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An overview of China's recyclable waste recycling and recommendations for integrated solutions

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Abstract:

Due to rapid economic growth and population increase, problems of environmental pollution, climate change, and resource depletion have become increasingly serious in China. Recyclable waste recycling

(RWR) is becoming one of the key approaches to simultaneously respond to the above issues, and the Chinese government has begun to regulate and promote source separation and urban waste recycling in recent years. However, several barriers still exist, and it is therefore crucial to review China's RWR system in order to identify these barriers, and propose appropriate solutions. This paper firstly summarizes the current situation for China's RWR: (1) recycling in 2016 reached 246 million tons, with 0.3% increase from the previous year; (2) regulations have been greatly strengthened in recent years, although regulations on specific RW, source separation, and interrelated technology are still lacking; (3) a pilot recycling program at the city level was initiated in 2006, covering 90 cities, 51,550 recycling sites, 341 collection centers, 63 terminal markets, and 123 recycling & processing bases. The paper then identifies several key problems and challenges, including ineffective governance and market construction, inefficient source separation, and the lack of a recycling information platform. In responding to these barriers, a number of solutions are proposed: an integrated RWR framework using a Public-Private-Partnership (PPP) investment model; combining the RWR system with municipal solid waste (MSW) collection system; and using internet technology to establish a comprehensive information platform. The use of internet technology is suggested as a unique and effective way of solving China's RWR problems.

Keywords:

Recyclable wastes recycling (RWR), pilot city program, regulation and policy, internet+, integrated framework

1. Introduction

With rapid urbanization and industrialization, China is facing multi-challenges, including resource depletion, environmental pollution and climate change mitigation (Chan and Yao, 2008; Gu et al., 2011; Shen et al., 2005; Zhou et al., 2004). In addition, the increasing quantity of municipal solid waste (MSW) is problematic due to the limited availability of land for new landfill sites (Zhang et al., 2010). Therefore, it is essential to promote the reutilization of recyclable wastes, which can simultaneously respond to the issues of limited landfill space, environmental pollution, and natural resource depletion. The Chinese central government regards recycling of recyclable wastes as one of the main measures for promoting a circular economy (SCC, 2013). Several governmental documents and regulations have been released, particularly in recent years, to promote urban waste recycling and source separation in China (MOC, 2006; MOC et al., 2016; MOC et al., 2007). An ambitious target was also set, aiming for a recycling rate of 35% for MSW and a source separation coverage rate of 90% for 46 targeted pilot cities by 2020

(NDRC and MOHURD, 2017).

Recyclable wastes (RW) are those generated from industrial production and residential sources, but which can be recycled after appropriate sorting and processing (MOC et al., 2007). Typical examples include waste paper, waste plastic, waste glass, waste tire, waste metal, discarded home appliances and waste electrical and electronic equipment (WEEE) (MOC et al., 2007). Developed countries started the MSW management earlier and have achieved significant achievement in building an urban recycling system, especially Japan (Fujii et al., 2012; Geng et al., 2010). However, China is still at its early stage in establishing such an urban waste recycling system and some barriers still exist. Therefore, it is crucial to have a holistic overview on China's urban recycling system so that key barriers on RW Recycling (RWR) can be identified and appropriate policy suggestions can be proposed.

Academically, many studies on MSW management have been done, but few focusing on the RWR (Dong et al., 2001; Hong et al., 2010; Wang and Nie, 2001). Existing RWR studies can be classified into three types. The first type refers to those case studies in developed cities and focusing on high value recyclable wastes, such as waste plastic (Chen et al., 2011; Zhang et al., 2007), waste paper (Liang et al., 2012), and particularly WEEE (Awasthi and Li, 2017; Dong et al., 2001; Hong et al., 2010; Kumar et al., 2017; Lu et al., 2014; Wang and Nie, 2001). For example, several studies on extended producer

responsibility to manage WEEE in China have been conducted (Kojima et al., 2009; Wang et al., 2017; Yu et al., 2010). The second type refers to those qualitative discussions on China's RWR system. For example, Ouyang and Cao (2012) identified the poor recycling system, outdated development concepts, and disordered marketing rules as the three main barriers for developing China's recycling system, and proposed nine measures for constructing an effective recycling system. The third type refers to those studies on formal sectors and informal sectors in the RWR system. The major finding is that informal recycling practices dominate waste recycling, and will continue to be required in China for the short term (Fei et al., 2016; Li, 2002; Steuer et al., 2017; Wilson et al., 2006).

However, no review studies on recyclable wastes in China has been published, with the exception of reviews focused specifically on MSW management. For instance, Chen et al. (2010) reviewed the current situation for MSW management in China, including regulations and policies, waste collection, treatment and disposal, and proposed an integrated waste management framework to improve the overall eco-efficiency of MSW management. Tai et al. (2011) compared the MSW source-separation performance of eight pilot cities and found that only Beijing and Shanghai had a relatively positive result, and recommended that source-separation should be a key priority in MSW management. Wang and Du (2012) summarized relevant experiences from the United States, Japan and the European Union, such as

government leadership, legal promotion, technology support, system security, clear authority and public participation, and the authors recommend that China should learn from these experiences to establish its own RWR system.

