increasing severity of urban environmental problems, the NED theory offers a promising approach to addressing waste management challenges, promoting resource recycling, reducing environmental pollution, and enhancing residents' environmental awareness and social participation. This research adopts the NED theory to explore the formation of sustainable UCWM orders through qualitative methods. This research constructed an NED-based framework to integrate technology empowerment, stakeholder collaboration, resource activation, and value creation. Two urban communities in Beijing and Shanghai are selected as cases. Research indicates that technology can activate the endogenous development potential of communities when acting as an exogenous force. Leveraging platforms to empower and aggregate diverse stakeholders, enabling data interoperability to activate grassroots resources and constructing interactive scenarios to strengthen social connections and environmental awareness can all drive the transition of waste management from external, policy-driven approaches to community-based self-governance. At the heart of the NED model is the coordination of external technological inputs with internal community capabilities, which promotes the synergistic effects of multi-stakeholder collaboration, technological innovation and community empowerment. This provides a replicable theoretical framework and practical pathways for urban ecological governance in China.

The core concept of the NED theory—the integration of external support and internal resources—serves as the foundation for constructing an effective UCWM model. By introducing external resources such as technology, finance, and expertise from social organizations, combined with the community's internal culture and human resources, a more efficient and sustainable waste management system can be achieved. The cases of XS and PS communities demonstrate that successful UCWM models cannot be realized without high levels of resident participation and social mobilization. ENGO and volunteer teams play crucial roles in raising residents' environmental awareness and sense of responsibility, thereby facilitating the smooth implementation of waste classification policies.

Moreover, this study highlights the importance of community consensus and technological acceptance in fostering grassroots innovation. When community members deeply understand and recognize the value of new waste management technologies, they are more likely to accept and actively participate in their implementation. This creates a positive feedback loop, where increased participation leads to more visible benefits, further motivating more residents to engage.

Based on the NED framework set out in the paper and two community case studies, this study makes the following policy recommendations from the perspectives of three key stakeholders: the government, technology companies, and community residents. Firstly, the government should increase subsidies for smart devices in older communities. Additionally, legislation should be enacted to clarify primary responsibilities and technical standards for waste sorting. Technology companies should develop waste sorting apps with image recognition capabilities and voice-interactive and simplified interfaces tailored for elderly residents. In collaboration with communities, technology companies should establish "technology-governance" research laboratories to convert biotechnology into modular devices. They should also provide accompanying operation manuals and maintenance training to lower the community's technical adoption barriers. They should also encourage residents to provide feedback on their needs and suggestions through community deliberative forums and other channels, jointly refining waste management plans.

There are several limitations that should be acknowledged in this study. In terms of case selection, the selected community reflects a relatively organized and resource-supported urban environment, which may not represent the situation of low-income or marginalized communities. Therefore, the research findings may not be fully applicable to communities lacking strong institutional or social foundations. In addition, the limited number of case studies restricts broader representation in different urban and regional contexts. In terms of research methods, we mainly use semi-structured interviews and participatory observation, and the research conclusions may be influenced by the subjective perspective of the researchers. In terms of the sustainability of the NED model, the research data mainly comes from field surveys conducted from 2021 to 2023, covering only 3 years and making it difficult to verify the long-term stability of the waste management order.

Future research should extend the analytical framework to include more diverse communities, especially those facing infrastructure or participatory challenges, and conduct longer surveys of more communities to test the adaptability and scalability of the NED model.

Data availability statement

The original contributions presented in the study are included in the article/Supplementary Material, further inquiries can be directed to the corresponding author.

Ethics statement

The studies involving humans were approved by School of public administration, Hohai University. The studies were conducted in accordance with the local legislation and institutional requirements. The participants provided their written informed consent to participate in this study.

Author contributions

MX: Writing – review and editing, Conceptualization, Writing – original draft, Data curation. ML: Supervision, Investigation, Writing – review and editing, Resources.

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Conflict of interest

The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

Generative AI statement

The author(s) declare that no Generative AI was used in the creation of this manuscript.

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Supplementary material

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