Promoting Chinese urban residents' participation in source separation and recycling

Binxian Gu [a, b, c, *], Yanbin Yao [a], Huimin Hang [a], Yulin Wang [a], Renfu Jia [d], Lingxuan Liu [c], Hui Ling [a], Xinyi Tang [a], Haijie Zhang [a], Zhiwei Wu [e], Yongxiang Wu [a], Takeshi Fujiwara [f], Yanchao Bai [a, b, *]

[a] College of Environmental Science and Engineering, Yangzhou University, Yangzhou, 225127, China

[b] Jiangsu Collaborative Innovation Center for Solid Organic Waste Resource Utilization, Nanjing, 210095, China

[c] Management School, Lancaster University, LA1 4YX, Bailrigg, Lancashire, United Kingdom

[d] College of Civil Science and Engineering, Yangzhou University, Yangzhou, 225127, China

[e] College of Industrial Design, China Jiliang University, Hangzhou, 310018, China

[f] Graduate School of Environmental Science, Okayama University, 3-1-1 Tsushima-naka, Kuta-ku, Okayama, 700-8530, Japan

[*]Corresponding Author: bxgu@yzu.edu.cn (B. Gu), ycbai@yzu.edu.cn (Y. Bai).

Abstract

Source separation and recycling (SSR) for municipal solid waste is an important strategy for the transition to a circular economy and requires broader resident participation. How can residents' participation in SSR be promoted? Here, we consider 13 cities in Jiangsu as microcosms of China. We quantify residents' intentions to participate in SSR by distributing a validated questionnaire to 2,963 urban residents, analyze the results through structural equation modeling, and propose localized policy recommendations. We find that residents have positive attitudes toward SSR, although 92.6% of residents in southern Jiangsu were more willing to participate than those in northern Jiangsu (84.6%). Additionally, the influencing factors and their degree of influence on resident SSR participation intentions exhibit disparities across cities. "Accessibility of SSR facilities" simultaneously affects the 13 studied cities and is a key factor. "Environmental knowledge" and "environmental attitudes" are important impact factors, with occurrence frequencies of 84.6% and 69.2%, respectively. However, laws and regulations have no significant effect on residents' SSR participation intentions. We recommend that the government create favorable external conditions related to facilities and services, promote extensive publicity and educational activities through various channels, and improve the effectiveness of SSR laws and regulations. Future SSR management strategies should be localized, flexible and comprehensive. This research could help decision makers in China and other countries design policy guides to promote SSR and help link current research areas to social development.

Keywords:

Municipal solid waste, Source separation, Recycling, Urban residents, China.

1. Introduction

Global municipal solid waste (MSW)[1] generation is expected to increase from 2.01 billion tonnes in 2016 to 3.40 billion tonnes in 2050 and to reach 3.83 billion tonnes by 2100 (World Bank, 2018), approximately 70% of which is currently not recycled (Wilson et al., 2015). Poorly managed MSW can harm human health and the ecological environment, as recently reported particularly in connection with heavy metal-contaminated soils (Iftikhar et al., 2021; Tauqeer et al., 2021 (a, b); Turan, 2021 (a, b)) and ocean plastic pollution (Schweizer et al., 2020). As a result, the increasing amounts of MSW generation and rapidly increasing resource shortages have long been recognized as two major challenges facing human society sustainable development (Iyamu et al., 2020). Although the most economical method for handling MSW is to minimize its generation (Maung et al., 2017), given the development of the economy and the improvement in living standards, a rapid increase in MSW is inevitable. At present, various strategies are available with which to address an excess of MSW, such as eco-design and the research and development of products and function- or service-based business models, source separation and recycling (SSR) represents an important strategy and one that simultaneously transitions to an integrated circular economy framework (Czajkowski et al., 2014; Yildizbasi, 2021) because it can transform waste into resources. With this characteristic, SSR possesses a potential to create social wealth. At present, various strategies are available with which to address an excess of MSW, such as eco-design and the research and development of products and function- or service-based business models, source

[1] Acronyms—MSW: municipal solid waste; SSR: source separation and recycling; RIPSSR: residents' intentions to participate in source separation and recycling; EK: environmental knowledge; EA: environmental attitudes; FS: facilities and services; SN: social norms; CL: cost losses; SEM: structural equation model; KMO: Kaiser–Meyer–Olkin; RMSEA: root mean square error of approximation; NFI: normed fit index; CFI: comparative fit index; CMB: common method bias.

separation and recycling (SSR) still represents an important strategy. Meanwhile, SSR simultaneously transitions to an integrated circular economy framework (Yildizbasi, 2021) because it can transform waste into resources. Some developed countries and regions, such as Germany (Bilitewski, 2008), Japan (Tang et al., 2014), Hong Kong of China (Sakai et al., 2008), have had clear success in MSW management via SSR. This implies that SSR can also be successful in developing countries, including China.

In fact, China has been devoting considerable effort to promoting its SSR. As early as 2000, China launched an SSR pilot in eight cities (Fig. S1), but an assessment of this practice has indicated a generally poor performance (Tong et al., 2019). In 2016, Chinese President Xi Jinping specifically noted the need to introduce SSR in more cities, regions, and provinces and even in rural areas. The ultimate goal was to promote SSR nationwide. Since 2017, the national government has restarted SSR efforts, requiring 46 cities nationwide to take the lead in implementing mandatory SSR and requiring that the recycling rate exceed 35% by 2020. SSR has received unprecedented levels of attention. However, promotion of SSR is still not satisfactory. Since 2011, we began to systematically track MSW in Suzhou, Yangzhou, and Suqian, Jiangsu Province, China (Gu et al., 2014, 2015, 2018, 2021), and recyclable components of MSW exceeding 90% were found. We also reviewed the status of MSW management from a national perspective (Gu et al., 2017). We found that there is no substantial SSR momentum in localized cities, and the participation rate remains low. Few cities have even reported an official recycling rate. SSR has become a political task of local government rather than an activity that involves active participation by the public. Several other studies have identified similar outcomes (Xiao et al., 2017; Meng et al., 2019). Fan et al. (2019) explored stories of successful SSR implementation in developed regions. They found a full level of participation

among residents to be the key. Residents are the largest group directly involved in SSR practice, and the SSR policy takes effect through residents. If residents' support and participation are low or inefficient, it may be particularly challenging to build social acceptance for SSRs. Meng et al. (2019) reported that effective policies fully incorporate the views of local residents into specific policy formulations. Thus, a clear understanding of local residents' intentions to participate in SSR (RIPSSR) and the main factors influencing those intentions, as well as the mechanisms underlying decision-making about RIPSSR, is required.

To better understand the field, we searched Web of Science for related research using the terms "urban residents", "public", "source separation", "recycling", "participation intention/willingness", and "influencing factors" as keywords and/or research topics. Sixty-two articles were found, which are included in Table S1. Grazhdani (2016) revealed a positive correlation between public education, knowledge, information promotion and RIPSSR. Chen and Gao (2020) reported that time spent and storage space used to store waste at home hinder resident participation in SSRs. Meng et al. (2019) found that the convenience of environmental facilities and services is the most effective control variable for promoting resident participation in SSR. Tang et al. (2014) revealed a sound system of supporting laws and regulations, incentives and penalties for SSR, which are effective in promoting waste recycling and reducing environmental contamination. Moreover, attitudes and social/personal norms attract more attention in developed countries (Bortoleto et al., 2012). More reviews are presented in the Supporting Information because the space is limited. We summarized the influencing factors that occurred most frequently and that had a significant effect and found that RSSRPI may be affected directly and/or indirectly by

five community-based concepts, namely, environmental knowledge, environmental attitudes, facilities and services, social norms, and cost losses.

