Quantifying the Contribution of Youth to Urban Carbon Mitigation in Waste Sorting: An ESE Model Based on Beijing

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Abstract

Based on actual survey data from Beijing in 2025, this study establishes an Environmental-Social-Economic (ESE) model to calculate the impact of waste sorting among young people aged 15–24. The study used both Life Cycle Assessment (LCA) and field observations. The results showed that young people indeed have a clear gap between knowledge and action. In other words, many young people think they sort well, but in practice, they are still prone to errors. In terms of carbon reduction effects, young people's waste sorting mainly contributes significantly to plastic and paper materials, accounting for 42.1% and 28.4% of total emission reductions respectively. The study also found an important finding: the accuracy rate of waste sorting affects the final emission reduction by about twice the number of participants. In other words, rather than simply involving more young people, it's better to first find ways to help those already involved sort waste more accurately. Besides, if a co-production model is adopted, allowing young people to participate in community management and related decision-making rather than just passively sorting waste, their interest in green careers increases by 24.5 percentage points, on the other hand, the operating costs of urban waste management drop by 6.8%. Overall, these data show that young people's participation in waste sorting indeed has environmental and economic value. Improving the quality of young people's participation may be more important than simply expanding the number of participants.

Keywords

Waste Sorting; Youth Engagement; ESE Model; Carbon Mitigation; Co-production; Urban Governance.

1. Introduction

From a global perspective, It is estimated that by 2050, the amount of municipal household waste in cities may reach 3.539 billion tons. [1] This situation will lead to unprecedented pressure on urban governance issues. Currently, the main issues facing waste sorting are high operating costs and limited efficiency. Moreover, this challenge is not only technical; public participation and social inclusiveness are also insufficient, especially for young people. They are a large but underutilized group of people, and they can actually fully drive changes in waste management models. [2]

Current research shows the efficiency of urban household waste management largely depends on the precision of the management process. Source sorting is regarded as an important indicator of efficiency. However, a one-size-fits-all management approach is not always effective; sometimes it can lead to unreasonable resource allocation. Take Shanghai as an example. Although its waste sorting policy achieved significant results in its early implementation, over time, maintaining residents' sorting habits over the long term has become a new challenge. One important reason is because there is a serious disconnect

between many households' sorting methods and the subsequent waste treatment stages. For example, residents may seriously sort waste at home, but during later collection, transportation, and processing, different waste may be mixed again. This leads to source sorting, but the problem of collection mixing is currently one of the major obstacles facing waste sorting. [3] In fact, current technological means can alleviate this problem to some extent, including AI-based image recognition and intelligent monitoring tools like RFID tags. However, technology alone cannot guarantee long-term changes in residents' behavior. Therefore, to achieve sustained change and progress, residents need to develop a stronger sense of environmental responsibility and participate in waste sorting.[4]

Young people are considered as an important force driving environmental protection and sustainable development. As school provides environmental education for young people, helping them understand why and how to sort waste. But knowing doesn't mean actual action. In daily life, peer influence and family environment are often more direct than classroom education and more easily influence young people's actual behavior. For example, at home, teenagers' waste source sorting rate can reach as high as 80.3%. But once they reach school, community, or other public places, their sorting behavior may drop significantly. This shows that a person's environmental behavior is not only about "knowing" but also related to their surroundings and others' actions [5]. Additionally, there is a more practical issue: career choice. Nowadays, many young people recognize the importance of environmental protection and are willing to support green development, but few (32.6%) are truly willing to treat waste sorting or related work as a long-term career. It is not because they don't care about environmental protection, but the industry itself still lacks the conditions to attract young people. For example, professional training is insufficient, there are few career models to refer to, and there is no clear path for the future development of the green industry or what career options are available. Therefore, young people may not lack environmental awareness; what they truly lack is turning this awareness into a condition for long-term action and career choice. [6]

Regarding quantifying the impact of young people's participation on urban emission reduction, related studies and field measurements show that more accurate classification of kitchen waste can indeed reduce the amount of waste sent to the landfill and improve the efficiency of waste incineration power generation. This can reduce overall carbon emissions to 28.7%. [7] Another research has found a relationship between dose and response, such as the recycling rate of recyclable materials. For every 10% increase, overall carbon emissions can decrease by 5.2%. However, these studies usually evaluate from the perspective of the entire urban population and rarely distinguish the specific contributions young people make to emission reductions. [8]

