SUSTAINABLE URBAN MINING: THE CASE OF CHINA

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UNIVERSITY OF TWENTE.

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LIST OF ABBREVIATIONS

Ag	Sliver
AHP	Analytical Hierarchy Process
Al	Aluminum
Au	Gold
B2B	Business to business
BAU	Business-as-usual
C2B	Customer to business
CACE	China Association of Circular Economy
Cd	Cadmium
CDM	Clean Development Mechanism
CNRRA	China National Resources Recycling Association
CNY	China Yuan
Cu	Copper
ELV	End-of-Life Vehicle
EPR	Extended Producer Responsibility
EU	European Union
E-waste	Electrical Waste
FYP	Five Years Plan
Fe	Iron
GAT	Governance Assessment Tool
GDP	Gross Domestic Product
GHG	Greenhouse Gas Emission
GIS	Geographic Information Systems
GPS	Global Positioning Systems
GPRS	General Packet Radio Service
GSM	Global System for Mobile
GWP	Global Warming Potential
Hg	Mercury
HH	Human-Human Interaction Collection
HM	Human-Machine Interaction Collection

ICT	Internet and Communication Technology
IoT	Internet of Things
IPRA	Internet Plus Resources Recycling Alliance
kg	Kilogram
Km	Kilometer
MEP	Ministry of Environmental Protection
MFA	Material Flow Analysis
MLR	Ministry of Land and Resources
MOF	Ministry of Finance
MOFCOM	Ministry of Commerce
MSW	Municipal Solid Waste
Mt	Million tonnes
NEE	Negative Environmental Externalities
NDRC	National Development and Reform Commission
Ni	Nickel
PEE	Positive Environmental Externalities
Pb	Lead
PDRC	Provincial Development Reform Commission
PET	Polyethylene Terephthalate
ppm	Parts per million
PSR	Pressure–State–Response
RDF	Refuse Derived Fuel
RFID	Radio-frequency identification
RS	Remote Sensing
Sb	Antimony
S. Korea	South Korea
SO ₂	Sulphur dioxide
t	tonne
Ti	Titanium
UM	Urban Mining
UMPB	Urban Mining Pilot Bases
UNEP	United Nations Environmental Program
USD	US Dollars
VHFR	Very High Frequency Recorder

WEEE	Waste Electrical and Electronic Equipment
WIFI	Wireless Fidelity
Zn	Zinc

CHAPTER 1: INTRODUCTION

1.1 BACKGROUND AND RESEARCH QUESTION

1.1.1 NATURAL RESOURCE EXPLOITATION AND ITS IMPACTS

Resource scarcity is one important sustainability issue first raised by the Club of Rome in the well-known book 'The Limits to Growth' in 1972 (Meadows et al., 1972). Nowadays, with the accelerating global phenomena of industrialization and urbanization, particularly in most developing countries, resource consumption has rapidly increased, and the problem of resource scarcity has become pronounced. It is predicted that, by 2050, world metal consumption will witness increases of copper (Cu) from 19 to 37 million tonnes (Mt), lead (Pb) from 8.4 to 9.55 Mt, zinc (Zn) from 11.6 to 14 Mt, and Nickel (Ni) from 1.8 to 2.7 Mt (Halada et al., 2008). If the total world population were to enjoy the same levels of use as industrialized countries, the amount of global in-use metal stocks required would be three to nine the present levels (UNEP 2010). By 2050, the supply of copper, zinc, and lead may not meet the demand if we continue with the current use patterns (Elshkaki et al., 2018). Even with up-to-date technologies, the current natural resource deposit could not meet the global demand of the resource.

An equally pressing issue is the environmental impact associated with this natural resource exploitation. Mining and mineral processing (particularly acid mine and tailings drainage) induce severe repercussion on the quality of air, water, ecological systems and

land (Jain et al., 2015). Mining is known to be one of the most significant sources of soil heavy metal contamination (Liu et al., 2005). A study of 72 mining areas across 22 provinces in China revealed that soil heavy metal contamination was prevalent throughout southern China, and 30-70% sites were moderately to heavily contaminated with copper, lead, zinc, and cadmium, respectively (Li et al., 2014). Mining has generated 15,000 km² of wasteland in China, and this figure had been increasing at a rate of 46,700 ha per year (Zhuang et al., 2009). Many mineral reserves are located in forests, vital watersheds, areas rich in biodiversity and lands inhabited by indigenous people. Environmental degradation, displacement and the loss of livelihood associated with mining expansion have resulted in serious conflicts in many parts of the world. Mining is also an energy intensive activity with high carbon emissions. One study has shown that the gross output value of China's mining sector accounted for 4.09% of the total industrial sector during 1999-2013, but its contribution to carbon emissions was 8.61% (Shao et al., 2016).

Driven by the economic and population growth, more and more resources are being 'mined' and turned into products that, subsequently, turn into wastes after the end of life. To the ecological economist, this is a continuous material flow process where materials only change their form, location, and function according to the 'Law of Conservation of Mass.' The rapid transfer of materials from the geosphere to urban and industrial areas has led to an accumulation of a stock of materials in cities. These stocks are defined as social stock. There are many such stocks in the anthroposphere. They include mining residues left behind as tailings; material stocks of industry, trade, and agriculture; urban stocks of private households and the public infrastructure; and, the

comparatively small, but growing, stocks of wastes in landfills (Brunner and Rechberger, 2004). Given the large-scale exploitation of mines and ores, many natural resources are transformed massively into anthropogenic resources. This growing stock will become increasingly more important as a resource in the future. Metal spectra can be seen as indicators of development. Per capita metal use in developed countries is more than ten times the global average (Graedel and Cao, 2010). The total stocks in Australia are estimated at 4.3 Mt of Cu and 3.8 Mt of Zn (240 kg Cu/capita and 205 kg Zn/capita), 50% of which resides in just 10% of Australia's land areas. The largest copper and zinc densities in some urban areas can be one hundred times higher than in rural areas. These urban regions are expected to be major Australian 'metal mines' in the future (Van Beers and Graedel, 2007). In some mines, anthroposphere stock could soon exceed the natural stock. For example, the social stock of Au, Ag, Pb, Zn, and Cu account for 69%, 70%, 72%, 60% and 48% of the sum of the social stock and natural reserve as illustrated in Figure 1.1.

Figure 1.1 On-surface stock and underground stock of Au, Ag, Pb, Zn, Cu

Source : (Nakamura and Halada, 2015)

On the other hand, generation of waste stocks is increasing. In the past century, as the world population has grown and become more urban and affluent, waste production has increased tenfold and is expected to double again by 2025 (Hoornweg and Bhada-Tata, 2012). Landfill sites, such as Laogang in Shanghai, China, and Sudokwon in Seoul, S. Korea, receive more than 10,000 tonnes of waste every day. Incineration has been promoted as a major solution for waste management in China, but often this is impeded by Not In My Back Yard campaigns (Dente et al., 1998; Li et al., 2016). Meanwhile, waste management has become one of the greatest cost burdens on municipal budgets (Hoornweg et al., 2013). However, waste could provide a valuable stream of resource too (Li, 2015). In some developed countries, up to 55% of wastes are composed of recyclable resources (Hoornweg and Bhada-Tata, 2012). The combined effects of the increasingly difficulty and cost of high-grade ore exploration and

exploitation, together with the ever-increasing social and environmental cost of waste disposal, means that mining of the urban waste resources is becoming increasingly attractive from both an economic and an environmental point of view.

Therefore, to address the environmental, social and economic problems imbedded in the outdated systems of resource management and waste management, attention should move from the limited and fixed natural stocks of raw material more into the increasing anthropogenic stocks of materials and wastes. Every city has become a rich mine consisting of massive in-use stock and waste stocks and to reclaim these valuable resources from and urban mining (UM) activities should be viewed and undertaken in this context. UM refers to the recovery of materials and energy from the urban metabolism. It provides a systematic and comprehensive approach to manage materials and wastes for long term environmental protection, resource conservation and economic benefits (Cossu, 2013).

The next section will review the development of the UM concept.

1.1.2 DEVELOPMENT OF URBAN MINING CONCEPT

Urban mining (UM) is a metaphorical term to describe the reclaiming of non-renewable resources from the anthroposphere. This concept has developed through several stages and has come to involve many disciplines from the mineral, urban metabolic, environment and waste management sectors. Urbanist Jane Jacobs first coined the term UM half a century ago. She had noticed that the cities might "become huge, rich and diverse mines of raw materials. These mines will differ from any now to

be found because they will become richer the more and the longer they are exploited" (Jacobs, 1969). Between 1960-1980 metal recycling in the industrialized countries developed fast and to the point that the amount of Al, Cu, Pb, and Ti reclaimed from metal scraps in America soon exceeded that extracted by primary metal production (Yang and Li, 1985). Since then, UM is often used to describe metal recovery from new and old scraps. Metallurgists paid much attention to UM from the perspective of what amount of metal resources UM could provide. Japanese metallurgist Nanjo noted that rare earth metals contained in industrial products already exceeded the grade of natural mines. He also defined the area of industrial products accumulated on the surface as urban mines (Nakamura and Halada, 2015; Nanjo, 1987). In China, Yang was the first Chinese scholar to propose the concept of UM and discussed the metal recovery potential of many kinds of scraps and waste, including the aneroid battery and the Al-based toothpaste tube (Yang and Li, 1985). This is followed by Zhang, who reinforced the idea of metal recycling under the UM concept (Zhang, 1989).

However, in the past ten years, UM has received much attention from scholars of urban metabolism and waste management, and the content focus goes beyond metal recycling. Baccini and Brunner postulated that UM covered all activities and processes of reclaiming compounds, energy, and elements from products, buildings, and waste generated from urban metabolism (Baccini and Brunner, 2012) and this has become a well acknowledged consensus. As converting waste to energy has been intensively studied in the municipal waste management sector, the majority of UM research focused on the domain of reclaiming materials. Johansson developed a more comprehensive urban mines taxonomy, including: in-use stocks; landfills; tailing dams/ponds; slag heaps;

hibernating stocks; and dissipated metal resources (Johansson et al., 2013). We may reclaim resources from these defined urban mines groups.

Current research into UM concentrates on two aspects. First is the estimation of resource potential and size. Urban mines metal stock and flow analysis are frequently observed at a global and national level with the assistance of the material flow analysis method (MFA) (Nakamura and Halada, 2015). Graedel and Cao (2010) developed a national metal metabolism by analysis in 49 countries and territories showing metal stocks were highly correlated to GDP per capita. Per capital metal use in developed countries was more than ten times higher than the global average. Future metal flow into use by 2050 is expected to be five to ten times today's supply levels. Therefore, the balance between demand and ultimate supply from UM must be considered. It is also useful to investigate specific national metal in-use stock. For example, in Italy, Al in-use stock per capita is 320 kg and 20 Mt in total, and 90% of the aluminum stock is embedded in the transportation sector, building and construction, and machinery equipment (Ciacci et al., 2013). This analysis is an important knowledge basis for developing a national UM strategy. Most observations have been made at a country level. For example, Chen and Shi (2012) estimated 60 kg Al in-use stock per-capita in China, 490 kg for the United States (Chen, W.Q. and Graedel, T.E., 2012). Metal flow analysis at a city level has been relatively small. Chen and Graedel (2012) reviewed 350 articles and found only five dealt with metal resources in a city.