Distinct from the above studies that focus on the review of MSW management, this study focuses more specifically on reviewing China's RWR system and management. Moreover, due to increasing quantities of waste in China, and the lack of a mature RWR system, it is crucial to have an overview of China's current RWR system, including progress, challenges and possible solutions. This paper aims to fill this gap by reviewing China's RWR regulations and policies, identifying existing problems and proposing feasible solutions for improving China's RWR. The remainder of this paper is organized as follows: Section 2 provides an overview of the current situation for China's RWR system, including the existing recycling modes of recyclable wastes;. Section 3 further elaborates on the development of China's RWR regulations and the pilot city program initiated by the Ministry of Commerce; Section 4 then identifies the problems and challenges for RWR in China; Section 5 proposes an integrated framework to efficiently develop China's RWR system; Finally, we draw our conclusions in section 6.

2. RWR development in China

2.1 Regulations and policies on RWR

China's regulations on RWR date back to 1958, when the first governmental document *Instructions on Improving Collecting and Utilizing of Waste* was issued (SCC, 1958). However, this document mainly focused on the collection and reutilization of valuable wastes, including scrap metals, waste chemicals, waste oil, waste fiber, *etc*. Later, the Chinese government released several national regulations and policies to promote the recycling of recyclable resources, particularly during recent decades (Table 1). The most important laws in the field of RWR is the *National Circular Economy Promotion Law* released in 2009, and the *National Cleaner Production Promotion Law* released in 2003, which build up a legal framework to guide recycling activities. Besides the aforementioned laws, many regional or local regulations and policies are proclaimed to govern specific recycling activities.

Besides the above mentioned comprehensive regulations, there are also many specific regulations relevant to waste electrical and electronic equipment (WEEE), including *"Administration Measure on Prevention of Environmental Pollution Caused by Electronic Waste"*, "*Management Measure on Prevention of Environmental Pollution Caused by Electronic*" and" *Information Industry, and Pollution Prevention of Waste Electrical and Electronic Equipment*". These regulations provide detailed measures on collecting, delivering and treating WEEE. In addition, the *"Provisional Management Measures on Packaging Resources"* was released in 1999, with descriptions of recovery channels, principles for

sorting, and requirements for the treatment of different kinds of packaging materials, including paper, wood, plastic, metal and glass. However, there are no other specific regulations to manage those low value recyclable wastes at the national level, such as waste textiles, waste rubbers and waste glasses. The only national general regulation is "*Measures for the Administration of Recyclable Resources Recycling"* issued in 2007 (NDRC et al., 2007).

Several local governments introduced their own local regulations to supervise and manage local recycling markets. These regulations consider the local situation and can better promote the enforcement of national regulations at a local level. For instance, Shanghai released "*The City of Shanghai Guidance Catalogue of Recyclable Resources Recycling"* on 2nd May, 2013 (SMCC, 2013). Kunming, the capital city of Yunnan in the southwest China, issued "*The City of Kunming Administration Regulations on Recycling of Recycled Resources"* on January 1st, 2014 (SCKMPC, 2014). It clearly stipulates relevant municipal sectors' responsibilities. For instance, the Bureau of Commerce is responsible for preparing a recycling development plan and supervising recycling activities at the county level. Bureau of Urban-Rural Planning is responsible for integrating the plan for recycling sites into the urban-rural plan. The Bureau of Environmental Protection is responsible for controlling pollution generated from processing recyclable wastes (including collection, sorting and final treatment). These local regulations proactively

129 promoted the local development of the RWR system.

130 **Table 1**

131 Laws or policies which refer to RWR in China

Effective Time	Laws or Policies	Brief Description	Issuer
1991/12/26	Notice on Strengthening Administration of Recyclable Resources Recycling	Specifying categories of recyclable resources; Preventing illegal business in recyclable metals; Requiring enterprises positively collect low value recyclable resources.	SCC
2003/01/01	Clean Production Promotion Law	Setting rules to require enterprises employ clean energy, advanced technology and integrated management to decrease pollution and increase utilization efficiency of resources all the way.	NPC
2007/05/01	Measures for the Administration of Recyclable Resources	Providing crucial provisions to collect, trade and administrate recyclable resources; Identifying government departments' responsibilities.	NDRC, MOPS, SAIC,

	Recycling		MEP
2009/01/01	Law on Promoting the Development of Circular Economy	Clarifying requirements of Reduce, Reuse and Recycle (3R); Emphasizing process of recycling should meet national required standards.	NPC
2010/05/28	Guideline on Further Advance in Development of Recyclable Resources Recycling Industry	Making policies to develop industry of recyclable resources recycling and establish administration schemes. Suggesting governments to foster leading enterprises and set up modern information system	MOC
2011/10/31	Opinion on Construction of Complete and Advanced Waste Recycling System	Forming basic principles and main targets to construct modern and advanced RWR system; Listing major tasks, including improving sorting level, strengthening technological support and completing recycling system.	SCC
2013/01/23	Development Strategy of Circular Economy and	Concluding achievements and obstacles of circular economy in 2005-2010; Making action	SCC