In recent years, to increase public participation, various economic and organizational models have emerged. For example, the Waste Bank model proposed by Putri and others. A waste bank means residents take recyclable waste to the bank for weighing and registration, then assigning a certain value to the recyclable, which residents can earn points or account balances, which can then be exchanged for cash, rewards, and other benefits. 52% of the participants are young people. This model suggests that digital points and incentive mechanisms may be very effective ways to attract young people to participate in waste sorting. [9] Besides, some other research has proposed co-production model, whose core is to distribute responsibility among community residents and public institutions. Current research shows that the management model is community-led and has strong autonomy. Its participation rate (78%) is significantly higher than the traditional government-led model (42%). [10]

Based on existing research, there still exists some obvious shortcomings in this field. Currently, quantitative evidence on how much young people can contribute to the waste sorting system is very limited. Current research focuses more on young people's attitudes and willingness to participate, rather than actual behavioral performance. Besides, there is a lack of a systematic indicator that can link young people's behavior to the efficiency of urban waste management.

also, current carbon emission calculation methods usually evaluate waste systems at the overall level. Therefore, this is difficult to go further. Identify the long-term emission reduction effects brought by young people's participation. Finally, the current economy. There are also models of public participation, focusing only on a single dimension. With that being said, we need to establish a more comprehensive research framework that integrates environmental outcomes, social behavior, and economic incentives into the same environmental, socio-economic, and environmental framework. From there, we can better support it and maintain young people's long-term participation in waste sorting.

2. Methodology

2.1. Research Design and Theoretical Framework

This study used mixed methods approach to construct a comprehensive ESE (environmental, social, and economic accounting) model. The main purpose of this study is to quantify indicators to assess the specific contributions of young people in waste sorting.

From an environmental perspective, this study uses a life cycle assessment method. It focuses on calculating the carbon reduction and emission reductions and landfill reductions caused by residents' source sorting. From the social perspective, this study mainly focuses on changes in residents' behaviors and related abilities. By examining changes in social participation and interest in green occupations due to increased environmental awareness, it further influences social behavior and may have long-term effects on social development. The subject of the research is targeted to young people aged between 15 to 24 years old (this is consistent with the age classification of the United Nations and relevant statistical standards). Beijing is selected as the main research case area because Beijing has a relatively complete waste sorting system that can provide relatively rich data. The data collection period is from January to December 2025. This is because this time range ensures that the obtained behavioral data is highly time-sensitive and can be integrated with current waste sorting policies.

2.2. Data Collection and Sources

To ensure the accuracy of this ESE model, we established a multi-source data collection system (primary field survey data and secondary statistics).

First-hand data collection

We used both online and offline channels for questionnaire surveys. Specifically, we used stratified random sampling, which means that we divided groups based on school type and residential area, this is to ensure that young people from different educational backgrounds and living environments can be fully covered. To be specific, we distributed a total of 500 questionnaires, with an effective collection rate of 87.6%. The content of the questionnaire mainly focused on the frequency of waste sorting, the accuracy of waste sorting and the acceptance of green occupations. In other words, respondents may be inclined to report behaviors that better meet social expectations. To reduce this bias, our research team conducted a twenty-week field study and set up an observation point at smart waste disposal points within the study area. Our researchers recorded the weight and accuracy of waste sorting during youth participation and used this real data as a basis for calibration, adjusting the survey results.

Second-hand data source

During the construction of environmental and economic models. This study further utilizes reliable secondary data sources. Specifically, Annual total waste generation and waste component data mainly come from local statistical yearbooks and reports. Carbon emission factors are determined according to IPCC standards. Local waste disposal costs are referenced

from government-published fiscal data. By integrating data from these different sources, quantitative analysis from environmental, social, and economic dimensions is conducted.

2.3. Derivation of the Carbon Accounting Model

To calculate how much young people contribute to urban waste reduction and carbon emission reduction, this study refers to the life cycle assessment (LCA) and IPCC carbon emission nucleic acid methods to establish a carbon reduction model specifically for youth populations.

$$E_{total} = \sum_{i=1}^{n} (G_i \times P_y \times C_i \times EF_i)$$

The calculation steps can be divided into four steps.

1. Calculate how much waste there is.

For each type of waste, such as plastic paper and kitchen waste, first determine how much it is generated in the world, expressed as G_i. Then determine how much carbon emissions would occur if this waste is not properly sorted and recycled, but instead directly landfilled or other traditional treatments. This difference is the carbon emission factor (EF_i).