Second is the analysis of resource recovery from the various waste streams. Waste Electrical and Electronic Equipment (WEEE) is the most welcomed type of urban

mines given the high content of metal. Research about WEEE recycling covers various issues, including the metal resource potentials (Awasthi and Li, 2017), recycling technology (Cucchiella et al., 2015) and collections (Gu et al., 2016). Bottom ash from waste incineration plants is also included in the urban mining list (Crillesen and Skaarup, 2006). Experiences favor efficient recovery of nonferrous metals from the bottom ash (Morf et al., 2013). For example, bottom ash in Vienna city contains Cu 655 g/cap/year, accounting for 5% of the total CU consumption in the city, and having a market value of US\$ 8.8 million (Kral et al., 2014). Bottom ash residues can also be used for concrete after removing the Al substance (Ciacci et al., 2013). More evidence of resource reclamation from the bottom ash can be found from various other studies (Allegrini et al., 2014; Allegrini et al., 2015; Jung and Osako, 2009; Meylan and Spoerri, 2014; Morf et al., 2013). Landfill mining is another domain of urban mines. From an economic point of view, landfill mining appears to be attractive only if additional values are created. This could include gaining new land for building sites or reducing the costs for long-term landfill after care (Kral et al., 2014). Thus, landfill site recovery projects, which aim exclusively at resources reclaiming, are rare. Case studies in China also support this conclusion showing that resource recovery from landfill mining is not economically viable. Whereas, reclaiming the land for commercial development may pay the required compensation (Zhou et al., 2015). A recent report of successful landfill mining was of a bottom ash mining operation serving a Municipal Solid Waste (MSW) incineration plant, instead of the raw MSW landfill site (Wagner and Raymond, 2015).

The UM approach is still developing, and only a few authors have discussed this. It is widely agreed that baseline information on size, concentration, and spatial location

in the anthroposphere are fundamental for any viable urban mining system (Chen, W.-Q. and Graedel, T.E., 2012; Johansson et al., 2013; Krook and Baas, 2013; Rudenno, 2012). The pioneering scholar of urban metabolism, Brunner (2011), pointed out that UM is more advanced than recycling and is a more focused and effective way. Several important issues need considering when developing an urban mining strategy. First, there is a core knowledge base around material flows and stocks in the urban area. For this, there are many national and global scale studies but few at a city level. Second, there is the estimation of potential for recovery. This needs modelling to construct and estimate the economic return of important mines, such as the urban stocks, landfill mining, tailing or residue from nature mining.

Third, there is the location and selection of recycling facilities because the generation of the urban mines is quite relevant to the economic and demographical factors. Fourth, there is the UM approach for different development phases of the city as the UM approach can be different depending on a cities' development stage. Similarly, Graedel (2011a) raised several important questions about the urban mining of metal resource. These included the potential, available time and forms of metal to be recovered. Urban mining potential can be estimated by either 'bottom up' or 'top down' methods. Practical recovery is quite difficult to attain since many metals exist in alloys where the separation process is complicated. Besides, urban mining systems consist of various collection, separation, sorting and processing steps and resource recovery efficiency in every step cannot achieve 100% recovery and efficiency. Therefore, optimizing the whole system is particularly important to achieve any estimated potential. Also, current UM cannot be deemed sustainable if it is driven by economic incentives

alone to extract the high valued metals while dissipating others back into the environment. Furthermore, Nakamura identified other social and technological problems in the recovery of many rare metals from Waste Electrical and Electronic Equipment (WEEE), both in European Union (EU), and in Japan (Nakamura and Halada, 2015).

So far, the review of the UM concept development has shown that current research focused on the knowledge base, e.g., the potential estimation of the resource aspects. Meanwhile, the environmental, social, and economic aspects have been less touched even though these are the key issues of any successful future for UM. Graedel and Brunner have given some small attention to these questions, but with few answers as yet. Other researchers who have similarly touched on them have done so in a fragmented fashion.

What is needed is a far more systematic UM framework. Urban mines have significance in that their generation and social stocks are obviously associated with the social and demographic factors that should be taken into consideration. Equally, UM has developed into an industry with strong economic features that also need to be investigated in detail. UM activity is closely associated with environmental, pollution and health problems, for example, those impacts induced by the WEEE recycling activity that have been well noticed (Pascale et al., 2018). These all tie into how sustainable development of the UM industry itself can be best addressed.

The fact that urban mining has much potential for resource recycling, energy saving, and contribute to the circular economy and sustainable development solutions,

a systematic UM analysis framework would help guide government and business in designing and deploying a viable UM strategy.

1.1.3 CORE RESEARCH QUESTION STATEMENT

The UM concept was first raised by metallurgists interested to recycle metal scraps and harvest secondary resources. Later this idea expanded into the waste management area with scholars working in urban metabolism also to reclaim resources from various waste streams. This paradigm is fixed in single resource dimension. The same is true of traditional waste management, which is also a single environment dimension paradigm with the harmlessness as the initial need. However, wastes/urban mines have other multiple attributes apart from their resource attribute. Their generation, collection, recycling, and disposal embody various environmental, economic and social attributes. And the degree of these attributes can be changed following the change of the social and economic circumstances. Single dimension paradigm is not sustainable as the principle of the sustainable development requires fairness between the generations, and a balance among the environment, social, and economic aspects and outcomes.

Therefore, sustainable urban mining needs a multi dimensional paradigm to embrace the three fundamental domains of sustainable development, e.g., economic, environmental and social, to complement the resource dimension as the core merits of urban mining. Section 1.3 will elaborate more on this. Having acknowledged the multiple attributes of urban mines and their changing dynamic, the focal points in each dimension, as well as the corresponding management and policy needs, need identifying to

formulate a sustainable urban mining framework. This provided the lead into the core research question of this study:

***What are the multiple attributes of urban mining and the relevant focal points embodied in the resource, environmental, economic, and social dimensions?
And what the corresponding management and policy mechanisms towards sustainable urban mining?***

This study takes the case of China to study and answer this research question. To achieve this objective, section 1.2 will firstly elaborate on the multiple dimensions of the paradigm for a sustainable urban mining framework. This is followed by a set of research sub-questions and outlines of this thesis.

1.2 A FOUR-DIMENSIONS SUSTAINABLE UM FRAMEWORK

This section will develop four dimensions of a UM framework drawing on the theory of sustainable development. The concept of sustainable development has become a global commonly recognized principle to ensure “meeting the needs of the present generation without compromising the ability of the future generation to meet their needs” (WCED, 1987). The United Nations Millennium Declaration identified economic development, social development and environmental protection as the three fundamental dimensions of sustainable development. This three-sphere framework laid a starting basis for this study. Since the resource is the essential aim of UM at its initial development stage, resource recovery and supply become the first function and merit

of UM. Therefore, 'resource' is added as a fourth dimension to the framework, formulating a starting frame for sustainable UM (Figure 1.2).

Figure 1.2 Starting frame for sustainable UM

To understand UM better, a comparison of the processes of UM with those of natural mining (NM) is necessary (Figure 1.3) as the two are very different at each step. At the initial generation step, natural mines are formed by geological processes over millions of years, while urban mines are generated in the social consumption and industrial production process. Exploration of natural mines is an intensive outdoor engineering process involving professional geologists and prospectors, while the estimation of urban mines is an indoor process of material flow analysis that involves social and economic data processing. Similarly, natural mining takes place in one fixed place, while urban mining starts from collection process across a city. Extraction from natural mines is a long process with high energy consumption, while recycling resources from urban mines is a shorter process that expends less energy but has other associated

environmental problems. Therefore, urban mines have various specifically different attributes when comparing them with the natural mines. These special attributes determine key issues to be investigated for a sustainable UM. The subsections will analyze these attributes and key issues in the four-dimension framework.

Figure 1.3 Comparison between natural mining and urban mining

1.2.1 RESOURCE ATTRIBUTES

Resources are the fundamental attribute of urban mines because the primary purpose of urban mining waste is to harvest resources. In this perspective, urban mines have several significant attributes compared to mining from nature.

First, the grade of resources from urban mines is high. New scraps from the metal production process are pure metals with the highest grade. Waste Electrical and Electronic Equipment (WEEE) contains a wide variety of materials, including precious metals of gold, silver, and palladium with satisfactory grades. Table 1.1 lists the typical composition of electronic devices. Gold concentrations are reaching 300-350 g/t for mobile phone handsets and 200-250 g/t for computer circuit boards, while the grade in

natural golden minerals only 3-6 g/t. The high-grade resource attributes of urban mines make this level of extraction easier than extraction from natural mines. For example, steel production from recycling scraps involves a short production process that saves much energy and costs less than steel production from the ores in the long production process. Naturally mined resources exist as ores, and urban mines exist as waste by-products and compound. Some metals resources exist as alloys where it is hard to achieve satisfactory recycling results even with the best available recycling technologies. To solve this problem would require innovation in the product design stage to ensure the raw material input could be easily recycled at the end of its economic or useful life (Graedel, 2011a).

Table 1.1 Value and weight distribution of typical electronic devices

Source: (Hagelüken and Corti, 2010)

Weight-share	Fe	Al	Cu	Plastics	Ag(ppm)	Au(ppm)	Pd(ppm)
Monitor-board	30%	15%	10%	28%	280	20	10
PB-board	7%	5%	18%	23%	900	200	80
Mobile phone	7%	3%	13%	43%	3000	320	120
Portable audio	23%	1%	21%	47%	150	10	4
DVD-player	62%	2%	5%	24%	115	15	4
Calculator	4%	5%	3%	61%	260	50	5
Value-share	Fe	Al	Cu	Sum PM	Ag	Au	Pd
Monitor-board	4%	14%	35%	47%	7%	33%	7%
PB-board	2%	1%	13%	86%	5%	69%	12%
Mobile phone	0%	0%	6%	93%	11%	71%	11%
Portable audio	3%	1%	73%	21%	4%	16%	3%
DVD-player	15%	3%	30%	52%	5%	42%	5%
Calculator	1%	4%	10%	85%	6%	76%	3%

Sum PM: the sum of precious metals

Second, urban mines generation is a dynamic material flow. Natural minerals develop during long geological processes and exist as static deposits in the geosphere. Recoverable reserves of minerals are static in the long term. This means these are not renewable. Comparatively, generation of urban mines is a dynamic process in the short term. From the perspective of urban metabolism, material input and output to the city is a continuous flow process, materials and energy are inputted continuously into a boundary system generating products, wastes, and emissions in different material forms. The quantities of available reserves are constantly changing and highly related to economic and demographic factors. For example, WEEE generation in China has increased sharply in the past ten years following the high rate of economic growth and electronic devices consumption (see Figure 1.4).

Figure 1.4 Estimation of WEEE generation in China

Source: adapted from (Li et al., 2015)

Natural minerals are deposited in underground geological belts that tend to be concentrated in one place, often in the mountains. This means excavation of natural

minerals is a centralized mining activity. Meanwhile, urban mines are generated in urban areas in locations that are scattered across industrial plants, households and remote infrastructure. This means that systems to collect and transport urban mine materials to recycling plants are an important part of the UM system. The location selection of recycling plants is important to ensure collection and transportation optimized and supply rationalized to the recycling plants.

1.2.2 ENVIRONMENT ATTRIBUTES

Environmental attributes of urban mines include both positive environmental externalities (PEE) and negative environmental externalities (NEE). PEE refers to the direct environment benefits of UM. On the one hand, UM helps to reduce exploitation of natural resources. This avoids the environmental impacts associated with the extraction and refining of primary resources. On the other hand, if the waste materials are not recycled and simply discarded to landfilling and dumps, this will create impacts of unmanaged waste disposal, such as land occupation and pollutions. In China, every ton of recycled Pb, Cu, Al, Zn, iron, and steel can help save substantial energy and water consumption, as well as reduce solid waste generation and air pollution as listed in Table 1.2.