	Recent Action Plan	plans to promote development of circular economy at social level.	
2014/12/31	Implementation Plan of Important Resources Recycling Engineering (Technology Promotion and Equipment Industrialization)	Making plans to promote technological development and equipment production in the aspects of urban mineral (recyclable resources), remanufacturing, industrial waste recovery and construction of waste goods recycling system.	NDRC, MOST, MIIT, MOF, MEP, MOC
2015/01/21	Construction of Recyclable Resources Recycling System in Mid-long Term Planning (2015-2020)	Introducing current characteristics and problems of recyclable resources recycling; Planning major tasks and programs to construct a complete and advanced RWR system in 2020.	MOC, NDRC, MOLR, MOHURD, ACFSMC
2016/05/05	Opinion on Promoting Transformation and Upgrading in Recyclable	Encouraging innovating RWR system, such as Internet+; Transforming extensive management modes to intensive management modes.	MOC, NDRC, MIIT,

Resources Industry	MEP, MOHURD, ACFSMC

Note: ACFSMC (All-China Federation of Supply and Marketing Cooperatives), SCC (State Council of China), MEP (Ministry of Environmental Protection), MIIT (Ministry of Industry and Information Technology), MOC (Ministry of Commerce), MOF (Ministry of Finance), MOHURD (Ministry of Housing and Urban-Rural Development), MOLR (Ministry of Land and Resources), MOPS (Ministry of Public Security), MOST (Ministry of Science and Technology), NDRC (National Development and Reform Commission), NPC (National People's Congress), SAIC (State Administration for Industry & Commerce).

2.2 Pilot program of RWR

The Ministry of Commerce (MOC) of China initiated a program of RWR systems in pilot cities in 2006, in which 26 cities were included in the first batch of pilot cities (MOC, 2006). Later, 29 pilot cities and 35 pilot cities were announced as the second batch and the third batch in 2009 and 2012, respectively (MOC, 2009, 2012). The geographical distribution of the three batches of pilot cities in China is shown in figure 1. Most of them are located in the relatively rich and developed area of eastern China. Statistical

data show that 51,550 recycling sites, 341 collection centers, 63 terminal markets, and 123 recycling & processing bases were established under the three batches of pilot city projects (ChinaIRN.com, 2014). The aim of the pilot program was to promote the construction of a formal RWR system, strengthen the enforcement of regulations on RWR, and normalize the qualification standards for recycling enterprises and individuals. MOC anticipated that by end of the third batch of pilot city program, approximately 90% of communities could set up formal RW recycling sites, 90% of the RW could enter into the formal trading market and final treatment system, and 80% of the typical RW can be recycled in pilot cities. The intention of the program was that all the local governments involved should summarize the successful experiences from the pilot projects, and then share them to guide the development of RWR system in other Chinese cities. All the pilot cities were required to elaborate on implementation schemes, make annual plans, and prepare their MSW policies by considering the local realities.

The implementation of the pilot program is a step-by-step process. The first pilot cities include four province-leveled municipalities and many provincial capitals. These cities have relatively large economies and mature infrastructure for collecting, delivering and treating RWR. Four main objectives were included. Firstly, all the pilot cities should establish and improve their management of RWR, including construction planning, policies, and standards. Secondly, all the pilot cities should develop

networks to support their RWR system, such as a community-based recycling network, a non-community-based recycling network, an industrial waste metal recycling network, and a recyclable wastes transaction market. Thirdly, all the pilot cities should foster recycling enterprises to promote the development of the whole industry. Finally, in order to improve the awareness of recycling amongst employees, all the pilot cities should engage in capacity building activities for both bottom participators and senior experts.

The second batch of pilot program includes 29 cities and 11 waste transaction markets. The aims of this batch include energy saving and emission reduction, resources conservation, ecological protection and increasing the consumption of recycled wastes. There are three key objectives in this batch. Firstly, all the pilot cities should create new business models and standardize the recycling sites. According to the construction plan, the local government should encourage all communities to build up their waste collection sites so that more recyclable wastes can be collected. Secondly, all the pilot cities should improve their treatment technologies. The program also intended that successful experiences and useful technologies from other countries should be transferred to these pilot cities to improve their source separation. Moreover, all the pilot cities should support the delivery of such wastes so that treatment companies can easily source adequate wastes for their operations. Thirdly, all the pilot cities should

improve their waste transaction markets so that recycled wastes can be easily sold. Necessary environmental protection facilities should be established as well so that secondary pollution can be avoided. The key feature of this batch is the promotion of waste transaction markets as these markets play an important role in connecting the upstream collection firms and the downstream treatment firms.

The third batch of 35 pilot cities mainly came from prefecture-level cities and some county-level cities. Most of them have reasonably stable recycling systems and good economic conditions. The pilot cities were required to not only make detailed construction plans but also to coordinate the plans of relevant government departments. Moreover, at least two leading recycling enterprises should be fostered for each pilot city to facilitate the development of the RWR system. Finally, the pilot cities should make relevant local laws and supporting policies to support recycling system construction, such as financial support, land arrangement and tax preference.