However, the limitations of these studies can be interpreted in several ways, and each offers opportunities for this study. First, previous efforts have, for the most part, simultaneously ignored factors influencing RIPSSR and their degree of influence. Such studies have also neglected to quantify each potential influencing factor and assess their importance, so these factors remain uncertain. It is difficult to fully understand resident participation and provide effective government intervention without first understanding the contributions of multiple influencing factors (Meng et al., 2019). Second, previous work on both internal subjective factors and external situational factors that influence RIPSSR is rare. The selection of residents for SSR participation is the result of related external and internal factors working together, which is widely recognized (Meng et al., 2019). Third, most of the relatively mature research on RSSRPI has been conducted in countries other than China. It is unlikely that conclusions drawn from non-Chinese studies and management theories will apply to China due to China's rapid increase in MSW generation and differences in its recycling potential, as well as in the cultural and social attitudes of its population and legislative environment (Gu et al., 2017). Furthermore, after reviewing the 62 previous articles, we found 29 Chinese locations for SSR research (Fig. 1). These 29 locations are scattered randomly across China and composed of 23 prefecture-level cities (including 11 provincial capitals and 12 prefecture-level cities), four district-/county-level cities, and Hong Kong and Taiwan. Governance in China is centralized and top-down with four administrative levels. Generally, villages/towns belong to districts/counties that belong to prefectural cities, each prefectural city belongs to a province, and each province belongs to the government of China. SSR

planning and management is usually presented in the form of a national strategy. That is, the administrators of provinces first receive information and then pass on that information to the cities in the province, which then implement the policies. It must be emphasized that cities should be subordinate to provinces to facilitate the assignment of tasks. However, China has not focused on the mechanisms underlying decision-making, which has led residents to willingly participate in SSR strategies of provincial and provincial-level city administrative systems. From a national perspective, any locally effective, targeted and strategic policy, law or legislation that can stimulate a province's residents to participate in SSR is welcomed.

The question, then, is, how provinces and cities can promote resident participation in SSR. To solve this problem, three minor questions must be addressed:

(1) To what extent do residents intend to participate in SSR?

(2) What are the main factors that influence RIPSSR, and to what degree do they affect it? What are the spatial disparities in these factors across cities?

(3) What is the localized decision-making mechanism that drives RIPSSR?

To answer these questions, this paper is organized as follows. Section 2 proposes research hypotheses based on previous studies from around the world. Section 3 introduces the study area, describes the data acquisition process, and explains the measurement model. Section 4 presents the results of our empirical analysis. Sections 4.1–4.3 answer minor questions (1)-(3), respectively. Section 5 discusses the results and proposes localized policy recommendations, and Section 6 presents the conclusions and limitations of this study. The results of this study provide feasible theoretical and empirical support for SSR policy formulation that can promote resident participation as well as for strategies to help countries worldwide promote SSR and provide excellent MSW management.

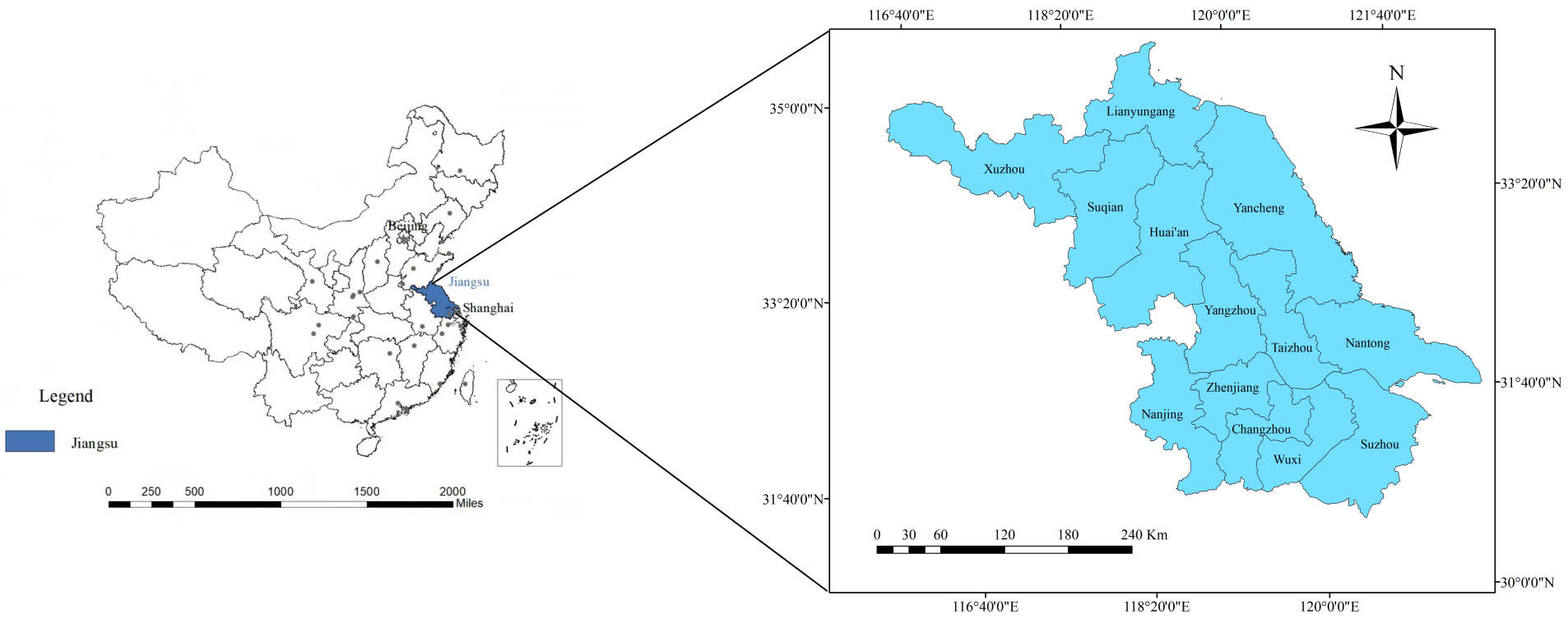

Fig. 1. Location of Jiangsu and SSR outreach throughout China

Note: The black dots represent locations throughout China in which previous SSR research has been conducted.

2. Research hypotheses

After conducting our literature review, hypotheses of RIPSSR are proposed in Fig. 2. The hypotheses were developed by combining the theory of planned behavior and attitude-behavior conditions. It states that resident intentions to participate in SSR are based on five community-based concepts, which are related to RIPSSR through five paths (H1–H5). These paths provide direct routes to tasks and goals related to RIPSSR: H1 provides a direct line to environmental knowledge, H2 leads way to environmental attitudes, H3 points to cost losses, H4 shows way to social norms, and H5 gives direction to those seeking to promote facilities and services. More information on H1a-H5b is presented in the Supplementary File.