2. Calculate how much of it belongs to young people.

Not all urban waste is generated by young people, so we need to use P_y to estimate the amount of waste generated by young people. Here, P_y is not just about how many young people make up the population; it also needs to be combined with questionnaire data from youth waste generation, so that youth waste can be further calculated from the city's total waste.

3. Calculate how much young people are sorting correctly.

Just because young people generate waste doesn't mean all of it is properly sorted. So C_i is added to the model, which is the sorting accuracy. For example, if a group of young people generates 100 kilograms of plastic waste, but only 80 kilograms are sorted correctly, then the sorting accuracy is 80%. This data is mainly calibrated through questionnaires and field observations. Because people say their sorting scores are good in the questionnaire may not actually be that accurate.

4. Add up all the waste.

Finally, we need to calculate different categories such as plastic paper, food waste, etc., and add them all together to get the total emission reduction E_{total} for the youth group.

3. Results and Discussion

3.1. Age-Specific Discrepancies in Waste Sorting Performance

Based on the previous multi-source data, this study found that young people of different age groups have noticeable differences in cognition and behavior. Simply put, many people think they are good at sorting waste, but what they observe is not as good as they think. This issue is especially pronounced among younger age groups.

As shown in Figure 1, all surveyed groups overestimated the accuracy of their waste sorting to varying degrees. Among them, high school students aged 15 to 17 were the most obvious. In the questionnaire, 94.2% of students believed they could accurately sort waste collection, but actual observation showed that only 82.5% did so. The gap in kitchen waste is even more pronounced. Students aged 15 to 17 believe their sorting accuracy is 82.1%, but the actual observed accuracy is only 58.4%. The difference between the two is 23.7%, meaning they believe they have basically sorted everything correctly, but in practice, there are quite a few errors. In contrast, young professionals aged 22 to 24 give self-assessments that are much closer to reality. Their calibration coefficients for sorting recyclable and kitchen waste are 0.97 and 0.95 respectively, both very close to one. Simply put, they say they say they can roughly do

it, and their actual observed performance is very close. This shows that as young people move from schools to relatively regulated environments, they enter a more independent work and life state. Their judgment of their environmental behaviors also becomes more objective. The study also found that for young people, recyclable waste pens and kitchen waste are easier to sort. The accuracy of sorting recyclable waste across all age groups exceeds 80%, while the accuracy for kitchen waste is only about 58% to 68%. In other words, young people have already mastered the relatively intuitive dry waste of plastic and paper very well. But when it comes to the more complex wet waste like kitchen waste, it is easy to make mistakes. Therefore, sorting kitchen waste is a clear and difficult issue in urban waste management.

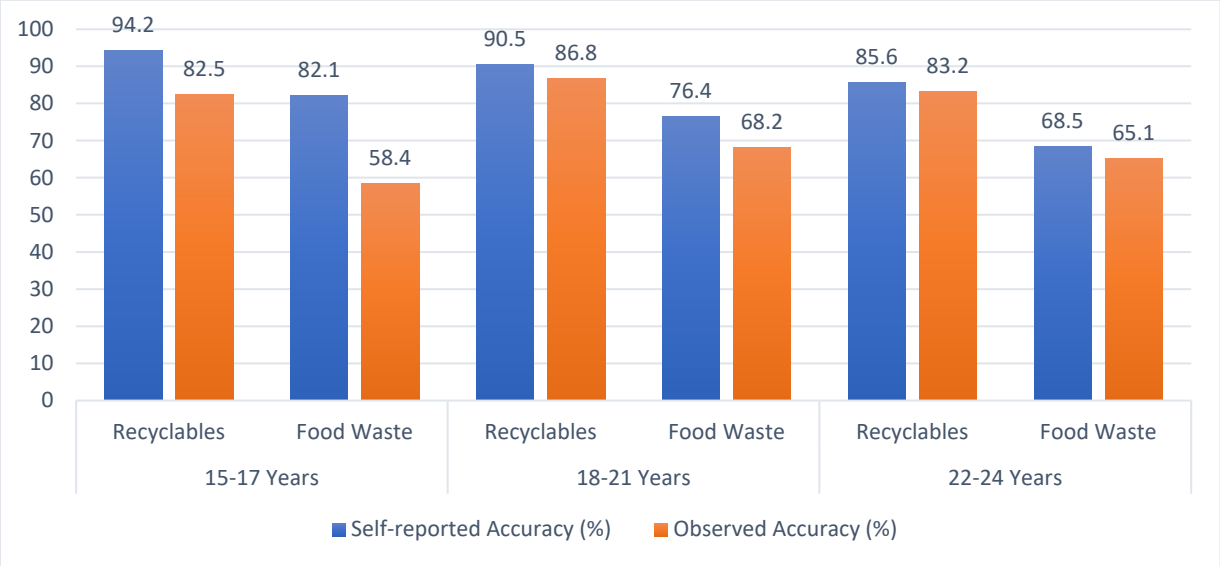


Figure 1. Sorting accuracy across different youth age group.