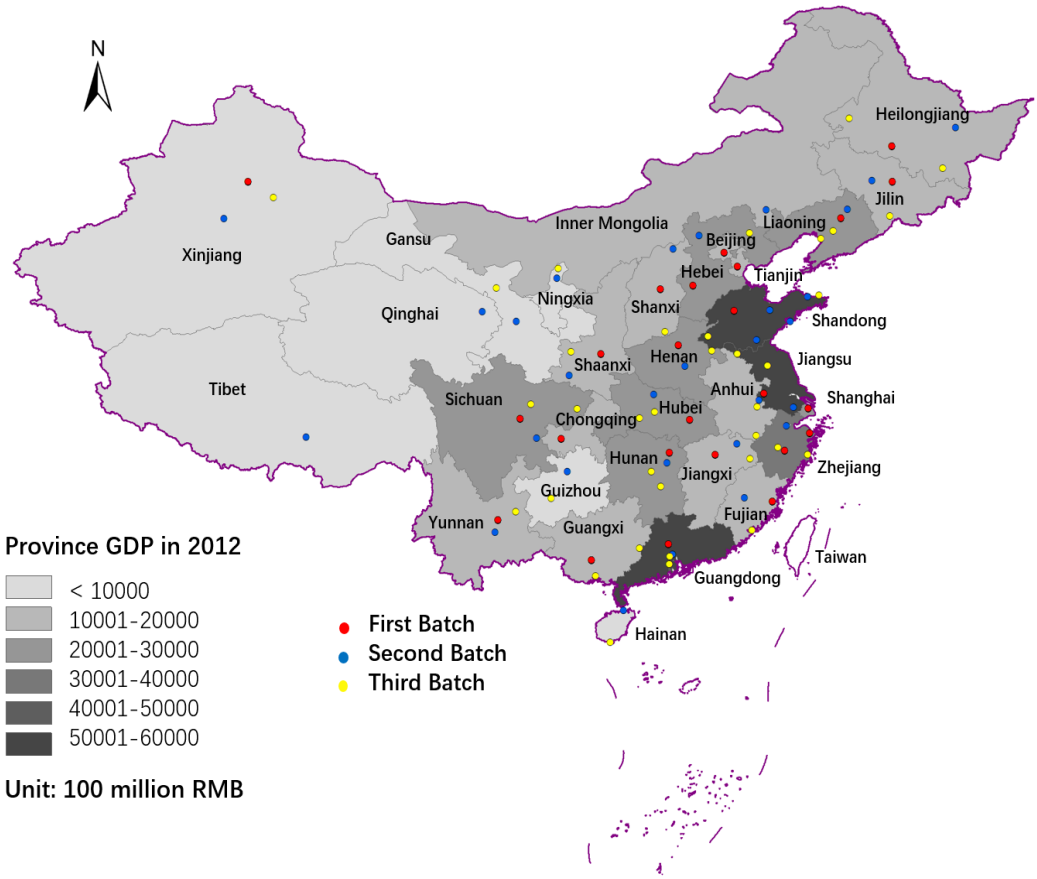

Figure 1 The distribution of RWR pilot cities

3. Current situation and achievements

3.1 Status quo of China's RWR

After several decades of development, China has made considerable progress in RWR. The total recyclable amount of the ten dominant types of recyclable wastes reached 246 million tons in 2016 (0.3% increase from previous year), with an economic value of 515 billion RMB (MOC, 2017). The recycling of several common wastes, such as waste paper, waste plastic, WEEE, waste automobiles and waste steel, has been improved. For instance, waste paper is one of the most common recyclable resources in China,

and its recycling rate increased from 27.5% in 2001 to 46.7% in 2015 (figure 2). Compared with waste paper, waste plastic has a lower recycling rate, ranging from 20% to 30%.

With the improvement of living standards, more and more WEEE and waste automobiles were generated. The recycling rate for WEEE increased sharply from 31.3% in 2012 to around 50% in 2015 (figure 2). One feature of China's RWR is that the recycling of waste depends on policies. On July 1st, 2012, *Measures for the Collection, Use and Management of Waste Electrical and Electronic Equipment Treating Funds* was issued (MOF et al., 2012). This policy stipulates that the subsidy for recycling one television or one microcomputer is 85 RMB, for one refrigerator is 80 RMB, and for one washing machine or one air conditioner is 35 RMB. Although this policy increased the collection of WEEE, almost half of WEEEs still cannot be collected through this official channel due to the lack of a mature recycling system.

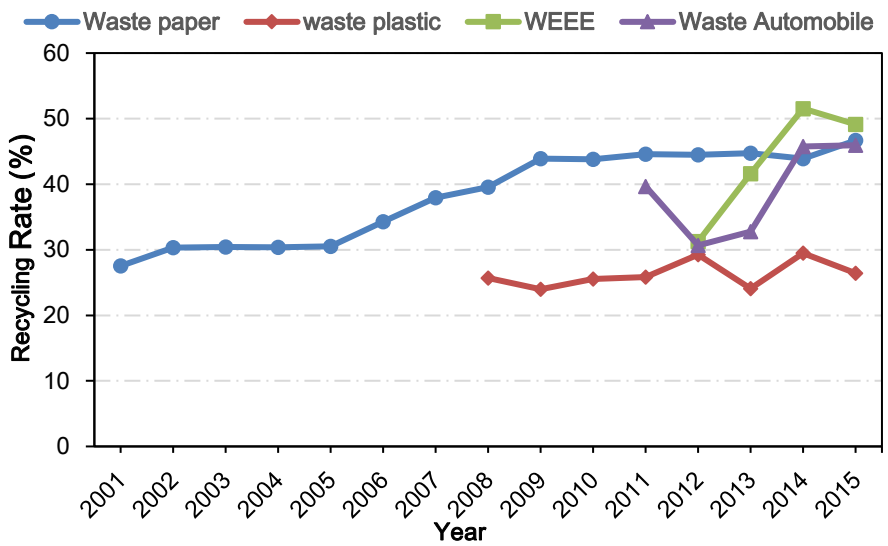

Figure 2 The recycling rates of four main recyclable wastes in China.