Table 1.2 Environmental benefits of recycling secondary metal resources

Environmental benefits	Pb	Cu	Al	Fe	Zn
Coal saving kg/t	659	1054	3443	430.8	458
Waste water reduction m ³ /t	235	395	22	2.12	120
Solid waste reduction t/t	128	380	20	3	39
SO ₂ reduction kg/t	3	137	60	3	1000

Source: (CAMU, 2010; Chen, W.-Q. and Graedel, T.E., 2012; CNMIA, 2015; MIIT, 2011)

UM also helps to save greenhouse gas (GHG) emissions and mitigate climate change by avoiding the emissions that would have occurred otherwise as the production required virgin materials. The CO₂-equivalence of GHG emissions reduces through recycling a unit weight of washing machines, refrigerators, air conditioners and televisions could contribute 17.70, 27.34, 45.62 and 3.61 kg respectively (Menikpura et al., 2014). Recycling of plastics from work boards reduced GHG emissions of 1.66kg CO₂ per kg plastics (Chen et al., 2011). An economic and environmental assessment in Sri Lanka showed that more than 1.6 Mt CO₂ equivalent of GHG emission from dump sites could be eliminated by turning the waste into Refuse Derived Fuel (RDF) (Maheshi et al., 2015). In 2008, primary aluminum production per ton emitted 17,000 kg GHG, while that number of recycled aluminum is only 715 Kg; a 237 fold difference (Ding et al., 2012). Therefore, UM could contribute to climate change mitigation, but this deserves further investigation (Krook et al., 2015) and might be considered as one approach of Clean Development Mechanism (CDM).

UM, as with other human activities, also induces environmental problems of air pollution emissions during the collection and transportation, energy consumption, air and water pollution during recycling, as well as the final disposal of residual waste and hazardous substances. Table 1.3 lists the major negative environmental externalities induced in each stage of UM.

Table 1.3 Negative environmental externalities in UM system

UM sections	Negative environmental externalities
Collection	Energy, air pollution, CO ₂ emission
Dismantling sorting	Energy, air pollution, CO ₂ emission, waste water, solid waste
Recycling	Energy, air pollution, CO ₂ emission, solid waste
Disposal	Environmental impact induced by incineration or landfilling

Furthermore, informal WEEEs recycling, common in many developing world countries, poses more serious environmental impacts. The informal sector stores and processes WEEEs in the open air and this releases hazardous substances that are extremely unhealthy (Huabo and Jinhui, 2011; Kaur, 2013). Studies have shown that unregulated dismantling and recycling of WEEEs caused heavy metal contamination to the regional water and air and transformed the soil and ecology system. This even posed a threat to human health and birth quality (Xu et al., 2012). Therefore, sustainable UM needs to enhance UM efficiency to optimize the environmental benefits and reduce the environmental impact.

1.2.3 ECONOMIC ATTRIBUTES

Urban mines have multiple economic attributes. The first relates to the resource aspects when compared with the natural mines. To harvest the same amount of metals, the cost of recycling from urban mines is much lower than production from natural mines. For example, the short process of steel production from the scraps needs 75% less investment than the long process of steel production from ores. Also, their operations and environment pollution control cost are much less.

Secondly, UM has developed into a large-scale industry. It consists of collecting, transporting, sorting, recycling, and utilizing the recycled materials. These all generate economic value and create jobs. It has been predicted that the global waste recycling market revenue for MSW, WEEEs, industrial non-hazardous waste, and construction and demolition (C&D) waste would likely increase to \$265.65 billion in 2017 (Frost and Sullivan, 2017). The EU's WEEE Directive requires all member countries to recover 45% of e-waste by 2016, 65% by 2019 or 85% of all waste generated. The European WEEE recycling market alone was estimated to be 2 billion USD by 2020 (Frost and Sullivan, 2013). The industry also creates substantial jobs. Globally, UM collection employment is secondary to the agricultural sector (Minter, 2015). In China, 245 Mt from urban mines were collected and recycled in 2016. This included the Ferrous metals, nonferrous metals, waste plastics, waste paper and cardboard, waste tires, WEEEs, end-of-life vehicles, waste textile, waste glasses, and waste batteries. They were worth 590 billion CNY (equal to 80.7 billion USD) (MOFCOM, 2016). China's urban mining industry employed 18 million workers (CNRRA, 2014). Figure 1.5 shows that urban mines operations in China have doubled in the past ten years.

Figure 1.5 Major urban mines collected in China 2006-2016

Source: Adapted from multi years reports of China recycling industry by Ministry of Commerce (MOFCOM)

UM industry development is closely related to a country's pace of industrialization and urbanization. Most developing countries' cities have experienced rapid industrialization and urbanization. This is a context where the UM industry can contribute economic revenue and jobs as an economic growth sector in its own right. On the other hand, it can form an urban and industrial symbiosis development model (Van Berkel, Rene et al., 2009). For already industrialized countries, UM can make its contribution by reindustrializing the city through the recycling of waste and feeding back to the urban metabolism (Brunner, 2011). Fostering and enhancing the UM industry to enhance its economic contribution to the urban system is an important role undertaken by a sustainable UM system.

1.2.4 SOCIAL ATTRIBUTES

The social attributes of UM lie in its deposit. Urban mines are generated from the social stock as a result of human activities in production and consumption. The generation of urban mines is a dynamic process that follows social and demographic factors, and their distribution is scattered in the residential and industrial area. The social attributes of the stocks determine urban mines have strong and significant social attributes. In order to harvest the resources, the collection of the urban mines from the households and industrial sites are the first part of UM system. Therefore, it is important to study people's consumption behavior and waste disposal behavior; both of which are closely related to social, cultural and economic factors (Li et al., 2012; Yin et al., 2014).

Informal recycling occurs in many developing countries for a variety of social and economic reasons and has evolved as the predominant issue of UM system. The informal sector has formed in China driven by the absence of environmental management, high demand for second-hand appliances and the custom of selling e-waste to individual collectors (Chi et al., 2011). The informal sector contributes to waste recycling with quite high recycling rates ranging from 20% to 50%. This comprises of 5–15% for paper and cardboard; 10–40% for scrap metal; 20–40% for plastics and 25–70% for bottles and glass (Wilson et al., 2009).

However, the informal sector has led to severe environmental pollution and health problems. The intensive uncontrolled e-waste processing in China has resulted in the release of large amounts of heavy metals into the local environment and caused high concentrations of metals in the surrounding air, dust, soils, sediments, and plants (Song

and Li, 2014). Guiyu, the town most well known for WEEE dismantling aggregation in South China, has four times the risk of stillbirth compared with the average level in the region (Xu et al., 2012). The other social problem associated with the informal sector is spontaneous aggregations in the city. Typically, the informal sector is located in the rural-urban fringe and forms 'waste villages' or informal waste trading markets. Once, there were 121 such aggregations in Beijing, occupying 50 hectares (BDRC, 2004). These waste villages often are located in the undeveloped area of the city, out of range of city planning and public services. Environmental and social problems, such as sanitation, health care and education for children are common challenges in these villages. The villages become a grey space in the city. When the city develops and expands, the informal sector is expelled to other places and rebuild a new grey space (Tao et al., 2014). Integration of the informal sector becomes a necessary issue to be settled for a sustainable UM system alongside urbanization.

1.2.5 SUMMARY: A SUSTAINABLE UM FRAMEWORK

The four dimensions of urban mines focus on key points in the system to form a systematic theoretical framework of sustainable UM as shown in Figure 1.6.

Figure 1.6 A four-dimensional sustainable UM framework

In the resource dimension, urban mines are characterised by resource attributes such as the high grade, scattered location, and dynamic generation. These raise the fundamental need for quantity estimation and generation mechanism of UM. As the resource supply for an economy depends on domestic exploitation, imported stock, and secondary production from UM, the development of UM is necessarily a core part of a nation's resource strategy. It is also important to explore the extent of recycling of resources by UM as they substitute for primary resource supply whether by imports and domestic exploitation. This information can help governments make sound decisions on a sustainable resource supply strategy. Thus, the focal point in the resource dimension of sustainable UM is identified as follows:

What are the resource supply potentials of UM and their substitution rate to the primary resource?

In the environmental dimension, UM has both positive and negative environmental externalities. Knowledge of the negative environmental externalities is particularly needed in order to choose the appropriate UM technology. We also need to explore the management and policy measures to minimize the environmental impact of UM. Therefore, the focal point in the environmental dimension of sustainable UM is:

How to evaluate positive environmental benefits of UM and reduce the negative environmental externalities?

The economic attributes of UM arise when UM becomes an industry and contributes to a city's industrialization and (re)urbanization. Planning and optimization of the system become important when considering the location and selection of the recycling facilities to achieve maximum coverage of people whose recyclables can be collected within an economic distance. This is one significantly different aspect of UM when compared with the natural mining. Therefore, the focal point in economic dimension of sustainable UM is to be covered by the following question:

How to optimize locations of UM recycling facilities to serve the maximum coverage?

The social attribute of urban mines renders collection an important issue in the UM system. We need to understand consumer behavior and waste disposal behavior to ensure efficient collection. Even though informal collection still mainly prevails in developing countries, it remains the cause of various environmental and social problems, but is facing competition and decline in the face of new social and economic development trends. Thus, the integration of the informal sector under a new collection

model is one option to ensure a sustainable urban mines supply. The focal point in the social dimension is identified as:

How to integrate the informal sector under the new social and economic circumstances to ensure sustainable urban mines supply?

However, the four attributes of urban mines are not independent, but rely on each other with one being transformed to find expression in another attribute in certain social, economic, and technology circumstances.

Firstly, different materials and devices in which valuable resources are embedded have different degrees of the four attributes. WEEEs and end-of-life vehicles have high resource and economic attributes because the metal resource content in these material wastes flows is high. Meanwhile, the plastics, textile, and woods have low resources and economic attributes. The other materials and devices, such as fluorescent lamps, have low resource and economic attributes but high environmental attributes because they may induce serious environmental impacts if improperly disposed of. Kitchen food wastes in China has a very high social attribute since they can be collected by the informal sector to produce low quality food oil and returned to restaurant table again. This poses harmful threats to human health. For waste streams with high resource and economic attribute, the free market will compete for the recycling value. For waste streams with low resource and economic but high environmental and social attribute, the government needs to intervene to ensure these items are properly recycled and disposed of.

Secondly, the attributes can be changed following changes in economic circumstances. For example, waste plastic bags were collected by the informal sector during the years of high oil prices and when they were able to demand a sound market price during the time they had high resource and economic attributes. In the days of economic depression, plastic bags are not welcomed in the UM market, and dumped to landfill or incineration sites. When this occurs, environmental attributes become obvious issue to be addressed. Policies may also change the attribute. An evaluation of recycling Al and Cu from the disconnect-and-leave-behind power grid cable in Linköping showed that urban mining benefits are currently more environmental than financial. It will only make economic sense when the climate change benefits of UM are counted in. UM can be seen as a means to contribute to societal goals, such as climate change mitigation and reduced mineral resource dependence (Krook et al., 2015).

Therefore, the four-dimension framework can be an analysis tool for a country or region to help make a UM strategy. It helps to distinguish urban mines from natural mines and highlights its social and economic attributes. It helps to distinguish UM from recycling, as the concept of UM pays more attention to environmental and social attributes. It helps to distinguish UM from waste management, as UM attaches more attention to the resource attribute, more than the waste management scheme in which avoiding harm is the first concern. This four-dimension framework offers a basis to analyze UM in the urban metabolism. It aids proper policy design and helps to ensure a balance between resource, environmental, social and economic needs.

1.3 SUB-RESEARCH QUESTIONS AND THESIS OUTLINES

1.3.1 SUB-RESEARCH QUESTIONS

This study takes China as a case study to answer the core research question of what constitutes sustainable UM. Scholars in China first raised the concept of UM during the 1980s. However, collection and recycling activities had started much earlier in the 1950s during China's post-war recovery era and when resource supply chains faced many shortages. To supplement supplies, the government of China set up recyclables collection stations within the commodities retailing system. By the end of the 1970s, a profound formal recyclables collection system had been established. Following the implementation of open up policy in the 1980s, more and more informal collectors joined in the industry. By 2015, about 400,000 (in)formal collection stations served some 10,000 collection business. Over 5,000 recycling plants actively were recycling more than 250 Mt of urban mines generated in China, as well as 40 Mt of imported wastes (MOFCOM, 2016). Urban mining became a vital industry from the perspective of resource saving, waste management, and economic contribution, in spite of numerous remaining challenges. Small recycling businesses dominated the industry. They used outdated equipment and technology with low resource production efficiency and few means to minimize the environmental pollution they generated. The informal collections dominated the urban mines supply system and faced challenges, including the stable resource supply for the established UM facilities. Meanwhile, the government of China initiated several policies to promote the upgrading of UM development, one of which was the National Urban Mining Pilot Basis program in 2010. This program intended to

select 50 urban mining industrial parks as national pilots to support their upgrading with financial subsidies (NDRC, 2010). This was the first specific urban mining public policy. There was also an obvious and practical need for China to develop sustainable urban mining.