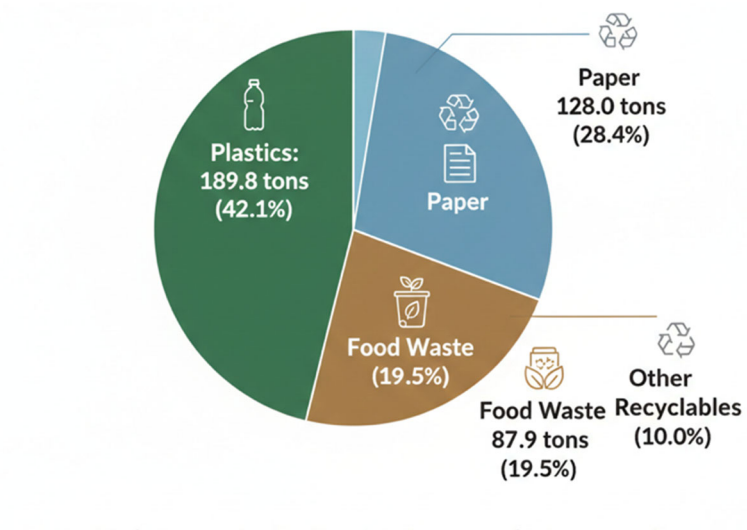
3.2. Structural Distribution of Carbon Mitigation

Quantitative analysis revealed that different types of waste contribute significantly to carbon reduction. As shown in Figure 2, plastics are the largest category of waste contributing to carbon reduction, accounting for 42.1% of total emission reductions, equivalent to a reduction of about 189.8 tons of CO2 equivalent. Next is paper products, accounting for 28.4%, equivalent to about 128.0 tons of CO2 equivalent. Food waste contributes 19.5%, about 87.9 tons of CO2 equivalent, with this reduction mainly coming from anaerobic digestion and resource recycling. The remaining 10.0% comes from other recyclables, such as metals and glass. Simply put, the carbon reduction effect brought by young people's waste sorting mainly focuses on materials like plastic and paper. Plastic contributes the most partly because plastic production itself consumes a large amount of energy, so reducing or recycling a portion of plastic can help avoid significant carbon emissions. On the other hand, it is also related to the lifestyle of young people. Compared to older groups, teenagers and young people may be exposed to more packaged goods, takeout, and bottled beverages, so a high proportion of plastic is in daily waste, including plastics with high recycling value such as PET and HDPE. Although kitchen waste is heavy, its contribution to carbon reduction is only 19.5%, mainly for two reasons.

First, the unit emission reduction is relatively low. Food waste itself biodegrades, but compared to plastics, which consume a lot of energy during production, the carbon emissions avoided per ton of kitchen waste are usually not as high. Therefore, simply looking at the weight of the waste does not directly determine its contribution to carbon reduction.

Second, kitchen waste is harder to separate. The previous calibration data has already shown that especially young people aged 15–17 have relatively low accuracy in food waste sorting. This means that even if food waste itself has some emission reduction potential, if it is not

properly sorted and treated, this potential cannot be fully realized. Therefore, this study demonstrates that future urban carbon neutrality policies can fully utilize young people's relatively high accuracy in sorting dry waste such as plastics and paper, while focusing on addressing the difficulty of sorting kitchen waste. Only in this way can the carbon reduction potential brought by young people's participation in waste sorting be further unleashed.



Source: Calculation based on ESE Model and Primary Field Data, 2025-2026

Figure 2. Composition of CO2 emission reduction by waste category from youth sorting