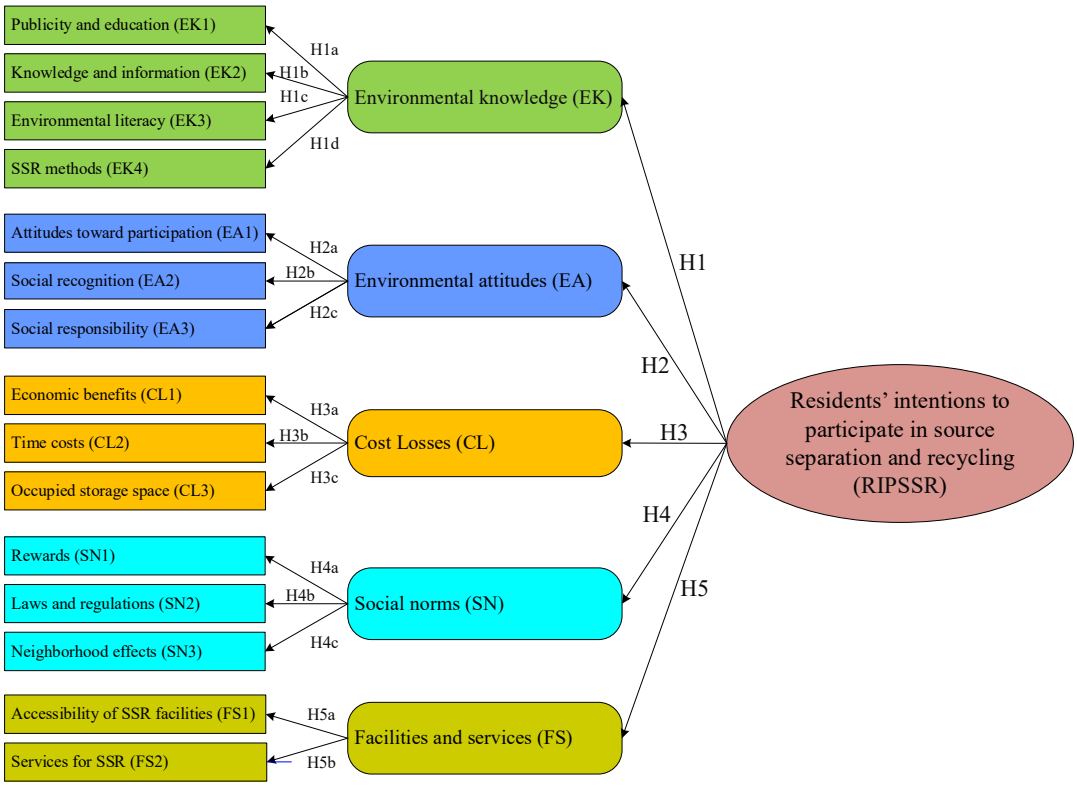

Fig. 2. Initial conceptual flow chart of RIPSSR hypotheses

200 **3. Data and methodology**

201 3.1. Study area

202 In China, there are 34 provinces, 333 prefecture-level cities, 2,846
203 district/county-level cities, and 38,755 villages/towns (CNBS, 2020). Jiangsu is a
204 province with 13 prefecture-level cities, 96 districts/counties and 757 villages/towns
205 and is located on the southeast coast of China (Fig. 1), bordering Shanghai and having
206 an urban area that covers 15,536 km^2, with an urban residential population of more
207 than 80.7 million people in 2019. Its annual per capita GDP (based on calculations
208 using the residential population) reached 123,607 RMB in 2019 and was ranked 3rd in
209 China, just below that of Beijing (164,220 RMB) and Shanghai (157,279 RMB)
210 (CNBS, 2020). MSW generation in Jiangsu increased from 4.3 million tons in 1996 to
211 18.1 million tons in 2019. Each inhabitant produced 0.9 kg of MSW per day in 2019,
212 1.8 times higher than in 1980 (Table S2). Its MSW management pattern is in line with
213 that of most other Chinese provinces and/or municipalities, and it is evolving from
214 mixed to source-separated recycling and treatment. To help the reader better
215 understand why we can view Jiangsu as representative of China, more information on
216 country and the 13 studied cities in Jiangsu, including urban area, urban resident
217 population, GDP, and MSW generation, is provided in Table S3.

218 3.2. Questionnaire design and data collection

219 Data collection for this study was performed through a questionnaire (Table S4).
220 Based on the initial conception of the RIPSSR hypotheses, four types of questions
221 (single choice, multiple choice, five-point Likert scale, and open ended) were used in
222 the design of the questionnaire to assess the relationship between the RIPSSR and its

influencing factors. The five-point Likert scale is a scale ranging from 1 to 5 (Strongly agree, Agree, Neither agree nor disagree, Disagree, Strongly disagree). The formal questionnaire consists of 30 questions, of which 29 questions reflect the 15 observable variables in Fig. 2 (H1a-H5b). In the 29 questions, there were 21 positive questions and 8 negative questions (Additional details are provided in Table S4 and Fig. S2). The other question explicitly asks about RIPSSR. The survey divides resident waste into four categories: organic waste (food waste, grass and wood), recyclable waste (plastic, paper, textiles, glass, metal), hazardous waste (e.g., batteries, insecticides, oil paint), and miscellaneous (ceramics, ash, unclassifiable waste). The four categories are generally used in mainstream SSR in China, although other sorting categories, e.g., three categories and five categories, have also been used.

The questionnaire consists of four parts: (1) a brief introduction to the investigation, including its background and research purpose; (2) questions about respondents' current level of SSR participation, including knowledge and information, attitudes toward participation, sense of responsibility, time spent on SSR, and methods of selling recyclable waste; (3) questions about respondents' socioeconomic characteristics, including gender, age, education level, income level, and profession (Table S5); and (4) open-ended questions allowing respondents to answer freely.

The questionnaire respondents aged between 18 and 70, were residents of the 13 cities of Jiangsu and had lived in their city for more than one year. To verify the rationality of the initial questionnaire design, including its structure, questions and answer options, preliminary research was conducted in Nov. 2019. The preliminary investigation helped us to better understand the ways that residents tend to sort and/or recycle their recyclable waste, as well as the extent and nature of difficulties in SSR. Then, the preliminary questionnaire was revised and redesigned. A formal

questionnaire investigation was conducted from Dec. 2019 to Feb. 2020. We collected 2,963 valid questionnaires out of 3,177 sent out in total, resulting in a valid response rate of 93.3%. In these valid questionnaires, 1,997 were received via the internet (WeChat, Tencent QQ, and multimedia networks). The others were collected by face-to-face interviews (in households, at markets, on the roadside, and other institutions).

3.3. Structural equation model (SEM)

SEM is a family of multivariate statistical models that allow analysts to estimate effects and relationships between multiple variables and the intensity of those effects and relationships. SEMs combine the advantages of different statistical methods, e.g., factor analysis, path analysis, and multiple regressions. SEMs are well established and have been frequently used in the field of MSW management and policy (Xiao et al., 2017; Meng et al., 2019). Additionally, SEMs have been widely applied in other relevant fields, such as management science (Chou et al., 2014), political science (Shao and Hao, 2020), and social behavior (Lee et al., 2017).

The general formula for an SEM is:

$$\begin{cases} \eta = B\eta + \Gamma\xi + \zeta \\ Y = \Delta_y\eta + \varepsilon \\ X = \Delta_x\xi + \delta \end{cases}$$

where η is an endogenous variable, which refers to a variable that is affected by any other variable in the model; ξ is an exogenous variable, indicating that it is not affected by any other variable but can affect other variables. ζ is a random term; η can be explained by observation variable Y, ξ can be explained by observation variable X,

δ represents measurement error in exogenous variables, and ε captures measurement error in endogenous variables.

In this study, a hypothetical SEM was tested and debugged with IBM SPSS 22.0. The following tasks were completed: (1) the data were described and inspected; (2) the survey data's reliability and validity were tested; (3) factor analysis was used to reduce the dimensionality of influencing factors and to evaluate the validity of constructs; (4) maximum likelihood estimation was used to evaluate and correct the model; and (5) the model was constructed, and a sensitivity analysis was completed. Additionally, all SEMs of 13 cities were statistically tested before construction, and the results are recorded in Tables S6-8.

4. Results

4.1. Resident intentions to participate in SSR

The questionnaire results show a positive attitude toward SSR in Jiangsu. A total of 60.5% respondents were very willing to participate in an SSR program, 29.0% were willing, 6.4% were indifferent and only 4.0% stated that they were unwilling to do so (Fig. 3).

The spatial distribution shows that the RIPSSR in southern Jiangsu is higher than that in northern Jiangsu. "Strongly agreed" and "agreed" respondents accounted for 95.2%, 94.7%, 96.7%, 90.9%, 93.1%, 87.4%, 94.2%, and 88.8% that they intended to participate in SSR in Suzhou, Nantong, Nanjing, Changzhou, Taizhou, Wuxi, Yangzhou, Zhenjiang, respectively. The corresponding data for the other five cities are 86.3% (in Huai'an), 84.5% (in Lianyungang), 85.7% (in Suqian), 80.3% (in Xuzhou), and 86.2% (in Yancheng). Further examination of respondents "strongly

agreed" and "agreed" to participate in SSR found that the cities of Suzhou, Nantong, and Nanjing had higher levels of intentions to participate than the other 10 cities in Jiangsu. The proportions of respondents who "strongly agreed" in Nantong, Suzhou and Nanjing were 75.5%, 67.8%, and 67.1%, respectively.