This thesis has proposed that a comprehensive study of sustainable UM in China should cover four focal points covering the resource, environment, economic and social dimensions. Section 1.2 has identified these focal points: In the resource dimension, what is the resource potential of UM and substitution to the primary resource supply? In the environment dimension, the associated environmental benefits of UM in China should be explored. In the economic dimension, UM in China has developed into a large-scale industry where the government intends to upgrade the industry by selecting and supporting 50 national UM pilot bases. In this case, proper locations of the UM pilot bases need identifying to ensure economic supply of the urban mines. In the social dimension, the informal collection remains dominant but faces many challenges given the new social and economic development trends. A focal point should be the exploration of integrating the informal sector by introducing a new collection model.

To address focal points in the resource and environmental dimensions, we convened a research team that undertook a study and published as a paper in the *Journal of Ecology* (Wen et al., 2015). In this paper, we selected copper (Cu), aluminum (Al), lead (Pb), and iron (Fe) as research objects. We constructed a predictive model based on the stock analysis, material flow analysis, and life distribution model. We analyzed the four metals' demand, recycling, and stock, as well as the environmental

benefits in three economic development scenarios: business-as-usual (BAU) scenario, low resource scenario, and strengthened recovery scenario. Our results showed that the urban mining potential of Cu, Fe, Al, and Pb in 2040 under the BAU scenario would attain 8.1, 711.6, 37.0, and 12.1 Mt, respectively. Compared with 2010, the substitution rate (secondary metals substituting primary metals) of Cu and Fe will increase by 25.4% and 59.9%, whereas their external dependence decreases by 30.8% and 25.7%. However, substitution of Al and Pb was not obvious. The strengthened recovery scenario increased resource recovery and had a larger effect in reducing external dependence in the long term. Regarding environmental benefits, recycling four metals showed different performances regarding the energy saving, water consumption, solid waste discharge and Sulphur dioxide (SO₂) emissions. Recycled Fe and Al are significant for energy saving and SO₂ emissions reductions. In the 2020 BAU scenario, the two metals could save 96.3 and 32.0 Mt of standard coal, respectively, and achieved a reduction of 141.5 and 148.4 Mt of SO₂. Recycled Cu saved 1,305.5 Mt of water and reduced 1,255.9 Mt of solid wastes. These results lay down an important foundation for UM policy making in China.

Following the study of resource potential and environmental benefits of UM in China, this thesis focuses on the economic and social dimensions covering the focal point of UM facilities location optimization in the economic dimension, and the integration of informal collection in the social dimension. These form the first two sub research questions as follows:

Sub question 1: How to optimize the location of UM pilot bases to achieve maximum coverage of service under the social and economic circumstances?

Sub question 2: Can the new intelligent collection integrate informal collection to ensure a sustainable supply of urban mines in China?

Furthermore, management and policy aspects are specifically touched upon. First, UM aggregation has become a pillar industry in some emerging Chinese cities, contributing to local industrialization and urbanization. Urban mining at the city level can reflect the four dimensions attributes in one case. This led to sub-question 3. Finally, a policy assessment of urban mining in China is a necessary part of the wider sustainable urban mining study to help answer part of the core research question. This led to the sub-question 4.

Sub question 3: How does the UM industry development impact the host city industrialization and urbanization and ensure its sustainable development?

Sub question 4: Is the current legislation and policy setting sufficient for sustainable UM development in China?

These four sub questions form a logical framework. The first question focuses on the focal point of economic dimension, which also addresses the practical needs of China's Urban Mining Pilots Bases (UMPB) program. The second question focuses on the focal point of the social dimension, explores the potential approach in ensuring the adequate supply of UM. The third question touches upon the UM industry development at the city level, but also address the issues in the resource, environmental, economic, and social dimensions as an integrated case illustration. The final question comes back to the national level to evaluate the policy and governance settings for sustainable UM in China. These four questions help to answer the core research questions stated at the

beginning of the thesis. Section 1.3.2 elaborates more on the inter-linkages among the four sub questions.

1.3.2 THESIS OUTLINE

Following the four-dimensional sustainable UM framework, this study adopts an approach of publishing a series of papers that answer the four sub questions in an organised way. The thesis consists of an introduction chapter, four chapters that answer the four sub research questions and a conclusion chapter. Figure 1.7 shows the overall thesis research framework of this thesis.

Note:

JIE 1: The teamwork results published in Journal of Industrial Ecology (JIE) in 2015.

JIE 2: The second paper published in Journal of Industrial Ecology (JIE) in 2017.

JIE 3: The third paper submitted to Journal of Industrial Ecology, and it is under review.

JCP 1: The paper submitted to Journal of Cleaner Production, and it is under review.

Book chapter: The paper is published as a book chapter in 2018.

Figure 1.7 Thesis research framework

Chapter 1 introduces the background and development of the UM concept. UM is a multi-disciplinary concept involving various subjects, including industrial ecology, urban metabolism, metallurgy and materials, environmental, economics and sociology. Literature review in section 1.1 showed that the previous studies of UM paid much

attention to metals recycling and the resource potential estimation, but neglected the issues of economic and social aspects. Compared with natural mines, urban mines have distinguishing attributes, and consequently require specific UM approaches, which led to the four-dimensions sustainable UM framework being developed in this study. This consists of resource, environmental, economic and social dimensions where in every dimension focal points are identified. This framework seeks to develop the theory of sustainable UM as well as providing the 'concept and framework' basis for this thesis.

Chapter 2 answers sub question 1. UM in China has become an important industry, providing large quantities of secondary resource materials. Many UM recycling facilities aggregate in industrial parks that are specialized in resource recycling and new product manufacturing. However, the UM industry faces challenges and problems. In order to promote the upgrading of the UM industry development in China, the government puts forward a pilot program targeting to establish 50 nationwide UM pilot bases. Where to locate the pilot bases has become a practical question. To answer this question, this chapter took the factors of population, economic development, industry development and circular economy development into consideration, applied the combination of Analytical Hierarchy Process (AHP), maximal covering location model and GIS software to determine optimal locations of the UM pilot bases. The results of this chapter have been published in the Journal of Industrial Ecology.

In Chapter 3, the social dimension of UM is touched upon to answer sub question 2. Informal collection prevails in the UM industry in China and has many associated environmental, social and economic problems that are quite obvious often the same as

is the case in other developing countries. Also, the number of the informal collectors is decreasing given the new social and economic trends in China. Meanwhile, a new collection model involving intelligent collection has emerged following the wide application of Internet and Communication Technology (ICT) and the Internet of Things (IoT). More than fifty internet-based entities engaging in recyclables collection in China have emerged in the past three years. In this chapter, the business and organizational model of the intelligent collection is analysed, and the forms of intelligent collection, as well as the comparative advantages over the informal collection, are identified as the means to discuss the potential to integrate informal collection. The results of this chapter are awaiting publication in Journal of Cleaner Production.

The content of chapter 2 and chapter 3, together with the previous study published as JIE1 (Figure 1.7), touch upon the UM issues at the national macro level, setting up a whole picture of the subject. Chapter 4 shifts to the micro level at the city level and takes Jieshou as a case study. Jieshou is a middle sized city in China with a population under one million. However, the UM industry aggregated in Jieshou has become a pillar industry, contributing much of the economic growth to the city. Such a city is referred to as UM town/city. China has many other similar UM towns/cities. UM industry development in these cities contributes to industrialization and urbanization but also has caused environmental problems. Taking Jieshou as an example, chapter 4 uses interviews, material flow analysis and pressure-state-response (PSR) method to answer the sub question 3. It illustrates Jieshou's UM industry development history and the driving forces involved. It reveals how the UM industry development impacted the urbanization and industrialization of the city, and portrays a roadmap of the cities'

sustainable development. This case is a synthetic illustration to touch upon the issues in the resource, environmental, economical and collection dimensions of UM, but also provides a reference of lessons and experience for other UM cities/towns in China and around the world.

Chapter 5 shifts back to the national level and makes a policy assessment for UM in China. As the national UM pilot bases program is the most direct policy for UM, the chapter first reviews the content of the program, its evolution and the governance context, as well the supporting legislation and other policies. This helps to answer the question of sufficiency of policy setting for sustainable UM development in China.

Chapter 6 concludes the thesis, by summarizing the main findings, discussing the future research questions, and the policy and management implications of this study.

CHAPTER 2: LOCATION OPTIMIZATION OF URBAN MINING FACILITIES WITH MAXIMAL COVERING MODEL IN GIS: A CASE OF CHINA¹

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Abstract

Urban mining offers an efficient supply of resources because of rich mines and low environmental impacts. Location selection and optimization for urban mining facilities are more complicated than for natural mines, as it may vary according to the urban population, consumption habits and economic development. China initiated the National Urban Mining Pilot Bases program in 2010 that targeted 50 national urban mining pilot bases but unfortunately neglected the location planning issue. 28 bases have already been selected, which are concentrated in the central and eastern areas of China. This article combines the use of analytic hierarchy process (AHP), maximal covering location model and GIS software to optimize locations for China's urban mining pilot bases. Primary findings show that theoretically 40 urban mining pilot bases can

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sufficiently provide maximum GDP and population coverage service for China. Taking the current 28 bases as a precondition and 50 bases as a remained policy target, our second optimization results in a list of 22 cities for the location selection of future urban mining pilot bases. In total, the optimized 22 cities together with the selected 28 bases can provide a maximum 97.5% of GDP and 95.1% of population coverage in China. This study illustrates the optimization process for urban mining recycling facilities in general and provides policy advice for China in a specific case.

Key words : Urban mining, Recycling, Location optimization, China, GIS

2.1 INTRODUCTION

Urban mining is a metaphorical term for recycling materials from the technosphere, as opposed to mining primary resources from the biosphere (Brunner and Rechberger, 2004). As the rate of industrialization and urbanization increase, more and more resources are being exploited, diverted, accumulated, and depleted in cities, which consequently become rich urban mines (Jacobs, 1969). A study by the World Bank estimates that approximately 1,300 Mt of municipal solid waste is generated globally every year, and 55% of the waste from high income countries are recyclable (Hoornweg and Bhada-Tata, 2012). Wen finds that China will attain 8.1 Mt copper and 711.6 Mt iron from urban mining by 2040, which will substitute 25.4% and 59.9% of the consumption (Wen et al., 2015). Urban mining provides a systematic and comprehensive approach to manage materials and wastes for long term benefits (Cossu, 2013).

Urban mines are significant in three aspects compared with the natural deposits:

- 1) they mostly exist in the form of composite waste consisting of various materials, requiring complex separation and recycling process.
- 2) They are generated from consumption and production processes and have dispersed distribution. Thus building a sound collection system needs to consider the economy of transportation radius.
- 3) The potential of urban mines is largely related to demographic and economic factors as well as resident consumption habits in one region (Brunner, 2011). These social attributes of urban mines make some issues, for example, the location of recycling facilities, particularly important compared with mining the natural resources.