Data source: Industry Development Report of Recycled Resources of China (China National Resources Recycling Association, 2016).

3.2 *Existing RWR modes*

There are three recycling modes for China's RWR, namely, formal modes, informal modes and innovative modes (figure 3). Informal waste vendors collect and process a significant share of recyclables, while formal source separation of recyclables is still at a relatively small scale (Linzner and Salhofer, 2014). Taking Suzhou as an example, the informal system collected 60% of total domestic recyclable resources, while the formal system only accounted for 16% (Fei et al., 2016). As for innovative recycling, it is an emerging recycling mode and has developed rapidly in recent years with the development of information technology.

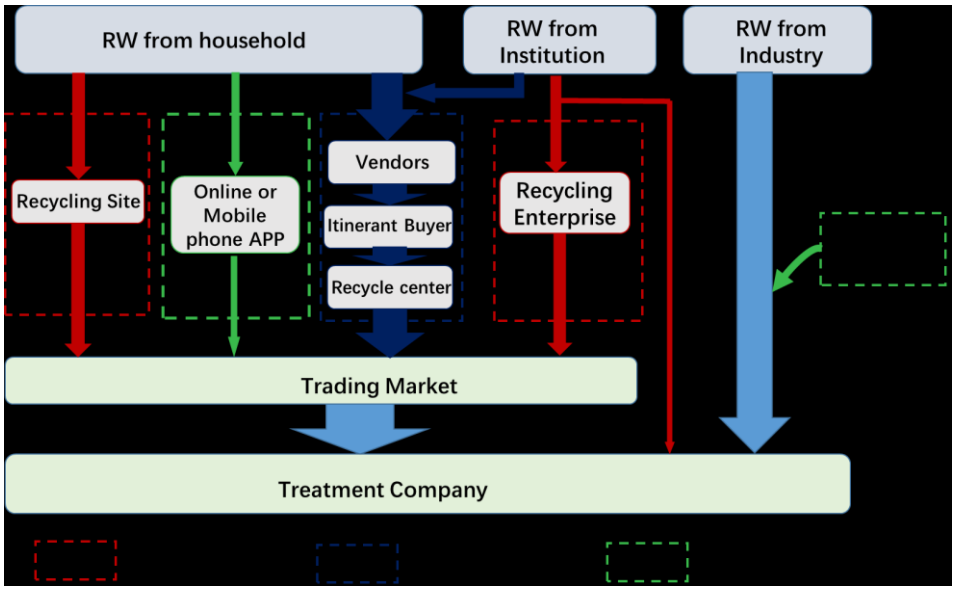

Figure 3 Network of recycling modes in China.

In terms of the formal recycling mode, formal recycling networks for households have been developed in some pilot cities, with fixed recycling sites within their communities. The fixed community-recycling sites are usually established on a commercial basis, although the waste collection companies were generally still supported by the local municipal government (Wang et al., 2008). The collected RWs are delivered to the local waste trade market so that potential buyers can easily purchase them. This process of formalizing the RW system can gradually substitute or eliminate the informal sector (Zhang and Li, 2010). This formal recycling mode also covers RW from different institutions, including governmental agencies, commercial buildings, schools and hospitals, etc. Recycling enterprises collect RW and deliver it to the local waste trade market or the treatment company. It is a simple and direct mode which has shorter transportation distances and higher efficiency.

In terms of the informal recycling mode, most informal vendors are small-scale and labor-intensive. They are mostly unregulated and unregistered, with basic recycling technologies and services (Wilson et al., 2006). However, they play a vital role in collecting RW, particularly for WEEE recycling. Statistical data show that the informal sector collected approximately 98% of WEEE in China in 2007 (Yu et al., 2009), and the majority of the collected WEEE is also processed by the informal sector (Li et al., 2006).

However, the distribution of the informal sector is uneven, and the sector mostly only engages in the higher value wastes, such as waste paper and waste plastic. Also, due to low barriers to entry, many informal vendors do not have higher education and rely on the informal recycling activities(Wilson et al., 2006). It is difficult to entirely forbid the informal sector, as doing so may induce several social problems such as increasing unemployment or lack of access to waste services for households. Most informal recycling vendors provide their services to local households, although occasionally they may also serve institutions. This is because the local government can easily control most public institutions while it is difficult for the local government to control households. Another feature of the informal sector is that most vendors use tricycles to collect RW, making them able to collect RW with lower costs (Li, 2002).

As for the innovative recycling mode, it applies modern information technologies such as the internet, big data, and mobile phone apps to facilitate online trade, which is more convenient, cheaper and easier to operate. However, this mode is still in its infancy but is highly likely to play an important role in promoting China's RWR in the future. For instance, Beijing Incom Recyclable Resources Recycling CO. Ltd. utilized kiosk machines for collecting waste clothes, and established relationships with local communities, universities and museums so that discarded clothes from these entities can be collected. For one individual, he/she can access a local kiosk machine and print a stub (with a matrix

code) by touching this machine's screen. Then he/she can attach the stub to an item of discarded clothing and then put it into this kiosk machine. The clothes will then be separated so that those clean and usable clothes can be donated to poor areas, while those that cannot be reused would be recycled. Individuals who donate clothes in this way can earn points which can be redeemed for philanthropic activities, which are implemented by the recycling company as well.