Participation intention in Jiangsu was slightly higher than that in Xiamen (Xiao et al., 2017); in there, 50.2% of respondents were very willing to participate in waste separation, a further 33.3% were willing, 14.0% were indifferent and 2.5% stated that they were reluctant to do it. Wu et al. (2021) reported that a large proportion of the Chinese public has a positive attitude toward waste sorting policy. The results of this study agree with Wu et al. (2021), who reported that regions with more developed economies paid more attention to SSR.

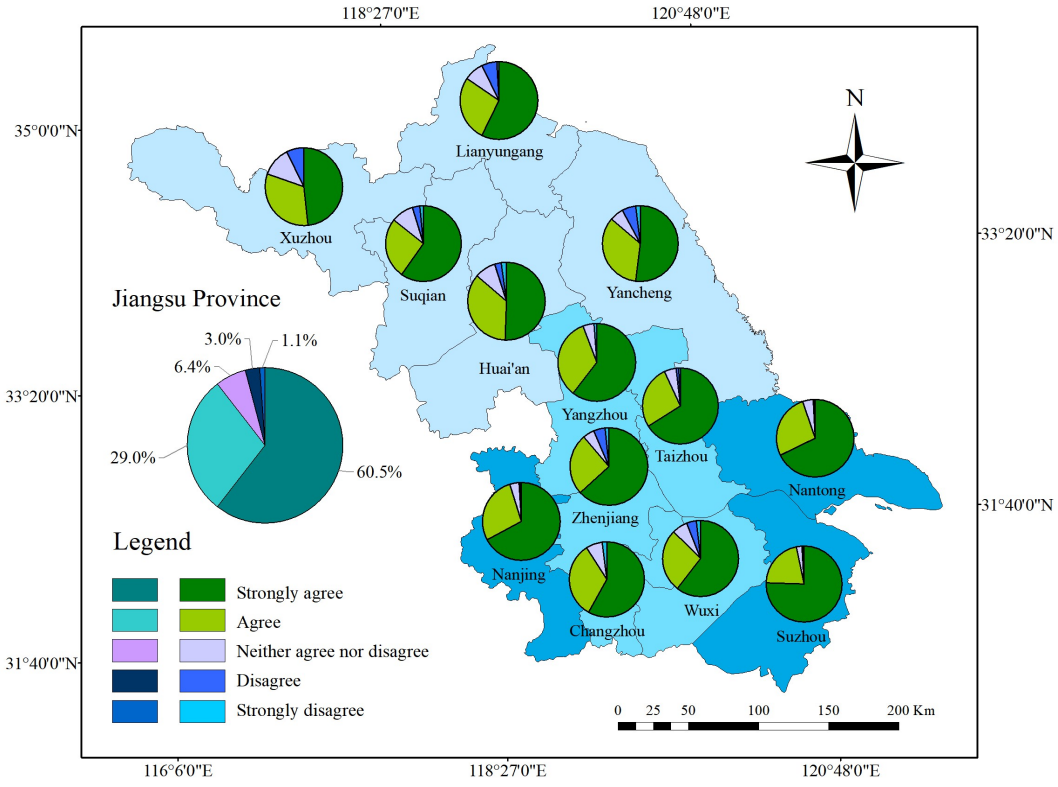

Fig. 3. RIPSSR in Jiangsu

309 4.2. Localized SEMs construction

310 Based on the results for residents' intentions to participate, we constructed 13
311 initial SEMs for RIPSSR. We used maximum likelihood estimation to estimate the
312 parameters, and the initial evaluation results are presented in Table 1(a) and Fig. S3.
313 The test results were less than satisfactory.

314 The initial SEMs were adjusted and optimized. A small number of rules and
315 steps were required: (1) a path coefficient value between 0.5 and 0.95 was considered
316 good; (2) a path coefficient corresponding to a driving factor has practical
317 significance; (3) the chi-squared value was reduced according to modification index
318 (MI) until all fitness indicators (e.g., root mean square error of approximation
319 (RMSEA), normed fit index (NFI), and comparative fit index (CFI)) satisfied
320 statistical criteria; (4) Harman's single-factor test for common method bias (CMB)
321 was executed to eliminate subjectivity of sociological investigation.

Table 1(a). Evaluation of suitability of internal structure of initial SEMs

Variables	Initial Model												
	Suzhou	Wuxi	Changzhou	Nanjing	Zhenjiang	Nantong	Taizhou	Yangzhou	Huai'an	Suqian	Yancheng	Xuzhou	Lianyungang
EK	0.918***	1.006***	0.920***	0.908***	0.935***	0.964***	0.927***	0.969***	1.003***	0.867***	0.934***	1.030***	0.917***
EA	0.992***	1.067***	0.993***	1.01***	1.033***	0.991***	0.969***	1.017***	0.918***	0.865***	0.873***	1.019***	0.975***
FS	0.766***	0.882***	0.847***	0.867***	0.740***	0.893***	0.925***	0.908***	0.732***	0.881***	0.904***	0.628***	0.902***
SN	0.796***	0.935***	0.792***	0.873***	1.033***	0.908***	0.909***	0.962***	0.800***	1.159***	0.939***	0.855***	0.667***
CL	0.368**	0.394**	0.213*	0.015	0.205	0.241***	0.177*	0.135*	0.659***	0.439***	0.012	0.070	0.299
EK1	0.570***	0.746***	0.665***	0.764***	0.746***	0.840***	0.709***	0.796***	0.558***	0.721***	0.760***	0.613***	0.647***
EK2	0.647***	0.673***	0.602***	0.842***	0.603***	0.862***	0.782***	0.807***	0.590***	0.409***	0.693***	0.627***	0.755***
EK3	0.607***	0.608***	0.621***	0.365***	0.639***	0.611***	0.528***	0.456***	0.697***	0.515***	0.474***	0.470***	0.608***
EK4	0.436***	0.645***	0.527***	0.434***	0.632***	0.581***	0.469***	0.509***	0.421***	0.323***	0.472***	0.311***	0.638***
EA1	0.690***	0.677***	0.684***	0.570***	0.626***	0.747***	0.588***	0.610***	0.694***	0.617***	0.556***	0.709***	0.650***
EA2	0.410***	0.434***	0.407***	0.560***	0.406***	0.548***	0.426***	0.525***	0.372***	0.409***	0.309***	0.429***	0.380***
EA3	0.760***	0.720***	0.827***	0.365***	0.723***	0.878***	0.785***	0.834***	0.601***	0.822***	0.996***	0.692***	0.814***
FS1	0.493***	0.628***	0.623***	0.781***	0.676***	0.807***	0.631***	0.703***	0.459***	0.479***	0.709***	0.500***	0.591***
FS2	0.786***	0.884***	0.838***	0.816***	1.013***	1.004***	0.833***	0.957***	0.696***	0.783***	0.920***	0.900***	0.810***
SN1	0.668***	0.585***	0.682***	0.652***	0.580***	0.686***	0.596***	0.678***	0.602***	0.583***	0.737***	0.538***	0.650***
SN2	0.077	0.192*	0.266**	0.311***	0.188*	0.357***	0.406***	0.383***	0.013	0.226**	0.343***	0.331***	-0.018
SN3	0.591***	0.542***	0.745***	0.803***	0.534***	0.809***	0.681***	0.758***	0.488***	0.453***	0.864***	0.642***	0.685***
CL1	0.449***	0.500***	0.491***	0.482***	0.341***	0.553***	0.384***	0.471***	0.669***	0.887***	0.165***	0.347***	0.483***
CL2	0.874***	0.777***	0.852***	1.063***	1.102*	0.932***	1.015***	0.967***	0.603***	0.347	1.148	1.062*	0.933*
CL3	0.456***	0.533***	0.624***	0.522***	0.493***	0.705***	0.585***	0.586***	0.389***	0.197	0.331**	0.478***	0.404**