Studies on selecting the location of recycling facilities are limited to specific waste streams, e.g., construction and demolition waste (Coelho and de Brito, 2013; Dosal, E. et al., 2013), and waste electronics (Queiruga et al., 2008). However, location selection for overall urban mining planning is neglected. Small-scale urban mining activities have developed in many countries over the last century. Most cities have recycling facilities spontaneously located in response to local cultural, policy and resource availability, and market price. With the rapid development of urbanization, industrialization and increasing price of resources, waste collecting and recycling will become a trend across cities. The agglomeration of the recycling industry or industrial parks will be formed that can provide several nearby cities with a recycling market (Chen et al., 2014; Ren et al., 2012). This is where location selection becomes particularly important for overall urban mining planning. Its absence may lead to vicious waste resources competition, while its inclusion can help several adjacent recycling facilities of different waste streams to share environmental and logistic facilities and thus enhance overall urban mining efficiency.

Waste management in most countries is mainly driven by environmental protection more than by resource concerns; wastes are collected and recycled separately. The concept of urban mining provides a comprehensive view that waste should be seen as a resource and managed collectively, environmental protection facilities and infrastructure should be shared, recycled resources can and should be exchanged to manufacture new products, and technologies should be upgraded for large scale recycling. By realizing the importance of urban mining, China initiated the National Urban Mining Pilots Bases program (NUMPB) in 2010, targeting the establishment of 50 urban mining pilot bases with the least 0.3 Mt of annual recycling capacity. Such a large

scale recycling agglomeration makes location selection of the urban mining bases a necessity, e.g., where the 50 bases should be located?

This article takes China's urban mining pilot base initiative as a case study, and illustrates a useful method of combining the maximal covering location model, AHP and GIS for location optimization of overall urban mining. We consider demographic, economic, resource recycling level and waste collection system development as the key factors to affect a city's potential of establishing an urban mining pilot base. Through optimization, we provide a list of ideal cities for China's urban mining pilot bases locations, evaluate the current selection of locations, and provide advice for the future selection of the bases. The article is structured as follows: the introduction introduces urban mining and the importance of location selection; a background is then provided of China's urban mining pilot bases initiative; the methods and data section details establishing the city indicator system, determining criteria weights, selecting city samples for optimization, and establishing the optimization model; this is followed by the discussion and conclusion.

2.2 BACKGROUND

Both social stocks and waste generation have increased significantly with the unprecedented urbanization and industrialization of China. Here, social stocks refer to the resources applied in society. The amount of a country or a region's secondary resources available for recycling is determined by the volume of its social stock and composition. China's metal consumption has increased 10-fold during 1990-2010. The social stock of aluminum (Al) contents and copper (Cu), for example, increased to 88.9

Mt and 51.4 Mt respectively by 2009 (Yue et al., 2012). Notably, many durable products consumed in 1980s and 1990s are approaching their end of life. China has become the world second biggest of Waste Electrical and Electronic Equipment (WEEE) generation (Hunt, 2013), where about 25 million TVs, 5.4 million refrigerators, 10 million washing machines, 1 million air conditioners, 12 million computers, 6 million printers and 40 million mobile phones will be disposed in 2009 (Yu et al., 2014). The major recyclable resources collected in China has doubled in the past eight years (CNRRA, 2014).

Neither collection nor recycling level has reached those of developed countries for various reasons. First, household waste source separation is still underdeveloped. It is currently in the pilot stage and remains ineffective both due to inaccessibility of waste separation services and lack of residents' awareness (Yuan and Yabe, 2014; Zhang, H. and Wen, Z.G., 2014; Zhuang et al., 2008). Second, collecting and recycling activities in China are driven by economic interest; low value wastes are not collected but discarded due to their inability to reap a profit, and they create a threat to the environment. The recycling rates of plastics and batteries are as low as 25%, and that of waste tires and energy-saving lamps is near negligible due to the absence of relevant policies and low economic value (CNRRA, 2014). An estimated 5 Mt of steel scrap, 2 Mt of non-ferrous metal scraps and 14 Mt of waste article are still not recycled ever year, which have a market value of 35-40 billion CNY (5.47-6.25 billion USD) (CCID, 2012). Third, many collecting and recycling facilities are developed in workshop factory and poorly equipped. Wastes are just piled in the open air and processed by simple machines, thus easily cause secondary pollution to the surrounding environment. Finally, most enterprises only extract easy-to-recycle components and discard those difficult to get that include many

precious metals. Strategic urban mining management in China is highly needed to advance the recycling industry, mitigate resource deficiency and reduce environmental threats(Wen et al., 2015).

To address this issue, China's National Development and Reform Commission (NDRC) and Ministry of Finance jointly initiated the NUMPB program in 2010. The program defines urban resources as ferrous metals, non-ferrous metals, precious metals, plastic, and rubber from the eight major types of wastes (electronic equipment, cables, communication facilities, vehicles, household appliances, electronic products, metal and plastic packaging, and scraps). The program's objective is in line with the Circular Economy Promotion Law, to promote the development of the recycling industry, and to help relieve resource and environmental bottleneck constraints. The program is targeting 50 national pilot urban mining bases, each with at least 0.3 Mt recycling capacity. Seven requirements were prescribed: systematic waste collection network, proper industrial chain, large scale recycling materials, advanced equipment, shared infrastructure, collective environmental facilities, standard management, and operation system. Through this process, it intends to promote large-scale recycling of key waste streams with high value outputs, to develop and disseminate advanced recycling technologies, and to explore proper urban mining development models and policy mechanisms (NDRC, 2010).

So far, 28 national pilot bases have been officially recognized. The selection process follows two steps: 1) provincial governments recommend candidate industrial parks to make applications to NDRC, and 2) NDRC experts evaluate the submitted

applications. While the provincial governments focus on gaining national support for local recycling, experts only rate the submitted applications according to the scoring rules. At no point, either the provincial government or the experts have a chance to consider location planning issues at overall scale. As a result, four pairs of pilot bases are located so closely that their direct transportation distance is within 100 km. Competition for waste resources already exists between some e-waste recycling plants (Qu et al., 2013).

The 28 bases are concentrated in the eastern costal areas and central China. Two factors contribute to this: 1) The eastern and central areas are economically more developed and have higher population density. Thus both urban mine stocks and market demand for secondary resources are high. The recycling industry was developed very early in these areas. 2) Some port cities have the geographical advantage to recycle imported wastes. The question now shifts to what cities are ideal for the remaining 22 urban mining pilot bases to achieve the maximum coverage of population and economy. To answer this question, we consider population, economic development, industry development and circular economy development in cities as important factors, and use a combination of AHP, maximal covering location modelling and GIS to determine optimal locations for the selection of remaining urban mining pilot bases.

2.3 METHODS AND DATA

2.3.1 OVERVIEW OF METHODS

Ideally, an urban mining pilot base in one city will also provide waste recycling service for several adjacent cities. Appropriate location planning of the base is thus important to achieve a greater overall urban mining efficiency. Selection of appropriate cities should, to a large extent, meet both urban mining and spatial distribution criteria. This study first developed the indicators to evaluate and select cities, followed by performing two optimization processes for different purposes. The methods applied in the study include Analytical Hierarchy Process (AHP), maximal covering location model and GIS. Integration of GIS with AHP is a powerful tool to effectively select a landfill (A. Effat and N. Hegazy, 2012; Şener et al., 2010; Wang et al., 2009). This combination is also used in location planning for incineration plants (Tavares et al., 2011), and planning the construction and demolition of waste facilities (Coelho and de Brito, 2013; Dosal, Elena et al., 2013; Dosal, E. et al., 2013). A proper distance among the bases is necessary to ensure enough supply of waste resources, so we add the maximal covering location model into the process. The integration transforms and combines geographical data and value judgments to obtain information for decision making (Malczewski, 2006).

Step 1: Selecting cities to be optimized

China's administrative system consists of five levels: nation, province, municipality, county, and township. Statistics show that municipality-level cities are most densely populated, economically developed and have the best infrastructure, so we include all 287 cities in the study. AHP method is then used to develop an indicator system and evaluate the potential of being a national urban mining pilot base. All 287

cities are evaluated and ranked using statistical data. The top 160 cities are selected for primary optimization in step 2.

Step 2: Primary optimization- Selecting the ideal cities for urban mining pilot bases

In this step, a maximal covering location model is developed and applied in GIS platform to optimize selection from 160 cities. The results will show the ideal distribution for China urban mining pilot bases.

Step 3: Conditional optimization- Selecting the 22 cities for future urban mining pilot bases

As 28 bases are already officially recognized, we need to determine the remaining 22 cities. This step will repeat the optimization model established in step 2 and result in a list of 22 cities.

2.3.2 ESTABLISHING THE CITY INDICATOR SYSTEM

Selection of cities for the urban mining pilot bases is based on waste type, the facilities service coverage, and the decision making purpose. For example, selecting a site for landfills needs to consider the environmental criteria more than the economic ones (Şener et al., 2010), and also needs to consider social factors such as the stakeholder opinion (Wang et al., 2009). The location of WEEE recycling plants mainly needs to focus on economics and infrastructure, including land, labor, energy, industry agglomeration and population et al. (Queiruga et al., 2008). Optimizing for the location of ELV's recycling facilities in one Poland case included transportation cost, storage cost,

and dismantling cost, because the cost was the largest factor(Gołębiewski et al., 2013). In short, environmental factors are important for waste treatment facilities while economic and social aspects are more important for recycling plants. In the end, however, criteria setting is different from case to case and is largely depending on the decision-making objectives.

For this study, we first establish an indicator system to evaluate the potential of the 287 cities as urban mining pilot bases. We construct the indicator system through two steps: 1) we list relevant indicators based on the above mentioned literature review and situation specific to China; 2) we consult experts first to confirm the selected indicators, followed by asking them to determine the value of the indicators. Meanwhile, considering the availability of quantifying the indicators, we select six quantifiable criteria under four themes: economic development (T1), urban mining social stocks (T2), recycling development (T3), and market demand for the recycled materials (T4) (see Table 2.1).

Table 2.1 Indicator system to evaluate cities’ potentials of locating urban mining pilot bases

Themes	Criteria	Weights
T1: Economic	C1: GDP per capita	0.1595
T2: Social stocks	C2: Recyclable waste generation	0.3589
T3: Recycling development	C3: Product value yield from recycling “three wastes	0.0624
	C4: Industrial solid wastes recycling rate	0.0624
T4: Market demand for recycled material	C5: Population	0.1784
	C6: Residential consumption	0.1784

GDP per capita (C1) reflects the level of economic development; a higher GDP per capita can provide better policy and infrastructure conditions for operating urban mining pilot bases. Higher recyclable waste generation (C2) will supply stable waste stock flow for the urban mining pilot bases. For recycling development, we use the product yield from recycling the “three types of wastes” alluding to waste gas, waste water and solid waste (C3), and Industrial solid wastes recycling rates (C4) to indicate the level of development of the recycling industry in one city. Market demand for recycled materials is an important driving force for establishing urban mining bases, whereby large population (C5) and high residential consumption (C6) can lead to demand for the secondary material.

All criteria data except C6 can be found directly from the China Statistic Yearbook 2012 and the China City Statistic Yearbook 2012. We calculated C6 as the sum of three items of Residential Consumption Sectors in the China Statistic Yearbook 2012 that include: Housing, Home Appliances, Travel, and Communication.

2.3.3 DETERMINING CRITERIA WEIGHTS

Determining weights for criteria is carried out in two rounds of Analytical Hierarchy Process (AHP). AHP is a powerful tool to consider complicated problems that involve several interrelated objectives, and has emerged as a formal methodology, especially in environmental decision making (Huang et al., 2011). It has also been applied in the site selection for waste management (Aragonés-Beltrán et al., 2010). Criteria importance is ranked by pair-wise comparisons through a nine point scale, where 9 means extreme preference and 1 means no preference. This pair-wise comparison

allows for an independent evaluation of the contribution of each factor, thereby simplifying the decision making process. In this study, we consulted eleven experts to develop the matrix, including two professors at Tsinghua University, two experts from the China Association of Circular Economy (CACE) and China National Resources Recycling Association (CNRRA), and two officials from the National Development and Reform Commission, and five managers of large-scale recycling enterprises.