3.3. Sensitivity Analysis of Key Parameters

Sensitivity analysis revealed that different parameter changes have different impacts on total carbon emission reductions, E_{total}. As shown in Table 1, classification accuracy C_i. significantly exceeds youth participation rate P_y. When the classification accuracy is adjusted by 20% or lower, the total emission reduction changes from 360.6 tons to 541.0 tons. In other words, the amount of carbon reduction that changes in classification accuracy basically corresponds to the same amount, showing a 1:1 relationship. In contrast, even after adjusting the youth participation rate and P_y. by 20%, the total emission reduction only changed by about 10%, from 405.7 tons to 495.9 tons. Getting more young people to participate in waste sorting is certainly useful, but having those already involved sort waste more accurately and with more obvious results. This shows that urban waste management systems are not as sensitive to the number of people participated and are more concerned about whether these people are sorting accurately. In other words, the environmental benefits of youth participation largely depend on the accuracy of waste sorting at the source. An important reason is that if the sorting accuracy rate, C_i, is too low, different types of waste are easily mixed. For example, recyclables contaminated by kitchen waste, or if food waste contains a large amount of other waste, will reduce the efficiency of subsequent treatment facilities, including anaerobic digestion and waste incineration. As a result, even if many people participate in sorting, if waste is still sorted messily, the carbon reduction effect that could have been achieved will be difficult to truly achieve. Therefore, the number of people participated is not the only important issue; "how well the waste was sorted" is equally important, if not even more. This aligns with the conclusions of existing research: if waste sorting is inaccurate, resorting will need to be done later, which itself consumes energy and may even offset some of the environmental benefits that could otherwise be achieved. Therefore, for city managers, rather than simply conducting large-scale campaigns to raise awareness of the importance of waste sorting, it is better to invest some resources in more concrete precision education. For example, digital waste sorting guides, smart bins, and real-time reminder tools can be used to help residents solve the problem

of "Where exactly should this garbage be thrown?" This is a practical question. Ultimately, this analysis shows Garbage sorting is not about involving more people but rather the combination of people participating and accurate distribution to truly achieve greater carbon reduction.

Table 1. Sensitivity analysis of carbon emission reduction potential

Parameter Variation (%)	Accuracy (Ci) Impact [tons]	Participation (Py) Impact [tons]
-20	360.6	405.7
-10	405.7	428.2
0 (Baseline)	450.8	450.8
10	495.9	473.3
20	541	495.9

3.4. Shift in Youth Employment Intentions

After shifting from traditional waste management models to "co-production" models, young people's interest in green careers has significantly increased. As shown in Figure 3, the average employment intention among all surveyed youth increased from 34.2% to 58.7%, an increase of 24.5 percentage points. However, changes vary by age group. Among them, college students aged 18–21 saw the biggest change. Originally, only 38.5% were willing to consider green-related careers, but after adopting the co-production model, this proportion rose to 69.5%, an increase of 31.0 percentage points. High school students aged 15–17 showed relatively smaller changes, increasing by only 12.6 percentage points. Young professionals aged 22–24 showed higher willingness, reaching 68.6% after the intervention. This shows that the co-production model is especially effective for young people who have already begun considering their future career direction. Why has this change occurred? The research results show that young people's reluctance to enter the waste management industry may not be entirely due to a lack of environmental awareness. Many young people agree with environmental protection concepts, but the real problem may be their lack of identification with the waste management industry and their difficulty connecting the industry with their own career development. The co-production model changes this. In the traditional model, young people are mostly people who follow sorting waste according to regulations. But in the co-production model, they can participate in community management, offer suggestions, and even take on certain management responsibilities. This is especially important for college students aged 18–21. Young people at this stage usually hope to gain professional skills and qualifications, as well as hope their work will have a certain social impact. When professional training and actual management authority are combined, the social image of waste management work may change, and young people's aversion to such jobs may decrease. As for high school students aged 15–17, their improvement is relatively small, possibly because students in this age group are still focused on studying and have not yet truly started considering entering the workforce. Therefore, career incentives naturally have less impact on them than university students. However, the willingness of all three age groups has increased, which points to an important issue: If we want young people's enthusiasm for environmental protection to ultimately turn into long-term green employment, it's not enough to just let them know that environmental protection is important，it's also necessary to give them real opportunities to participate, learn, and make a difference. This also supports the basic view of the ESE model: empowerment at the societal level can be a key driver connecting environmental protection and economic development.