4. Existing problems and challenges

4.1 Ineffective government administration and market construction

Ineffective government administration and immature markets are two critical factors that impede the development of China's RWR. Although the Chinese government has done a lot in recent years to promote the RWR, there are still scope for the government to strengthen its legal system and administration. For example, "*Measures for the administration of recyclable resource recycling*", which was issued in 2007, is the only specific regulation in the field of RWR. Besides, the legal power of this regulation is limited. Also, there is a lack of specific industrial standards, technology standards, classification standards and test standards for most of the recyclable wastes. Therefore, more general and specific legislation is needed in order to guide the development of the recycling industry. In addition, existing regulations concentrate more on WEEE and other high-value recyclable resources, and there are

no specific regulations governing low-value recyclable resources, such as waste glass or waste compact fluorescent lamps.

Another key problem is the lack of a centralized administrative department to take charge of the RWR system. Currently, several departments, including MOC, MOF, MEP and MIIT, are involved in RWR management. MOC has responsibility for RWR management, mainly related to trade and logistics for RW. The City Construction Administration Bureau is responsible for municipal waste collection and management at the local level. MEP is in charge of environmental pollution from the transportation of waste and final waste treatment. The coordination of these departments is extremely difficult and inefficient, leading to an urgent need for a new agency to specifically coordinate the RWR system.

Regarding to the establishment of recycling markets, several challenges still exist since informal recycling vendors and scavengers are the dominant components of the current recycling market, especially in recycling WEEE (Chi et al., 2011; Tong et al., 2017). Informal sectors have the advantages of flexibility and a low operation costs, and so they are more competitive than formal sectors, which hinders the development of formal recycling markets. Moreover, recycling rates are closely related to the value of recyclable wastes. Therefore, most of the low-value recyclable wastes have relatively low recycling rates due to their high recycling costs and low recovery benefits. In contrast, traditional

industrial wastes, such as waste steel and waste nonferrous metals, have comparatively complete recovery chains and high recycling rates. In summary, the disorder of informal recycling and low rates of recover for lower value wastes are key barriers for the establishment of China's formal recycling market, which requires government intervention.

4.2 Insufficient MSW separation

MSW is one of the main source for recyclable wastes, with approximately 30% of MSW being recyclable, although it has a high proportion of organic components (Table 2). However, the separation rate of household wastes is extremely low. Tai et al. (2011) found source-separation rates vary from 8.9-40.1% in eight Chinese cities. After the implementation of a pilot program for household waste separation in eight cities, only Beijing and Shanghai achieved around 60% household waste separation, while the other six cities had less than 20% household separation.

The reasons for low levels of source separation include two factors. First is the low level of public awareness and incentives for recycling (Zhuang et al., 2008). There is almost no promotion or guidance on RWR, and most of residents do not have the right knowledge to separate recyclable waste. The only motivation for waste separation is that they can receive some money from informal recyclers. Second is that there are not adequate or convenient recycling facilities, which is a considerable barrier to recycling

behavior. For example, some residents do not have space to keep their recyclable wastes. According to (Zhang et al., 2016), enhanced accessibility of recycling facilities would encourage people to take recycling action. As for the cost of building recycling facilities, it may be possible that recycling companies who will benefit from high value RW recycling, or companies who produce the RW, should be responsible for the investment in accessible recycling facilities.

Table 2

MSW compositions in four municipalities in China

Composition (%)	**Organic garbage**	**Paper**	**Plastic**	**Glass**	**Metal**	**Textile**	**Others**
Beijing (2006)[a]	63.39	11.07	12.07	1.76	0.27	2.46	8.98
Shanghai (2004)[b]	66.70	4.46	19.98	2.72	0.27	1.80	4.07
Tianjin (2006)[c]	56.88	8.67	12.12	1.30	0.42	2.47	18.14
Chongqing	59.20	10.10	15.70	3.40	1.10	6.10	4.40

(2006)[d]							
Average	61.54	8.58	14.97	2.30	0.52	3.21	8.90

Data source: a (Li et al., 2009); b (Hong et al., 2006); c (Zhao et al., 2009); d (Hui et al., 2006).

4.3 Limited recycling information platforms

Recycling information platforms refers to a comprehensive database that contains information on recyclable resources, which can be accessed by relevant stakeholders. Geldermann (2010) suggests that advanced recycling information platforms are not only beneficial for stakeholders, including producers, management authorities and third party service providers, but also increase the efficiency of recycling system. However, such platforms are still lacking for most recyclable resources in China, except for limited information focused on WEEE recycling.

The lack of information platforms has impeded the development of China's RWR system in several ways. For citizens, recycling information has a significant effect on recycling behavior (Nixon and Saphores, 2009). A recycling information platform should provide easy and convenient access to information about recycling sites, recycling categories and recycling prices. In terms of the recyclable resource trade, information asymmetry is a common phenomenon and is a great barrier. It makes the market inefficient, and lowers stakeholders' willingness to trade in a large quantities. In such a situation,

the formal sector cannot compete with the informal sector since the informal sector is more flexible. In addition, the lack of recycling information platforms has a negative influence on governmental management as well. Administrative authorities are not able to collect adequate data to make appropriate policies and govern the downstream recycling industry.