Checking the consistency of the matrix is a must for Analytical Hierarchy Process. The consistency of the matrix of order n is evaluated by $CR=CI/RI$, where RI is a given random matrix index of order n , and CI is calculated as:

$$CI = \frac{\lambda_{\max} - n}{n - 1} \quad (1)$$

Where $\lambda_{\max}$ is the largest or principal eigenvalue of the matrix, and n is the order of the matrix. As a general rule, a $CR \leq 0.1$ should be maintained for the matrix to be consistent (Şener et al., 2010). In this study, we only need to examine the consistency of the themes matrix, in which $CR=0.0153$, indicating that a consistent matrix is formed. For the criteria, we assign 0.5 to C_3 , C_4 , C_5 , and C_6 as relevant weights to the corresponding theme. By multiplying C_j by their corresponding relevant theme weights, we get the final weights of all criteria (see Table 2.1).

2.3.4 SELECTING CITY SAMPLES FOR OPTIMIZATION

A database of 287 cities is established from section 3.2, but the units are not uniform among results. Therefore data are normalized through:

$$Y_{ji} = (X_{ji} - X_{MinValue}) / (X_{MaxValue} - X_{MinValue}) \quad (i=1, 287) \quad (2)$$

where Y_{ji} is the normalized result of C_j for city i and X_{ji} is the original data, $X_{MinValue}$ is the minimum value of C_{ji} , and $X_{MaxValue}$ is the maximum value of C_{ji} .

Multiplying the normalized city data by criteria weights (C_i) from Table 2.1, we get a database of the potential for 287 cities as locations for urban mining pilot bases. They are ranked and sorted and illustrated in Figure 2.1.

Figure 2.1 Number of cities from the 287 cities index in each of 10 index intervals.

Note: The 160 candidate cities selected are the ones whose index value is above average

Among the 287 cities index, the maximum value is 0.7146, the minimum is 0.0026, and the average is 0.2697. Figure 2.1 shows that most cities fall into the interval of 0.2-0.3 and 0.3-0.4. Geographically, high index cities are mostly located in eastern and developed areas, while low index cities are in central and western China. Large economic disparities exist between eastern and western areas in China, where eastern cities are

featured with a large population, high consumption and large quantity waste generation, and developed recycling industries. These facts give a natural tendency for eastern cities and some developed central cities to be higher on the index. The city index indicates a requirement of at least 'above average'. Therefore, in this study, we select the cities that are above the average value of 0.2697 as sample cities for optimization, such that the top 160 cities are selected.

2.3.5 ESTABLISHING THE OPTIMIZATION MODEL

The problem of selecting the location of facilities was first introduced by Webber in 1909 when he studied warehouse location selection (Owen and Daskin, 1998). Then, Church and ReVelle developed the maximal covering location model which has been widely applied in various urban and environmental planning contexts (Church and ReVelle, 1974). The P-median model is normally used to address the location problem for public service facilities such as schools, hospitals and emergency centers (Hakimi, 1964), as well as in business for distribution chains (ReVelle, 1986). Location set covering model is used to meet all covering region needs with the least number of facilities and mandatory proximity (Batta and Mannur, 1990). Hierarchical location models are also often used to layout the medical service system, and solve warehouse and reverse logistic problems (Fleischmann et al., 1997).

In this study, we deploy the maximal covering location model using 0-1 integer programming and with a defined serving distance, to achieve maximum coverage of the population and GDP. The model is defined as:

$$\text{Maximize: } Z = \sum_{i \in I} a_i \times y_i \quad (3)$$

$$\text{S.T.} \quad \sum_{j \in N_i} x_j \geq y_i \quad i \in I \quad (4)$$

$$\sum_{j \in J} x_j = p \quad (5)$$

$$x_j = (0,1) \quad j \in J \quad (6)$$

$$y_i = (0,1) \quad i \in I \quad (7)$$

Equation (3) is the objective function, where i is the total number of cities in the study (287), y_i is city i , a_i is based on the population and economic information of city i . Equation (4) is the space condition equation, where $N_i = \{ j \in J, d_{ij} \leq S \}$, S is the maximum serving distance that we define as 200 km according to research by Guo about material flow analysis of lead in China (Guo et al., 2009), and J is the 160 candidate cities. Equation (5) denotes the restriction on the number of urban mining bases, where P is the number of planned urban mining pilot bases. Equations (6) and (7) express whether city i is selected as an urban mining pilot base location, where 1 stands for being selected and 0 stands for not being selected.

2.4 RESULTS AND DISCUSSION

2.4.1 RESULTS

We apply the optimization model in the software GIS to get a matrix of 0-1 liner programming for the 160 cities. The matrix shows GDP and population coverage when J cities are selected as urban mining pilot bases with the defined maximum serving

distance as 200 km. Counting the frequency of 1 appearing in the matrix results in Figure 2.2.

Figure 2.2 Ratio of China’s GDP and population coverage when a different number of cities are optimized as urban mining pilot bases

The figure shows the dynamics between the number of cities being selected as urban mining pilot bases and the percentage of GDP and population coverage. The first part of the figure illustrates a strong positive, almost linear relationship. When only one city is selected, maximum 16.7% GDP and 7.2% population can be served. When two cities are selected, 27.5% GDP and 13.4% population can be covered. Both the GDP and the population coverage curves sharply increase when selected cities are incrementally added from 1 to 20, but slowdown during the range between 20 to 30, and reach to peak

when the number of cities selected is 40, with a maximum 97.1% GDP and 94.9% population are covered. The second part of the figure shows a stationary relationship. When the number of cities increases from 40 to 160, the GDP and population coverage curves remain virtually unchanged. This result implies that a minimum of 40 urban mining pilot bases can theoretically provide maximum effectiveness for waste recycling services, as adding more cities will not provide any additional GDP and population coverage. These 40 cities are listed in Table 2.2, and their locations are shown in Figure 2.3.

Table 2.2 40 optimal cities as locations for urban mining pilot bases, including their GDP* and population coverage

City	GDP coverage (Billions USD)	Population coverage (Millions)	City	GDP coverage (Billions USD)	Population coverage (Millions)
Changchun	28.13	4.34	Nantong	795.3	62.92
Changzhou	727.19	78.88	Nanyang	157.55	54.53
Chengde	226.45	54.45	Ordos	107.2	7.37
Daqing	145.03	27.16	Qingyuan	637.43	46.84
Datong	81.3	17.67	Sanya	3.61	0.57
Fuzhou	155.95	25.81	Shantou	130.27	32.77
Guiyang	43.19	17.2	Shenyang	216.45	29.59
Guyuan	40.78	19.9	Songyuan	58.97	9.62
Hefei	260.12	64.91	Taizhou	354.32	38.47
Heze	408.35	115.01	Tangshan	28.43	6.61
Jinan	104.56	31.73	Urumqi	20.91	2.43
Jingdezhen	59.44	19.23	Wuzhong	26.19	4.25
Karamy	11.12	0.38	Xi'an	92.85	24.98
Kunming	68.54	15.52	Xiaogan	149.45	30.7
Laibin	92.11	33.25	Xingtai	118.51	25.38
Linfen	149.06	34.04	Xining	30.58	7.36
Linyi	167.31	39.44	Yantai	267.62	22.55
Maoming	77.04	24.18	Yingkou	44.21	11.71
Nanchong	312.33	92.94	Yongzhou	68.32	24.23
Nanning	11.14	3.35	Zigong	59.63	22.25

Note: Currency exchange rate: 1 USD=6.4 CNY

Figure 2.3 Spatial distribution of the 40 optimized urban mining pilot base cities

So far, the Chinese government has officially recognized 28 national urban mining pilot bases. Only three bases can be found on our list of optimized cities. The current 28 cities can only cover 77.2% of total GDP and 69% of China's total population, while 16 of the 40 optimized cities can achieve the same result. Given planning for 50 urban mining pilot bases in total, we identify the remaining 22 cities as candidate locations to assure maximum GDP and population coverage. We ran the established maximal covering location model in GIS with the 28 cities and their covered areas as a fixed base, and determined a new list of 22 cities. Their GDP and population coverage together with that of the 28 current bases are shown in Table 2.3, and their geographic locations are shown in Figure 2.4. Combined with the 28 cities acting as bases, an additional 22 cities can achieve a maximum GDP coverage of 97.5% and population coverage of 95.1%.

Table 2.3 GDP and population coverage of 28 current UMPBs and 22 proposed ones

Current cities (28)	GDP coverage (Billions USD)	Population coverage (Millions)	Proposed cities (22)	GDP coverage (Billions USD)	Population coverage (Millions)
Beijing	189.89	12.57	Changchun	98.73	10.57
Chenzhou	51.08	19.04	Daqing	155	33.64
Chongqing	135	29.06	Guiyang	43.19	17.2
Chuzhou	89.59	20.86	Guyuan	25.47	17.73
Daliang	133.3	15.43	Haikou	58.17	17.42
Dandong	27.95	5.96	Huhehaote	128.64	12.06
Foshan	511.53	30.71	Jinan	309.05	46.53
Fuqing	189.36	27.61	Jingdezhen	62.94	22.99
Fuyang	83.39	36.46	Karamay	11.11	0.38
Gucheng	101.66	28.3	Kunming	88.06	29.98
Korla	10.64	0.56	Linfen	68.09	18.86
Lingwu	38.33	7.29	Nanchong	51.28	24.84
Linyi	72.16	18.58	Nanjing	253.42	34.5
Neijiang	185.66	47.29	Nanning	69.75	24.01
Ningbo	124.34	10.13	Shantou	98.08	28.97
Pizhou	122.95	33.11	Shenyang	170.48	24.46
Qingdao	235.31	25.42	Taizhou	93.98	13.7
Qingyuan	128.48	16.19	Urumqi	20.92	2.43
Qitaihe	44.56	11.94	Wuhan	161.38	38.98
Shanghai	593.03	36.21	Xi'an	116.06	32.6
Tangshan	125.48	21.93	Xining	46.41	10.33
Tianjin	185.61	18.35	Yan'an	41.28	6.95
Tonglu	162.91	18..15			
Wuzhou	79.45	29.1			
Xinyu	104.56	31.73			
Xuchang	273.59	68.09			
Yangquan	172.72	39.69			
Yueyang	212.81	55.56

Figure 2.4 Spatial distribution of 28 current and 22 proposed urban mining pilot bases

2.4.2 DISCUSSION

The first optimization shows that China theoretically only needs 40 urban mining pilot bases in order to cover the maximum GDP and population of China. It illustrates a useful method for strategic location planning of urban mining in a country or region. Still, some practical facts need to be considered for the decision-making. One fact is the large amount of imported waste. China annually imports about 50 Mt waste including article, PET bottles, steel, and hardware refuse (MEP, 2014). These stocks foster the development of the waste dismantling and recycling industries in coastal cities. Three of the current 28 bases were developed on the basis of dismantling imported waste. For

instance, Qingyuan of Guangdong province was a center for family workshops recycling nonferrous metals from imported wastes since the 1980s. Today it has become an urban mining pilot base supplying for 32% of China's secondary copper. Similar examples can be found from other bases such as the Donggang in Liaoning, Wuzhou in Guangxi, Taizhou in Zhejiang, Haixi in Fujian, Ziya in Tianjin.

Another fact has been the spontaneous growth of the recycling sector during the past few decades. Since the 1980s, many farmers free from the agricultural sector sought additional income from waste collection and recycling activities. They work in informally organised networks that gradually evolved into recycling conglomerates. Typical examples include the Linyi of Shandong, Dazhou of Henan, Neijiang of Sichuan, and Jieshou of Anhui. These aggregations have good bases of informal waste collection networks and, nationwide, annually trade and recycle more than 1 Mt of waste stocks, and make major contributions to the local economy. For instance, Jieshou of Anhui engages 50 thousand people in national waste collection and recycling in local plants. They annually recycle 0.45 Mt of lead-acid battery, 1.2 Mt plastic, and 0.3 Mt of metal scraps, on top of contributing 75% of the local government's revenues. Practical selection decisions of urban mining pilot bases should also take into consideration the current infrastructure for recycling.