Table 1(b). Evaluation of suitability of internal structure of improved SEMs

Variables	Improved Model												
	Suzhou	Wuxi	Changzhou	Nanjing	Zhenjiang	Nantong	Taizhou	Yangzhou	Huai'an	Suqian	Yancheng	Xuzhou	Lianyungang
EK	0.930***	0.991***	/	0.943***	0.918***	0.959***	0.949***	/	0.893***	0.723***	0.945**	/	0.998***
EA	0.984***	0.937***	0.984***	0.956***	0.9933***	0.973***	0.954***	/	0.769***	0.831***	/	0.987***	0.950***
FS	0.765***	0.890***	0.870***	0.857***	/	/	0.914***	0.856***	0.767***	0.852***	0.848***	0.652**	0.808***
SN	0.753***	0.920***	0.744***	0.857***	/	0.926***	0.885***	0.926***	0.721***	/	0.974***	0.920***	0.604***
CL	0.702***	0.638***	0.737***	/	/	0.655***	0.504***	0.636***	0.743***	0.540***	/	0.598***	0.732***
EK1	0.563***	0.735***	0.640***	0.761***	0.670***	0.851***	0.724***	/	0.575***	0.834***	0.797***	0.622***	0.637***
EK2	0.652***	0.675***	/	0.843***	0.516***	0.870***	0.778***	0.822***	0.807***	0.581***	0.717***	/	0.841***
EK3	0.736***	0.6594***	0.737***	/	0.678***	0.744***	0.696***	0.659***	/	0.908***	/	0.572***	0.744***
EK4	/	0.661***	0.637***	/	0.672***	0.867***	0.783***	0.759***	/	/	0.488***	0.526***	0.745***
EA1	0.706***	/	0.678***	0.590***	0.653***	0.771***	0.604***	0.603***	0.831***	0.588***	/	0.690***	0.656***
EA2	/	0.467***	/	0.537***	/	0.561***	/	/	/	/	/	0.481***	/
EA3	0.769***	0.832***	0.844***	0.866***	0.744***	0.859***	0.791***	/	0.525***	0.896***	/	0.742***	0.814***
FS1	0.488***	0.619***	0.639***	0.741***	0.537***	0.676***	0.630***	0.681***	0.511***	0.479***	0.702***	0.490***	0.617***
FS2	0.794***	0.903***	0.817***	0.845***	/	/	0.833***	0.990***	0.608***	0.785***	0.923***	0.918***	0.780***
SN1	0.697***	0.626***	0.676***	0.668***	/	0.683***	0.603***	0.6561***	0.592***	0.700***	0.737***	0.521***	0.547***
SN2	/	/	/	/	/	/	/	/	/	/	/	/	/
SN3	0.568***	0.503***	0.762***	0.814***	0.567***	0.816***	0.684***	0.783***	0.548***	/	0.865***	0.581***	0.771***
CL1	0.536***	0.674***	0.447***	/	/	0.510***	0.492***	0.538***	0.762***	0.585***	/	0.532***	/
CL2	0.532***	0.458***	/	/	/	0.621***	0.660***	/	0.523***	/	/	/	0.483***
CL3	/	/	/	/	/	/	0.460***	/	/	/	/	/	/

Note: *** $p < 0.001$; ** $p < 0.01$; * $p < 0.05$. The latent variables of EK, EA, FS, SN and CL are environmental knowledge, environmental attitudes, facilities and services, social norms, and cost losses, respectively. The observable variables of EK1, EK2, EK3 and EK4 are publicity and education, knowledge and information, environmental literacy, and SSR methods, respectively. The observable variables of EA1, EA2 and EA3 are attitudes toward participation, social recognition and social responsibility, respectively. The observable variables of FS1 and FS2 are accessibility of SSR facilities and services for SSR, respectively. SN1, SN2 and SN3 are rewards, laws and recognition, and neighborhood effects, respectively. CL1, CL2 and CL3 are economic benefits, time cost and occupied storage space, respectively.

Taking the SEM for Suzhou as an example, the results of the goodness-of-fit tests show that the chi-squared value for the initial model is 240.432 (P =0.000), there are 85 degrees of freedom, and the values of all the commonly used fit indices satisfy the corresponding criteria. However, according to the parameter estimations for the initial model (Fig. S3 (1-a)), the standardized path coefficient for the influence of "laws and regulations (SN2)" on RIPSSR is only 0.077, which is very small, and the P value is 0.327, which means that the path coefficient is not significant at the 0.05 level. Therefore, the initial assumption that "SN2<—RIPSSR" is valid is not supported. From a practical point of view, laws and regulations place few constraints on minority residents' participation in SSR in Suzhou because most existing SSR laws and regulations in Suzhou as well as in China are merely guidelines, and thus, directives and incentive mechanisms are lacking. Even though the laws and regulations for mandatory SSR were introduced on June 1, 2020, in Suzhou, they targeted only a small number of pilot communities and had a coverage rate lower than 1%. In other words, given the current status, almost none of respondents' actual SSR intentions are significantly affected by the laws and regulations. Therefore, to optimize the model and reflect reality, the path between "SN2" and "RIPSSR" was dropped.

Then, the model was extended with an MI. The MI value between the observed variable "Environmental literacy (EK3)" and the latent variable "Cost losses (CL)" was very high, 21.32. This means that adding a path between EK3 and CL to the model reduces the chi-squared value for the modified model by at least 21.32. Moreover, realistically, residents are easily affected by "EK3"; they invest time and effort to absorb knowledge and information as well as to improve their environmental literacy, their SSR methods, and their ability to engage in SSR. Based on the model analysis and actual situation, a path between the observed variable "EK3" and the

latent variable “CL” was added. The path coefficients for the modified model were estimated (Fig. S3 (1-b)). The results are shown in Table 1(b). The improved SEM for Suzhou is very good.

The models for the other 12 cities were also optimized, mainly by dropping and/or adding paths; more detailed information is presented in Table 1 (a, b) and Fig. S3 (2a-13c). All estimated path coefficients for modified models are significant at the 0.05 level, and most parameters are significant at the 0.01 level, indicating a high level of significance. This significance implies that the other 12 SEMs are credible at 95%. A comparison of index evaluation results for initial hypothetical models and modified models shows that results of all chi-squared tests are lower; values for each fit index are better than those before modification; all RMSEAs are less than 0.08, indicating an acceptable level of model fit; the NFI and CFI are all greater than 0.90, showing that modified SEMs for RIPSSR fit well (Bortoleto et al., 2012; Meng et al., 2019); and the CMB are all less than 40%, indicating that model results present an objective truth.

372 Table 2. Goodness-of-fit evaluation results for the models

Model		RMSEA			NFI	CFI	CMIN/DF	CMIN	CMB
		Mean	P5	P95					
		Less than 0.1			Values higher than 0.9	Values higher than 0.10	<1 is good, 1-3 is fit and the acceptable range is 1-5	The smaller, the better	Values lower than 40%
Suzhou	Initial Model	0.085	0.072	0.098	0.755	0.823	2.829	240.432	25.2%
	Improved Model	0.059	0.037	0.080	0.902	0.950	1.881	71.460	
Wuxi	Initial Model	0.124	0.111	0.103	0.748	0.793	2.598	220.863	28.7%
	Improved Model	0.058	0.033	0.081	0.910	0.962	1.631	75.047	
Changzhou	Initial Model	0.107	0.093	0.121	0.742	0.802	3.243	275.626	25.8%
	Improved Model	0.072	0.046	0.098	0.906	0.949	2.031	62.956	
Nanjing	Initial Model	0.124	0.111	0.103	0.748	0.793	4.159	353.505	37.2%
	Improved Model	0.039	0.000	0.075	0.969	0.993	1.308	27.467	
Zhenjiang	Initial Model	0.104	0.085	0.123	0.730	0.820	2.332	198.234	27.3%
	Improved Model	0.081	0.031	0.126	0.901	0.951	1.815	30.858	
Nantong	Initial Model	0.122	0.112	0.132	0.842	0.862	6.339	538.786	38.5%
	Improved Model	0.095	0.082	0.109	0.915	0.933	4.271	205.022	
Taizhou	Initial Model	0.106	0.094	0.117	0.770	0.814	4.048	344.119	30.5%
	Improved Model	0.068	0.053	0.084	0.900	0.940	2.273	134.135	
Yangzhou	Initial Model	0.121	0.114	0.129	0.811	0.827	9.040	768.438	33.9%
	Improved Model	0.051	0.033	0.069	0.974	0.985	2.418	50.776	
Huai'an	Initial Model	0.110	0.095	0.125	0.623	0.697	3.184	270.649	22.0%
	Improved Model	0.054	0.011	0.086	0.905	0.963	1.526	39.682	
Suqian	Initial Model	1.119	0.104	0.134	0.618	0.688	3.339	283.846	25.4%
	Improved Model	0.044	0.000	0.083	0.934	0.983	1.322	29.075	
Yancheng	Initial Model	0.146	0.132	0.161	0.692	0.737	4.658	395.938	29.8%
	Improved Model	0.077	0.021	0.129	0.968	0.983	2.021	181.191	
Xuzhou	Initial Model	0.084	0.068	0.100	0.733	0.826	2.249	191.138	25.31%
	Improved Model	0.000	0.000	0.030	0.939	1.000	0.760	28.125	
Lianyungang	Initial Model	0.105	0.085	0.125	0.687	0.793	2.203	187.268	24.80%
	Improved Model	0.000	0.000	0.061	0.928	1.000	0.924	32.335	