5. Proposing an integrated framework for China's RWR system

Considering the reality of a large population, income inequalities, rapid development and limited management systems within China, it is difficult to directly adopt successful practices from other countries. We strongly recommend that economic incentives, modern technology support and government leadership are the three key areas for improving China's RWR system. A proposed integrated framework is illustrated in figure 4, which considers measures from the perspectives of capital flow, material flow and information flow to strengthen the recycling system under the support of a specific agency. Capital innovation through PPP (public-private partnership) is important for providing financial support, particularly for downstream processes such as collection systems and recycling treatment projects. Combining the RWR recycling system with the MSW collection system, and the modern internet technology is recommended for material flow optimization, especially for efficient upstream recycling. In addition, the establishment of a single information platform is proposed in order to provide

a holistic understanding of the RWR system, and to facilitate system control and optimization. It should be noted that these three recommendations are not new concepts. For example, PPP and internet+ have already been introduced, with some success, within individual systems. Our recommendation of an integrated system aims to provide a more systematic and comprehensive solution to the existing problems of limited investment in recycling, information asymmetry, and the lack of access to recycling facilities, by combining a number of existing promising solutions.

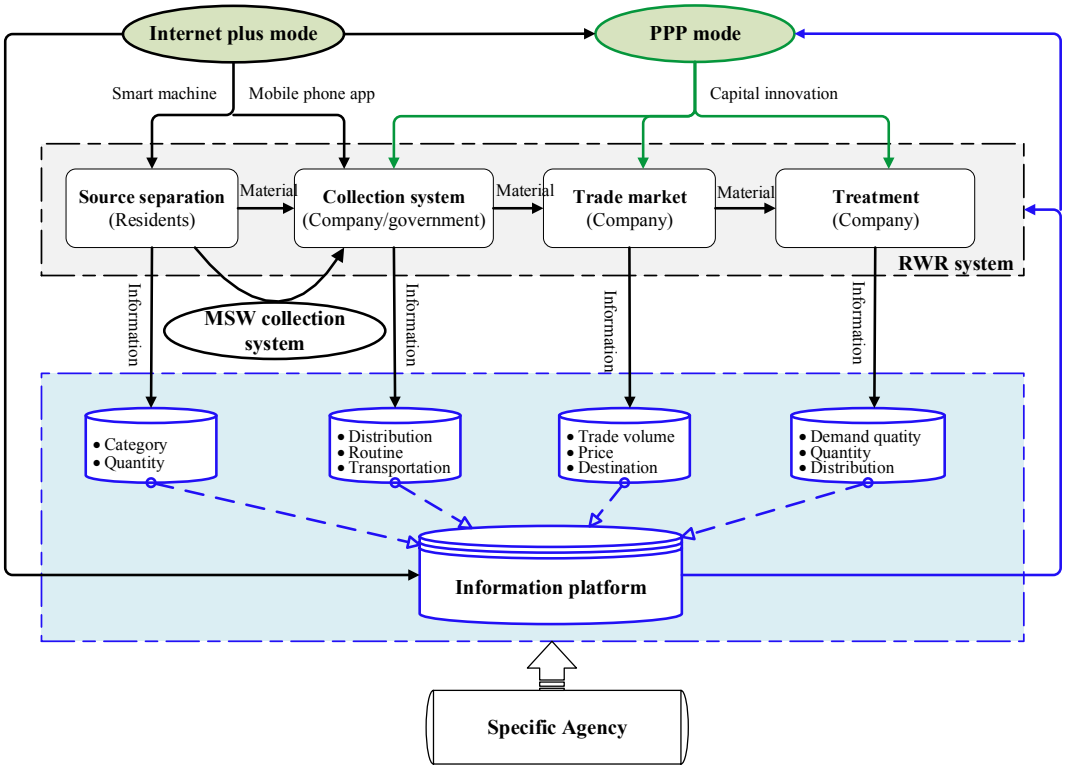

Figure 4 Proposed integrated framework for China's RWR system

5.1 *Capital scheme innovation to solve the capital barrier*

Capital is crucial for the RWR system. For instance, Japan's successful urban recycling projects

were enabled by government finance (Van Berkel et al., 2009). Due to the low financial returns within the RWR industry, and the existence of informal sectors, the formal recycling sector is less attractive for capital investment. Simultaneously, the government has limited financial budgets to support the development of recycling infrastructure and networks. Thus, financial innovation is becoming one of the key factors in establishing the RWR system.