The second optimization of selecting 22 candidate cities in Figure 2.4 shows that the optimal spatial distribution covers parts of the southwest, northwest and northeast areas, and is a good supplement to the current bases to achieve geographical balance. However, selection should certainly consider the two facts mentioned above, and will

thus probably not precisely follow the list provided. Further more, considering the fact that manufacturing industry shifting tendency from east to west, and the fact that urbanization in China will generate new urban centers, the future urban mining bases selection shall reserve some capacity for the western area and the potential new urban centers.

Other management measures also need to be taken to support the optimized locations for a comprehensive urban mining strategic plan. They include: 1) developing a regional waste collection network with waste stock trade centers; 2) assessing urban mines' social stock and long-term stock generation tendencies; 3) planning recycling plants capacities to avoid overinvestment driven by national subsidies; 4) incorporating local manufacturing industries in a large material loop to reduce the transportation distance for both waste and recycled resources.

2.5 CONCLUSION

Urban mining is becoming an efficient supply of resources because of large quantities of recyclable wastes and low environmental impacts. Urban mine stocks are not generated by nature but largely varies according to the size of the urban population and development of the economy. Thus location planning for urban mining needs to take these social and economic factors into consideration. Currently, there are many studies about selecting the location of single waste recycling facilities, but the subject is relatively untouched for urban mining as a whole. It is both economically and environmentally friendly to plan multi wastes recycling in industrial parks as the environmental protection facilities can be shared, and secondary resource exchanged

within short transportation distances. Location optimization for large-scale urban mining becomes a key issue. This article takes China as a case study to illustrate location optimization for urban mining by using the combined methods of AHP, maximal covering location model, and GIS.

Primary optimization shows that theoretically 40 urban mining pilot bases can provide maximum service coverage for China, i.e., 97% of total GDP and 95% of total population. As China's government targets a total of 50 bases and 28 are already officially recognized, our second optimization results in a list of 22 cities as the most efficient locations for future urban mining pilot bases. The current 28 cities together with the proposed 22 cities can in total cover a maximum 97.5% of GDP and 95.1% of the population in China. Some practical factors need to be considered for practical decision-making, however. For instance, 50 Mt of waste are imported annually into China, and some recycling aggregations have already been developed since the 1980s. Some urban mining bases should be awarded to cities with the advantage of imported waste, and to those with recycling aggregations. Other management measures should be taken to supplement location planning; these include: the development of a collection network, assessment of urban mines' social stocks, recycling capacity planning, and incorporation with other industry.

This article makes contributions at two levels. Brunner noticed that recycling facility location selection is one of the two key issues in urban mining strategy development (Brunner, 2011). This article illustrates a method to incorporate spatial planning for urban mining in one country that is applicable to other countries or regions.

The model developed in this article may not be perfect yet and may need further improvement regarding the selection of city indicators and transportation distance. In the larger context of industrial ecology, Van Berkel proposed a new term for urban symbiosis, referring to “the use of by-products (waste) from cities as alternative raw materials or energy sources in industrial operation.” Taking the Eco-town program as an example (Geng et al., 2010; Van Berkel, Rene et al., 2009), this article shows the spatial planning issues that accompany urban symbiosis.

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CHAPTER 3: CAN INTELLIGENT COLLECTION INTEGRATE THE INFORMAL SECTOR FOR URBAN RESOURCE RECYCLING IN CHINA?⁷

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Abstract: Collection is a key activity in sustainable solid waste management and resource recycling. In many developing countries, the collection is undertaken mainly by the informal sector. This is accompanied by various environmental, social, health and efficiency problems. Some top-down experiments to integrate informal collection into the waste resource recycling chain have proved unsuccessful. Meanwhile, internet and communication technologies in waste management are formulating a new collection model: intelligent collection. In China, there are dozens of emerging companies who are engaging in the intelligent collection of recyclables. What are the intelligent collection cases in China? Do they have potential to integrate the informal collection into the waste recycling chain? To answer these questions, we selected and interviewed 15 Chinese intelligent collection companies to identify their organizational model and comparative advantages over the informal collection. We found that intelligent collection companies

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in China operated in two forms: human-human interaction collection and human-machine interaction collection. Comparative advantages were found in the organization, trade, data accumulation, and profit making sources. These render them with a high potential to integrate informal collection. Intelligent collection in China is still at an early stage. Its potential for a sustainable business model needs to be further explored. Its application as a supplement to the Municipal Solid Waste collection system and as an exclusive collection for high value waste items under the Extended Producer Responsibility framework seems promising.

Keywords: Intelligent collection, Informal collection, Waste management, Recycling, ICTs, IoTs.

3.1 INTRODUCTION

Resource recycling provides the great potential of resource supply to the society (Brunner and Rechberger, 2004; Wen et al., 2015). As recyclable wastes are geographically scattered according to demographic and economic factors (Brunner, 2011). Collection of recyclables from residential households to the recycling facility is a key part of recycling (Nowakowski, 2017). Recyclables collection in many developing countries is undertaken mainly by the informal sector (Wilson et al., 2006). It is widely acknowledged that informal collection contributes to resource recycling in a positive way, but also is associated with various environmental, health, and social problems as well (Ardi and Leisten, 2016; Lange, 2013; Wilson et al., 2009). Therefore, integrating informal collector in some form seems necessary to move towards a sustainable resource recycling.

Integration of informal collection has been observed in many countries, but the successful case is rare. Most integration courses solely relied on the public policy and formal collection system, and the private sector is neglected. In recent years, a new collection model emerged because of the wide application of Internet and Communication Technology (ICT) and the Internet of Things (IoT) in waste management; we name it an intelligent collection. Private companies invested in the intelligent collection to collect the recyclable wastes with the facilitation of ICT and IoT tools. Within the intelligent collection system, consumers can make their collection order through their cellphone application (App) to have their recyclables collected at the door and receive credits as return. Consumers may also put the waste PET bottles into the

intelligent collection machine and receive credits as return. The credits may be spent on online shopping. Currently, more than fifty internet-based entities engaging in recyclables collection in China (Sun et al., 2018). It leads to our following research questions:

What are the key features of the intelligent collection in China? Do they have potential to contribute to the integration of informal collection?

Because development and application of ICTs and IoTs in waste management only rose in recent years, intelligent collection for waste or recyclables is newly sprouted things, the study of the intelligent collection are mostly ex ante and technology focused. For example, a smart waste collection system is studied for Copenhagen (Gutierrez et al., 2015); an architecture of an IoT driven system for solid waste collection is generally proposed (Thürer et al., 2016). In China, an IoT network system is experimented for food waste management in Suzhou (Wen et al., 2018), and similarly for waste electrical and electronic equipment management in Hangzhou (Gu et al., 2017).

This paper will take an ad hoc angle and focus on the economic and social aspects, to analyze the business and organizational model of intelligent collection for recyclables in China. We identify the forms of intelligent collection, analyze their comparative advantages over the informal collection, discuss their potential to integrate informal collection, and assess future development. This paper contributes to the study of intelligent collection and provides insights into the topic of informal collection integration. The paper is structured as follows: section one raises the research questions. Section two reviews informal collection and the recent development of intelligent

collection as background for this paper. Section three introduces the materials and methods. Section four presents the results of the two forms of intelligent collection and their comparative advantage to the informal collection, and the discussion and conclusion are provided in section five and six, respectively.

3.2 INFORMAL COLLECTION AND INTELLIGENT COLLECTION

3.2.1 INFORMAL COLLECTION

Informal collection for recyclables is the collection carried out by the informal sector. The informal sector refers to: “individuals or enterprises who are involved in private sector recycling and waste management activities which are not sponsored, financed, recognized, supported, organised or acknowledged by the formal solid waste authorities, or which operate in violation of, or in competition with, formal authorities” (Scheinberg, 2011). The number of total informal waste workers is estimated at 0.6% of the world population, who recycle up to 45% of the generated waste (Lange and Linzner, 2013). The positive contribution of the informal sector to resource recycling is widely acknowledged, but still, challenges remain (Botello-Álvarez et al., 2018). First is the environmental problem caused by the informal sector activity. This has been well documented by the academia. The other is the efficiency problem. The informal recycling system is characterised by small-scale, low-technology, low-paid, unrecorded and unregulated work (Fei et al., 2016). It only responds to market demands in the reclamation of high value wastes and leaves the others to be sent to dumps (Ezeah et al., 2013). This challenges the stability of Municipal Solid Waste (MSW) management system,

as fluctuations in the waste quantity collected by the informal collector may cause a sudden increase of waste sent to the incineration and landfilling site, and increase public expense as well. Therefore, seeking a solution for informal collection integration is also necessary for a sustainable waste management system.

Integration of informal collection has been observed in many countries. However, the results are not yet satisfying (Fei et al., 2016; Linzner and Salhofer, 2014; Wilson et al., 2006). Some integration solutions have been framed only through a poverty reduction lens that considers the economic survival strategies of the collectors, but without paying attention to the sustainability of the collection business model itself (Nzeadibe and Anyadike, 2012). Some have overlooked the social aspects of the informal sector. For example, a formal PET bottles recycling company in Beijing hired scavengers to guarantee their waste supply, but could not sustain this operation as the situation of the scavengers themselves was not stable in nature (Zhang, H. and Wen, Z.-G., 2014). Experiences of 20 informal sector integration cases from ten low and middle-income countries have shown that most integration attempts were constrained by policy/legal and institutional barriers (Aparcana, 2017). Li compared the formal and informal collection channel for recyclables and proved that governance mechanisms set by the government were unworkable to integrate the informal collection, with consumers preference as a vital factor (Li et al., 2017). Similarly, a survey in Taizhou of China showed that households prefer informal collection, rather than the formal collection as their disposal channel of e-waste because of the comparative advantages of the informal collection given its convenience of service, flexibility, and accessibility. Therefore,

integrated collection system should be designed to include the informal collectors (Chi et al., 2014). This conclusion is also supported by other researchers (Wang et al., 2017).

3.2.2 INTELLIGENT COLLECTION

Intelligent collection is a new collection model by which the waste or recyclables are collected with the assistance of Internet and Communication technologies (ICT) and the Internet of Things (IoT) tools. There are four groups of tools applied to waste management (Hannan et al., 2015). They are: 1) spatial technologies including Geographic Information Systems (GIS), Global Positioning Systems (GPS), Remote Sensing (RS), 2) identification technologies involving barcodes, Radio-frequency identification (RFID), 3) data acquisition technologies including sensors and imaging devices, and 4) data communication technologies relying on Global System for Mobile Communications (GSM)/GPRS, Zigbee, Wi-Fi, Bluetooth, Very High Frequency Recorder (VHFR). Combinations of these tools can help handle a variety of waste management problems in a more efficient manner and deal well with cost, time, risk, and environment issues (Lu et al., 2013). 87 cases of ICTs application in waste management have been identified, with nine of these employing intelligent collection (Vitorino de Souza Melaré et al., 2017). Recyclables collection using intelligent systems has been applied in 85 municipalities of Italy, which raised the recyclables collection efficiency by 85%. This also contributed to achieving a circular economy target assigned by the EU (Rada et al., 2013). Collection of used paper from small businesses through GIS techniques was trialed in Spain (López Alvarez et al., 2008). An intelligent waste management system, IEcosys, was trialed in Portugal. This changed the paradigm of people receiving for the recycled

rubbish instead of paying for the waste disposal (Reis et al., 2015). Thus, ICTs and IoTs help to formulate a new collection model in ways that are different from the informal collection, and also provide the potential for informal collection integration.