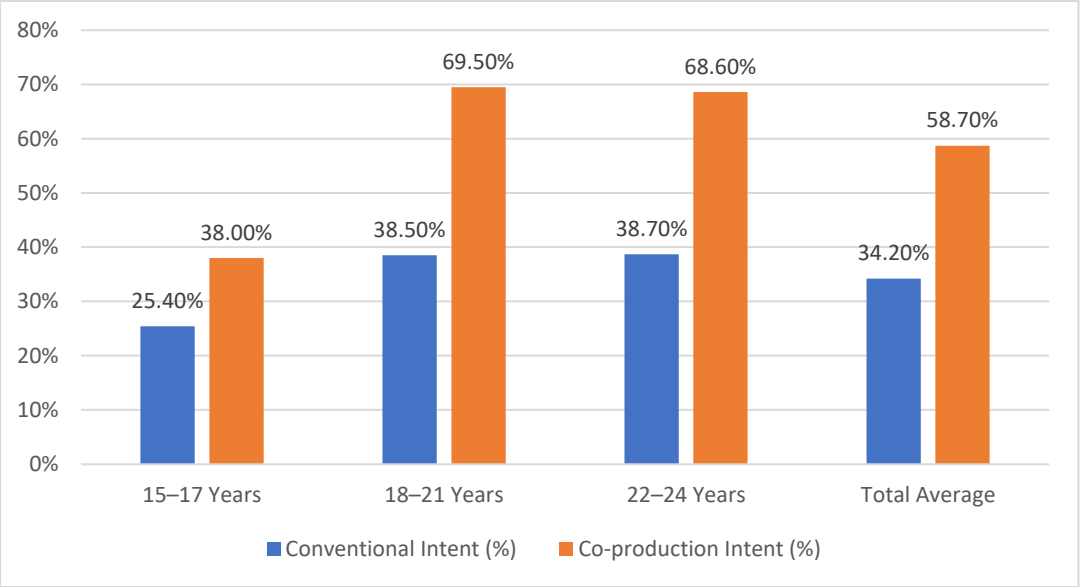


Figure 3. Impact of co-production model on youth green employment intention.

3.5. Economic Synergies and Systemic Efficiency

Changes in young people's waste sorting behaviors have also brought significant economic benefits to urban waste management systems. As shown in Table 2, the most direct change is a 12.5% reduction in mixed waste. When less waste is mixed, the easier it is to collect, transport, and handle subsequent waste, thereby reducing related costs. Waste collection and transportation alone are an important part of urban sanitation expenditure. Another notable change is the 5.4% increase in waste incineration efficiency. Simply put, kitchen waste contains a large amount of moisture. If young people separate the kitchen waste at the source, the water content of the waste that goes to the incinerator will decrease. This way, the calorific value of the remaining waste will increase, making it easier to reach a stable temperature during incineration, and there is no need to use much extra auxiliary fuel. Therefore, these results show that young people are participating in waste sorting not just for protecting the environment, this may help cities save money. The study found that the co-production model ultimately reduced the overall operating costs of urban waste management systems by 6.8%. This means that for governments, supporting co-production projects involving young people is not just an additional environmental expenditure but can also be an investment that can reduce long-term management costs. This forms a cycle: More accurate distribution among young people→ reduced mixed waste→ improved waste management efficiency→ lower urban operating costs→ and the resources saved can further support youth participation→ and youth participation continues to increase. This is the so-called green loop where environmental improvements bring economic benefits, and those economic benefits in turn support social participation.

Table 2. Economic performance of youth-led waste sorting interventions

Economic Indicators	Magnitude of Change	Financial Impact
Incineration Efficiency	+5.4%	Reduction in auxiliary fuel consumption costs
Mixed Waste Volume	-12.50%	Savings in transportation fuel and labor expenses
Total Operational Cost	-6.80%	Optimization of municipal sanitation budget

4. Conclusion

The study first found that young people generally have a certain cognitive-behavioral gap. Therefore, relying solely on questionnaires may overestimate young people's true classification level, so it's necessary to combine field observations and adjust the data using calibration coefficients. The research results show that young people's waste sorting can indeed bring significant carbon reduction effects. However, the key to the final emission reduction effect is not simply how many young people participate, but whether they distribute it accurately. If many people participate but the quality of waste sorting is low, the actual environmental benefits remain limited. At the same time, shifting from traditional waste management models to "co-production" also brings other benefits. After young people participate in community management, their interest in green careers has significantly increased, and the operating costs of urban waste management have also decreased. In other words, when young people no longer passively sort waste according to regulations but instead become active participants or even managers of community waste management, their involvement may simultaneously generate environmental, social, and economic value. This model may also create a circulation: young people distribute lead to less mixed waste, which in turn can improve efficiency of waste incineration, and thus lowering urban operating costs. The saved resources further support young people's participation in community management and waste sorting. Therefore, rather than seeing young people merely as executors of waste sorting, it is better to let them become true stakeholders and community participants. This role shift can not only help cities reduce carbon emissions but also potentially become a model for waste management and social sustainable development that can be promoted to other cities.

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