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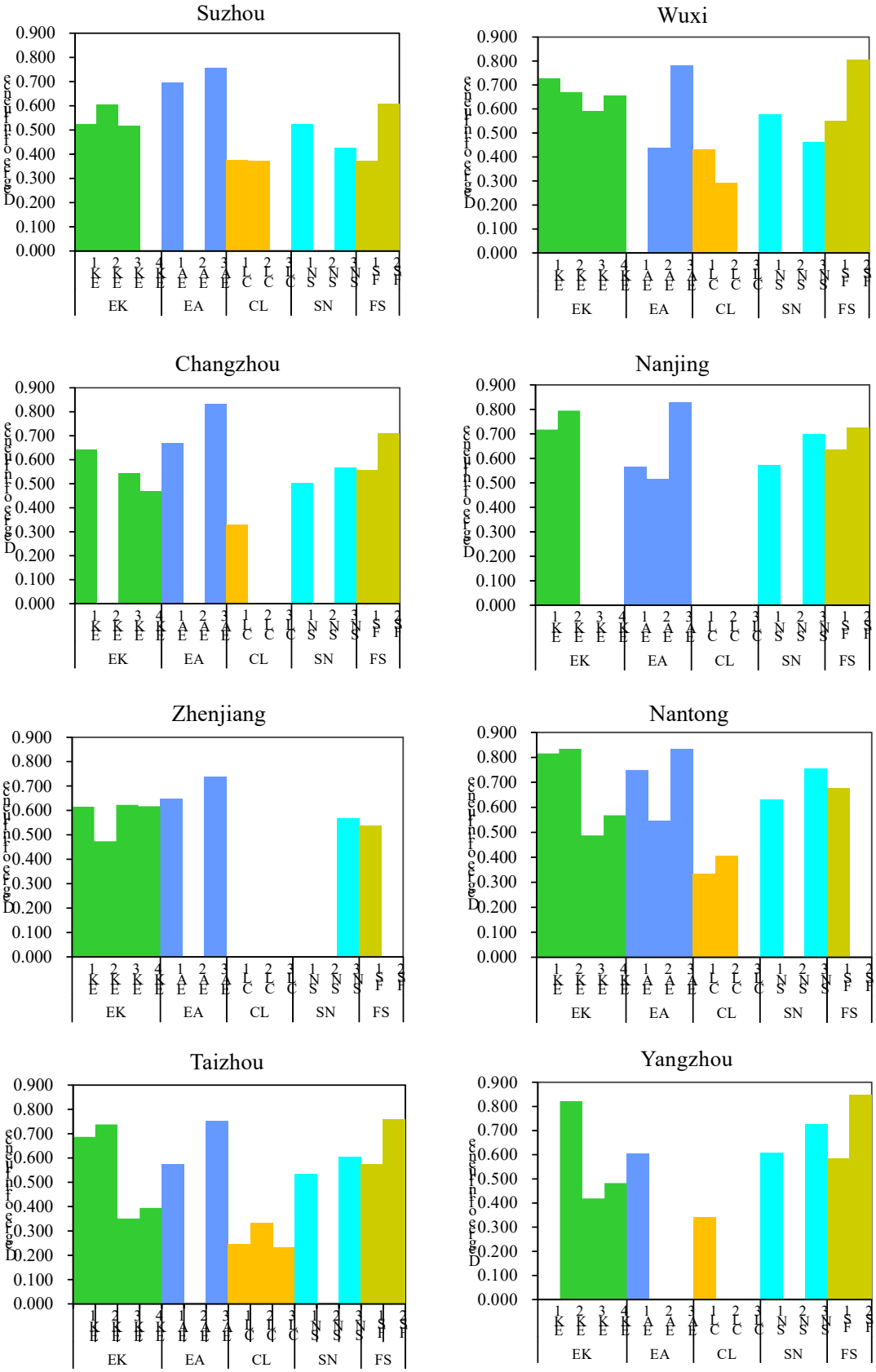
4.3. Factors influencing the discrepancy in RIPSSR across cities

The standardized path coefficient estimates for 13 cities are depicted in Fig. 4. We found that (1) “facilities and services” have a large overall effect on RIPSSR, with an occurrence frequency of 92.3% (12/13), and “accessibility of SSR facilities” is a key factor, which is the only factor that simultaneously affects 13 cities’ RIPSSR; (2) “environmental knowledge” and “environmental attitudes” are important impact factors determining residents to participate in SSR, with occurrence frequencies of 84.6% (11/13) and 69.2% (9/13), respectively; (3) intention to participate in SSR of residents of all 13 cities is not affected by “laws and regulations”; and (4) factors influencing RIPSSR and their degree of influence are different across 13 cities, which results in disparities at the local level. It should be noted that the frequency of occurrence here is the number of occurrences of one factor affecting the RIPSSR in 13 cities of Jiangsu. The importance ranking of the influencing factors for RIPSSR in the 13 cities is provided in Table S9(a, b).


Suzhou
Wuxi
Changzhou
Nanjing
Zhenjiang
Nantong
Taizhou
Yangzhou
0.900
0.800
0.700
0.600
0.500
0.400
0.300
0.200
0.100
0.000
EK
EA
CL
SN
FS