PPP is an innovative form of public financing that combines both public and private sectors, rather than relying exclusively on the public sector (Broadbent and Laughlin, 2003). PPP is particularly flexible and efficient in solving the financing problem for high-investment projects (Chen et al., 2010), and has been employed in fields such as infrastructure, transportation and environmental protection (Chen, 2009; Zhang et al., 2015; Zhang, 2014). Since 2015, PPP has been applied to the RWR industry in China. PPP increases the financial resources available to the recycling industry by leveraging private sector investment in recycling infrastructure and new recycling technologies. Several successful programs have been accomplished through PPP, for example, Yichang Supply and Marketing Cooperatives Jixin Assets Management Co., Ltd and Guangdong Zhishun Chemical and Environmental Protection Equipment Co., Ltd employed a PPP to recycle waste plastic in Hubei province (Sanxia Daily, 2016). This program solved the problem of RW collection and reduced the level of ‘white pollution’, i.e. pollution from discarded

plastic bags, with capital from the private sector. The program also formed a closed recyclable resources industrial chain, and provides an example of a successful application of the PPP approach.

Another important financial measure is the policy of tax deduction and exemption. A number of government and company representatives indicated, during discussions with the authors, that a favorable tax policy is one of the key factors determining the survival of RWR companies. The economic returns from RWR are much smaller compared with other manufacturing industries, thus it is impossible for the RWR sector to bear the same tax rate. Initially, many RWR companies started because of tax exemptions, but many subsequently closed following the abolition of the tax free policy. Both the government and the RWR sector are aware of the importance of the preferential tax policy, and the government is now considering an appropriate tax rate in order to promote the development of the RWR system.

5.2 *Support recycling by improving recycling convenience*

Accessibility and convenience are the most important factors influencing recycling behavior in developed countries (Davis et al., 2006; Gonzalez-Torre and Adenso-Diaz, 2005; Miliute-Plepiene et al., 2016). Recent studies show that individuals with easily accessible recycling facilities are 25% more likely to recycle than those without easy access (Zhang et al., 2016). Therefore, it is crucial to establish convenient recycling sites and facilities to promote China's RWR system. However, it is difficult to set

up a mature RWR recycling system within a short time. Two innovative recycling modes are strongly recommended to facilitate the convenience of recycling. The first is to combine RWR with the MSW collection system since MSW collection and transportation systems are already well established. The logistics network for MSW is also be used for recyclable resources, and RWR sites can use the same facilities as MSW, just adding more bins and vehicles for recyclable wastes. This integrated system could efficiently promote source separation by supplying enough convenient facilities. Moreover, sharing facilities and processes ensures comparatively low costs and higher efficiency.

Second is to strengthen emerging innovative recycling practices by integrating RWR with modern technologies. The Chinese Premier Li Keqiang proposed the notion of "Internet plus" in the Governmental Work Report in 2015 to create new engine for economic growth, meaning the application of the internet and other information technology such as cloud computing, big data and the internet of things in conventional industries (Xinhua News, 2015). Internet+ was on the list of significant economic keywords in 2015, and has been practiced by a number of recycling companies. Such innovative recycling practices can be achieved through three pathways. (1) Installing smart recycling machines so that people can recycle waste at any time, and can also get reward points to exchange for commodities. (2) Use mobile phone software such as Wechat to spread awareness of RWR recycling, and enable people

to reserve convenient times for door-to-door collection services. (3) Establish online trading platforms to connect upstream recycling companies and downstream treatment companies, which will not only greatly improve the efficiency of RW trade but will also facilitate the establishment of RWR supply chains. In summary, the obvious advantages of the above innovative recycling practices are convenience and low cost, which are the dominant barriers for the current RWR system. The government has also identified this solution for China's RWR system, and supports this approach in the "*Circular economy promotion plan in 2015*" (NDRC, 2015).

5.3 *Set up a comprehensive information platform*

As mentioned above, information asymmetry is another significant factor in impeding RWR in China. Almost all stakeholders are not able to get sufficient and accurate information on recycling activities. The government holds the most data about RWR, but currently does not share that information, and recycling companies do not have enough information to find sufficient recycling waste sources. As for residents, most are not aware of recyclable waste recycling, or how to participate in recycling. For researchers, it is also a great challenge to study RWR because of the difficulty in accessing information and data. Therefore, a publicly accessible and comprehensive information platform that integrates supply side and demand side information should be established to link all stakeholders and strengthen the

sharing of information. The Chinese national policy *Guidance action on promoting the "Internet Plus"* (SCC, 2015) suggests that the RWR industry should take full advantage of the rapid development of the internet to establish a successful information platform. Functions such as advertising, trading, statistics and management, can be added into this platform as well. It could not only help the government to administrate this industry, but can also help citizens and companies to access to recycling information. This would contribute to the development of the formal recycling sector in China, because citizens would be able to register their household recyclable resources online and select formal recycling companies rather than the informal vendors to sell their RW. In addition, formal recycling companies would be able to access information about upstream RW supply and downstream demand, thereby strengthening the formal recycling value chain.

6. Conclusions

The Chinese government and enterprises have made great efforts to promote the development of the RWR system. Several achievements have been made, including several laws and regulations on RWR, three batches of pilot city program, and increased recycling rates. However, it should be noted that several challenges still exist. The three main challenges are: insufficient regulations which encourages the informal recycling market; inefficient source separation caused by a lack of recycling awareness and

recycling facilities; and the absence of a recycling information platform. Finally, we propose an integrated framework to comprehensively improve China's RWR system. Capital flows, material flows, and information flows should be strengthened through financial innovations such as PPP, combined the RWR system with the existing MSW system, and the establishment of an information platform, respectively. The emergence of innovative recycling practices, particularly the use of an internet+ approach, is the key for developing China's recyclable wastes recycling.

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