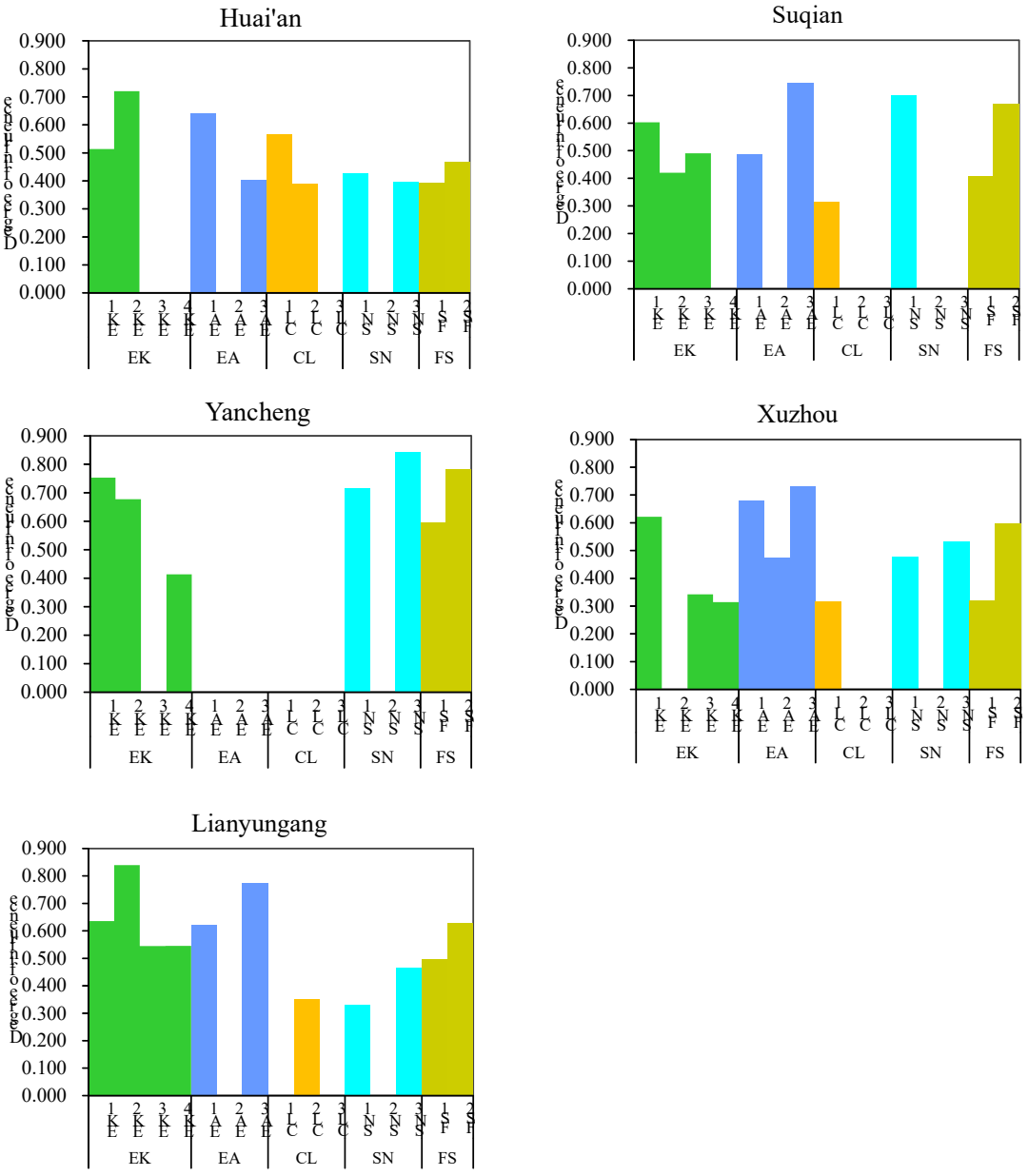


Fig. 4. The degree of influence of key local factors on RIPSSR

Note: The latent variables of EK, EA, FS, SN and CL are environmental knowledge, environmental attitudes, facilities and services, social norms, and cost losses, respectively. The observable variables of EK1, EK2, EK3 and EK4 are publicity and education, knowledge and information, environmental literacy, and SSR methods, respectively. The observable variables of EA1, EA2 and EA3 are attitudes toward participation, social recognition and social responsibility, respectively. The observable variables of FS1 and FS2 are accessibility of SSR facilities and services for SSR, respectively. SN1, SN2 and SN3 are rewards, laws and recognition, and neighborhood effects, respectively. CL1, CL2 and CL3 are economic benefits, time cost and occupied storage space, respectively.

5. Discussions and policy recommendations

The policy recommendations given in this study are valuable for other provinces and/or cities nationwide since Jiangsu represents a microcosm of China. Based on the results from the analysis of 13 established SEMs, four policy recommendations were proposed: 1) creating favorable external conditions regarding facilities and services, 2) promoting extensive publicity and educational activities through various channels, 3) improving the effectiveness of laws and regulations, and 4) implementing flexible, tailored, and localized management strategies. Each policy recommendation is described in detail below.

First, it is essential to plan and provide additional services and improve the accessibility of SSR facilities. According to the results of this study, “facilities and services” have a large overall effect on the RIPSSR, and “accessibility of SSR facilities” was the only factor that affected the RIPSSR in all 13 cities simultaneously (Fig. 4 and Table S7). Although China started SSR pilot programs in 2000, one of the reasons these programs failed is that back-end separation of waste, transportation, and recycling facilities and services was incomplete and inefficient, which seriously dampened residents’ enthusiasm (Meng et al., 2019). Even now, services provided by the accessibility of waste management systems in most Chinese cities are lacking. Facility accessibility and service refinement should be integrated, which requires detailed planning and construction of SSRs, as well as corresponding support facilities in all cities in Jiangsu and in China. Recycling facilities are inextricably linked to residential agglomerations. In 2018, China's urbanization rate broke through 60.0% (CNBS, 2020). Rebuilding all facilities in the old communities in a short time is unrealistic, generally, which is connected with the size of facilities and the availability

of funding. Therefore, the strategy presented here should involve retrofitting and upgrading old infrastructures in the old communities. It is conservatively estimated that there is still room for 20.0% of China's urbanization rate in the future (PRC, 2021). Then, in the process of urbanization, the accessibility of SSR facilities (e.g., appropriate distances, recycling sites and categories) should be carefully considered. SSR services should be diversified to include door-to-door collection, flexible times for accessing SSR services, and convenient SSR and community collection sites. Additionally, SSR services should also be integrated with telecommunications and the internet (e.g., Chinese Alipay, Chinese powerful nation, WeChat, MicroBlo, Tencent QQ, and Credit Cards). Moreover, the construction of recovery sites for renewable resources and the development of a standardized resource recovery system should be accelerated to make recycling facilities and/or services more accessible.

Second, according to the analysis results, “environmental knowledge” and “environmental attitudes” are important factors influencing the objective function of RIPSSR. If these observable variables (publicity and education, knowledge and information, environmental literacy, SSR methods, attitudes toward participation, social recognition, and social responsibility) are applied to management and governance, they will result in a common focus on strategies for managing citizens’ basic education, knowledge, publicity, which can occur only through gradual and long-term positive developments. Education can effectively bridge the gap between having the right attitude and doing the right thing (Liu et al., 2019). It is necessary to increase environmental education to establish environmental responsibility, which is an essential component of school curricula. Attitudes and behaviors are influenced by education and are formed in the long term. It should be included in preprimary- and primary-level curricula while capacity building initiatives in terms of knowledge and

skill transfer in solid waste management, and it should be focused on university courses. Xiao et al. (2007) reported that having more knowledge provides the biggest incentive to participate in recycling. The goal is to guarantee that children understand how to separate waste correctly while also ensuring that the benefits of doing so instill a sense of moral obligation. School education and social publicity education are generally the main sources of environmental knowledge. Existing studies (Grazhdani, 2016; Xiao et al., 2017) have revealed that there is a strong positive correlation between publicity efforts and residents' participation in SSR. If residents are exposed to such publicity more frequently through more channels, their awareness of the need for environmental protection and attitudes toward participation will become more entrenched as they increase their SSR participation. Therefore, governments and other administrative groups should increase SSR publicity and education through public channels such as media, advertisements, televised announcements, applications, billboards, mobile client services, and mobile internet. Plans must be made to organize SSR training in workplaces, schools, and communities to enhance residents' environmental awareness and willingness to participate in SSR, improve their SSR knowledge, and encourage them to build a green and low-carbon civilization and live sustainable "zero-waste" lifestyles. This finding also suggests that SSR policies should be subtle, with priority being given to residential daily life, as daily life has a larger effect on willingness to participate. Additionally, this finding suggests that various strategic SSR management initiatives should be improved and promoted simultaneously.

Third, the effectiveness of laws and regulations should be improved. Although we tried to change the "laws and regulations (SN2)" path during the model improvement process (Section 4.2 and Fig. S3), the results show that "SN2" does not

554 affect the RIPSSR in any of the 13 cities (Fig. 4). This suggests that current “SN2” are
555 not important for RIPSSR. The reason for this finding is that current “SN2” are void.
556 Although certain cities in Jiangsu (e.g., Suzhou, Nanjing, Wuxi) have enforced SSR,
557 even imposing fines, the entities where such enforcement occurs are generators of
558 group institution waste, such as shopping malls, supermarkets and owner-operated
559 shops. In fact, individual residents are not the subject of punishment. It is possible that
560 individual residents play multiple roles. That is, not only do they share responsibility
561 for the waste generated by a group institution. They also independently generate
562 household solid waste and street waste. However, such individual residents are rare.
563 As a result, current mandatory SSR policies are ineffective for RIPSSR. Jiangsu’s
564 urban population density is 2,221 person/km^2, more specifically, 4,160 person/km^2 in
565 Nantong and 5,420 person/km^2 in Huai’an (JNBS, 2020). If the authorities are
566 reserved in enforcing SSR laws, total costs (e.g., camera surveillance, personnel
567 supervision) will be high. SSR developers should also pay attention to the cost of
568 inputs and the introduction of mandatory “SN2”. At the same time, hurriedly
569 improving “SN2” may seem unrealistic since strict “SN2” has been in place for more
570 than 20 years in Jiangsu and elsewhere in China. For instance, waste separation was
571 introduced in Article 28 of the regulations issued by the Departments of the State
572 Council of Urban Appearance and Environmental Sanitation in 1996. Waste
573 separation was emphasized in Article 24 of the Law of the People's Republic of China
574 on the Prevention and Control of Environmental Pollution by Solid Waste. Chinese
575 governance is top-down. All provinces and cities must follow national “SN2”.
576 However, “SN2” in China was invariably first introduced and then followed on some
577 occasions in an attempt to motivate compliance (Xiao et al., 2017). We should
578 intensely recognize that effective implementation and supervision are essential;

otherwise, “SN2” is simply provisional and optional. Several demonstration communities initially adopted waste separation campaigns. However, those campaigns were followed by a policy of all waste being mixed together, which dampened residents’ enthusiasm. Because residents’ enthusiasm has been dampened, it will take longer to restore their trust. MSW is a nonpoint source pollution that “tracks” the whereabouts of humans and becomes scattered into every corner of the city. In other words, whether waste is sorted correctly and disposed of in a trash bin is closely related to residents’ participation intentions and behavior. At present, it is very important to improve environmental education and increase residents' sense of environmental responsibility, as mentioned above. Additionally, the priorities for future urban MSW management should differ from current legislative-centered measures. Provincial and city governments are required to strengthen the top-level design of urban SSR and formulate “SN2” with bite (Meng et al., 2019). As mentioned in the Introduction, several developed countries and regions, such as Germany, Japan, and Hong Kong, have succeeded in implementing SSR. An important tool is the firm establishment of “SN2”, which supports SSR, as its implementation and enforcement are effective in promoting SSR and reducing environmental contamination. Furthermore, more precise “SN2” systems should be enacted. For example, specific SSR management links such as source separation, collection, transportation, treatment and recycling can be implemented.

Fourth, flexible, tailored, and localized management strategies for residents should be implemented. The results in Section 4.1 show that SSR is highly feasible, both in Jiangsu as a province overall and in the 13 cities; additionally, RIPSSR in southern Jiangsu is higher than that in northern Jiangsu, and proportions of residents who “strongly agree” that they would participate in SSR in Nantong, Suzhou and

Nanjing are as high as 75.5%, 67.8%, and 67.1%, respectively. This could be attributable to the influence of publicity, knowledge, and education about environmental protection. There are 134 Chinese universities in southern Jiangsu, while northern Jiangsu has 33 universities (CNBS, 2020). Neighborhood effects are important: Nantong and Suzhou are Shanghai's "backyard" (Fig. 1), and Shanghai is China's leading city in terms of SSR (Xiao et al., 2020). The compulsory classification provision since 2019 has been successful in Shanghai (Wang et al., 2021), its focus is on promoting the source separation of kitchen waste (Zhang et a., 2012). Current, these successes and pilot areas are being expanded. Additionally, the efforts of the government to facilitate SSR should also be credited. For instance, Suzhou is a model city for ecological and environmental protection in China, and Nanjing has been an SSR pilot city since 2000 (Fig. S1). Waste policy making should reward residents who are very willing to participate in SSR programs. Moreover, the results in Section 4.3 show that factors influencing RIPSSR and their degree of influence are different across 13 cities of Jiangsu. Thus, we should implement flexible, tailored, and localized SSR management strategies for local residents. It should be emphasized that successful countries and regions set prevention as their priority, followed by the 3 "Rs" (reducing, reusing, recycling), with disposal at the bottom of the inverted priority pyramid.

6. Conclusions

The analysis of residents' attitudes toward SSR can facilitate MSW management. This study collected 2,963 valid questionnaires in 13 cities of Jiangsu, representing a microcosm of China, and utilized SEM to discuss localized influencing factors of

successful SSR planning and management. The main conclusions are as follows: (1) although a large number of residents showed positive attitudes toward SSR projects in Jiangsu, RIPSSR in southern Jiangsu was higher than that in northern Jiangsu; (2) the factors influencing RIPSSR and their degrees of influence differ across 13 cities, which presents localized disparities; (3) it presented that "accessibility of SSR facilities" is a key factor, "environmental knowledge" and "environmental attitudes" are important factors in all the 13 cities; (4) RIPSSR is not affected by "laws and regulations" in any of the 13 cities, this reason is that current laws and regulations are void. The government should create favorable external conditions related to facilities and services, promote extensive publicity and educational activities through various channels, and improve the effectiveness of laws and regulations. Future SSR management strategies should be flexible, comprehensive, and tailored to urban individuals.

This study makes both academic and practical contributions. From an academic aspect, this study analyzed urban residents' participation intentions and influencing factors and their degree of influence as well as decision-making mechanisms in SSR by using Web surveys and field surveys and model building. The use of such methodology provides an effective combination for traditional questionnaire interview methods and booming big data approaches. From a practical perspective, this study revealed that residents' participation intentions are high, which indicated that SSR is highly feasible. This study also identified and ranked localized influencing factors in SSR and proposed corresponding policy recommendations.

Additionally, this study points the way for future research. The results show that "facilities and services" have a large overall effect on RIPSSR in 13 cities of Jiangsu. In the future, we will place additional focus on facilities and services. For instance,

what SSR facility and service patterns make it more convenient for residents to participate, and which patterns cost less? The results also show that the RPISSR is not affected by “laws and regulations” in any of the 13 cities, which does not seem to agree with the advanced SSR experiences of developed countries. How laws and regulations can be made more effective should be a focus in the future. Notably, the sociodemographic characteristics of residents are inherent to them, making them inseparable from residents at any time or place. This fact means that more tailored policies should be assessed.

However, this study retains certain limitations that must be addressed. The measurement of environmental knowledge is multifaceted, and the selection of possible observation variables and the design of the measurement items in the questionnaire to reflect this complexity may not be adequate. Improvement in these areas could be topics for further investigation. Additionally, the study of individual environmental attitudes based on Likert scale-assessed questionnaire survey data has methodological limitations and involves subjectivity. To resolve these issues, other simulation methods can be applied in future research, such as Complex Adaptive System theory or Multi-Agent System theory.

CRediT authorship contribution statement

Binxian Gu: Funding acquisition, Investigation; Research planning, Data inspection and analysis; Methodology, Software, Formal analysis, Validation, Writing original draft, Review and editing. **Yanbin Yao**: Investigation, Data inspection and analysis, Formal analysis, Software, Writing original draft. **Huiming Hang**: Investigation, Data inspection and analysis, Formal analysis, Software, Validation.

Yulin Wang: Funding acquisition, Research planning, Formal analysis, Methodology, Modeling. **Renfu Jia**: Investigation, Data inspection and analysis, Methodology. **Lingxuan Liu**: Research planning, Methodology, Writing, Review and editing. **Hui Ling**: Review and editing, Proofreading, Validation. **Xinyi Tang**: Investigation, Drawing, Data inspection and analysis. **Haijie Zhang**: Data inspection, Proofreading, Validation. **Zhiwei Wu**: Investigation, Data inspection and analysis, Writing, Review and editing. **Yongxiang Wu**: Investigation, Drawing, Data inspection and analysis. **Takeshi Fujiwara**: Research planning, Methodology. **Yanchao Bai**: Funding acquisition, Investigation, Research planning, Methodology, Formal analysis, Writing original draft, Validation.

Declaration of Competing Interest

None

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