Most studies of the intelligent collection have focused on the technologies themselves, but have overlooked the business and organizational model of the collection. Most of the intelligent collection systems are still at experimental and prototype stage, insufficiently so to discuss their operation cost and efficiency. Intelligent collection systems have been mostly documented in developed countries. Rada et al. stated that intelligent collection was not yet well exploited in transition economies (Rada et al., 2013). However, in China, intelligent tools were explored for their applicability for solid waste management and restaurant food waste collection in some developed provinces early in 2009. An intelligent collection system for municipal solid waste was trialed in Pudong, a new district of Shanghai (Rovetta et al., 2009). Similarly, an intelligent system was implemented for restaurant food waste collection and treatment in Suzhou (Wen et al., 2018). These pilot projects are the early trails supported by public funds from the government.

In the past three years, intelligent collection for recyclables has been developed very fast in China (Zhou, 2015). This partly is due to the investment from the private sector. ‘Internet+ recyclable resource’ is another term referring to the intelligent collection. Sun observed more than 50 such entities, and identify the maps of the structure of two internet-based WEEE collection business ecosystems C2B (customer to business) and B2B (business to business) (Sun et al., 2018). Wang reviewed ten

representatives and illustrated four different cases as typical internet recycling modes (Wang, H. et al., 2018). These studies make a good foundation for profiling intelligent collection in China. The contribution of this paper is that we analyze such new collection model against the current informal collection background and provide insights of informal sector integration toward sustainable resource recycling.

3.3 MATERIAL AND METHOD

The research method we adopted is a qualitative analysis with an inductive approach using an open questionnaire and interviews. The approach consists of three steps. Step one is the selection of the research objects, which are from two sources. Firstly, the institution at Tsinghua University, with which the main author is affiliated, together with the China Association of Circular Economy (CACE), initiated the Internet Plus Resources Recycling Alliance (IPRA) in 2016. The author herself was nominated as deputy secretary-general of the alliance. More than 100 business members joined in the alliance, one third of which are engaged in the intelligent collection business. The research objects we selected were the companies that have operated for more than two years and have demonstrated business models that were evidently in operation. Secondly, in 2016 and 2017, the Ministry of Commerce of China awarded an excellency status to 20 new collection companies; some were not members of the IPRA, but we included them as a supplement to our research objects in this study.

Step two is information collection and validation. We took advantage of IPRA and initiated a call for paper submission by the business members. They were required to present their operation story, following a prescribed open structured questionnaire.

Table 3.1 lists the questions. The companies took this as an opportunity for dissemination and advertising. In total, 36 companies submitted their case paper. This resulted in IPRA annual report 2016 and 2017. We chose the twelve most relevant and complete IPRA case companies and three supplementary cases from the Ministry of Commerce awards upon which to carry out a field survey and interviews for information validation. In the case papers, the companies presented the information by answering the questions in a prescribed layout. This ensured the homogeneity of the information provided by the various companies. In the field survey, we interviewed the managers and staffs to verify the information provided in their case report to ensure consistency and accuracy.

Table 3.1 Questions list of the open structured questionnaire

Questions	
1.	When did your intelligent collection start?
2.	How much is the total investment?
3.	Where is your collection system mainly operated?
4.	What clients does your collection system target?
5.	What ICTs tools has your system applied and how?
6.	Please draw a chart of the material flow, cash flow, and information flow in your system
7.	How do the stakeholders interact with each other in your system?
8.	How many recyclables have been collected and how many registered clients?
9.	Any barriers and problems for the future development of your model?
10.	Any policy advice for the government?

Proceeding to step three, based on the collected and validated information, we used an inductive approach to extract the forms of the intelligent collection in China,

analyze their comparative advantages and associated integration potential for the informal collection. Table 3.2 provides the profile of the 15 interviewed companies, and Figure 3.1 shows their geographical locations.

Table 3.2 Profile of 15 interviewed intelligent collection companies

Nr.	Company name	Year started	City located	Service targeted	Items collected	Operation Status
1.	Income	2012	Beijing	Residential	Recyclables	In operation
2.	LM	2013	Beijing	Residential	Recyclables	In operation
3.	ZSH	2015	Beijing	Residential	Recyclables	Suspend
4.	MB	2013	Shanghai	Residential	Recyclables	In operation
5.	XJQ	2015	Shanghai	Residential	Recyclables	In operation
6.	AHS	2011	Shanghai	Residential	Waste cellphone	In operation
7.	YE	2015	Shenzhen	Residential	Kitchen wastes	Suspend
8.	FPDS	2015	Xiamen	Residential	Recyclables	In operation
9.	HG	2016	Hangzhou	Residential	Recyclables	In operation
10.	WJQY	2015	Hangzhou	Residential	Recyclables	In operation
11.	DF	2015	Dafeng	Residential	Recyclables	Suspend
12.	HSG	2015	Wuhan	Residential	Recyclables	Suspend
13.	YHHB	2015	Xining	Residential	Recyclables	In operation
14.	YYBS	2016	Yancheng	Residential	Recyclables	In operation
15.	YHS	2015	Feicheng	Residential	Recyclables	In operation

Figure 3.1 Geographical location of the 15 interviewed intelligent collection companies

3.4 RESULTS

3.4.1 TWO FORMS OF THE INTELLIGENT COLLECTION IN CHINA

Recyclables collection includes at least four steps: from the generator to collector; to middleman; to the separation station; and, to the recycling plants. Review of the 15 intelligent collection companies showed that innovation mostly took place at the first step, e.g., from the generator to collector. This is the most complex part of the whole collection process because the recyclables generated are large in quantity and widely dispersed. Also, collection from the generator to the collector is a high-frequency and

multi-player interactive process where the quantity and quality of the recyclables collected from this step will affect the whole recycling efficiency afterwards.

Intelligent collection in China has focused on the innovation at the first step of the collection. This takes place in two intelligent collection forms. We define these as human-human interaction collection (HH) and human-machine interaction collection (HM). As shown in Table 3.3, 11 companies adopted the HH collection pattern, and the other four companies adopted both HH and HM collection forms.

Table 3.3 Intelligent collection companies and the forms they adopted

Collection forms	Companies who adopted the forms
HH	LM, MB, YE, ZSH, HG, WJQY, DF, HSG, YHHB, YYBS, YHS
HH and HM	Income, XJQ, FPDS, AHS

Human-machine interaction collection (HM)

Human-machine interaction collection refers to collection by machine. The machine is a cabinet embedded with ICTs devices that include sensor, barcode and data communication devices. As illustrated in Figure 3.2, the HM collection process consists of four steps: 1) Identify account. The machine identifies generator's account information who has registered within the collection company system. 2) Hand over recyclables. The generator hand over the recyclables to the machine following prescribed instructions. 3) Send account/recyclable information. The machine identify the recyclable information and transmit it to the server together with the generator

account information. 4) Offer credit. The server offers credit to the generator's account upon receipt of the handed over recyclables information..

Figure 3.2 Procedure of HM interaction collection

HM collection needs several ICTs tools. The barcode identifies the generator account and the recyclables, which has complete product barcode. The sensor monitors the recyclables data and transmits to the server via GSM/GPRS.

HM collection machine is normally used for the standardized recyclable product, such as PET bottles. A few companies also have developed intelligent collection machines for low valued waste items, such as waste textiles and kitchen waste. PET bottles intelligent collection machines are located in public areas, such as office, schools and shopping mall. Income is the pioneer company to have developed the PET bottles intelligent collection machine. The machine adopts barcode, GPRS communication devices, helps the generator easily accomplish recycling of PET bottles through three steps.

Figure 3.3 shows the recycling procedure for the generator. 1) The generator chooses to start a collection from the LCD screen. 2) The generator handles the PET bottles following the displayed instruction ensuring the product barcode on the PET bottle is identified. 3) The generator can select the way to receive the awarded credits; he may choose to top up the public transportation commune card, or to donate to charity organizations. Since 2012, Income has put more than 5000 collecting machines in Beijing, and in total collect 55 million pieces of PET bottles.

Figure 3.3 Collection procedure of PET bottles collection machine

Source: Income company

Human-human interaction collection (HH)

Human-human interaction collection refers to collection by collectors via assistance of ICTs. Generator needs to register an account through the smartphone application (App) developed by the intelligent collection company. The HH collection

consists of five steps as shown in Figure 3.4. 1) Make appointment. The generator makes appointment through smartphone App about the collection time and items. 2) Give order. The server assign collection order to the nearby collector based on location. 3) Collect at door. The collector collects the recyclables at the door. 4) Send info. The collector input the information of the collected recyclables including the weight, the type and value. 5) Offer credit. The server offers credits to the generator account. One collection is accomplished.

Figure 3.4 Procedure of HH interaction collection

HH collection also needs several ICTs tools. Both generator and collector need a smartphone as basic hardware. The collector carries out the identification and submission of the recyclables information to the server. Data communication is by Wireless Fidelity (WIFI) or General Packet Radio Service (GPRS).

All interviewed companies adopt the HH interaction collection. In this collection pattern, every collector is in charge of the collection for certain residential area. When they receive the collection order from the server, they go to generator's door at the

appointed time to carry out the collection. For example, company HG established one collection service station for every 1,000 households to collect waste paper, cardboard, waste furniture and Waste Electrical and Electronic Equipment (WEEEs) via the assistance of the ICTs tools.

Comparison of HM, HH and informal collection

HM collection and HH collection have different advantages and applicability. HM collection is most applicable for standard waste items and for serving public spaces. HH collection is more applicable for all recyclables in residential areas. Compared with the informal collection, both the HM and HH collection do not pay the generators cash, but instead offer electronic currency or credit, which they are encouraged to spend on online shopping. Table 3.4 compares the ICTs tools, applicability and forms of HM, HH and informal collection.

Table 3.4 comparison of HM, HH and informal collection

	ICTs tools adopted	Applicability	Forms
HM collection	Barcode, GSM/GPRS, Sensors, Smartphone	PET bottles, Textiles, Kitchen waste	Collect by machine, trade in electronic currency
HH collection	APP、Web, GSM/GPRS, GIS, Smartphone	All recyclables	Collect by the collector at the door via appointment, trade in electronic currency
Informal collection	N/A	All recyclables	Collect by the collector at the door randomly, trade in cash.

3.4.2 FOUR COMPARATIVE ADVANTAGES OF THE INTELLIGENT COLLECTION

1) Organised intelligent collection

The intelligent collection is organised, and normative collection, operation by company provides the organizational safeguard for integration of informal collection. The informal collection is an unorganised and random collection. First, the informal collection primarily involves street vendors and scavengers. Vendors wander the street or stand by street corners waiting for residents to bring and sell recyclables to them. Scavengers pick up recyclables from the trash bins. Second, the collections time, place, items and their price are organised randomly. Third, the collectors are unstable, one collector can be active within a 20 km area, but they can leave the sector to take another job at any time. As recyclables in China have a market price, when they are in high demand in the market, the number of collectors and the recyclables collected will be increased, and vice versa. When the market demand is low, recyclables will be left in the Municipal Solid Waste (MSW) stream and end up going for incineration or to landfill sites. This creates significant challenges for sustainable MSW management. Such randomness is the root issue underlying the social, environmental and health problems of the informal collection.

When a company operates intelligent collection, the adoption of ICTs tools can standardize and monitor the collection procedure, and help solve the randomness problem of the information collection. This happens first, by the ICT tools facilitating

quick and easy access and recording of the collection time, place, and frequency that then become organised and regular. Second, as a company employs, every collector takes charge of a fixed residential area and can then more easily develop regular and a more ordered relationship with the residents. Such regularity also helps to cultivate the resident's recycling behavior that also helps ensure the quantity and quality of collected recyclables. Therefore, organised collection and operation by a company gives the collection legitimacy and helps eliminate the potential cause of the social and health problems associated with the informal collection. Figure 3.5(1) illustrates the organised intelligent collection, Figure 3.5(2) shows the random informal collection.

Figure 3.5 Organised intelligent collection and random informal collection

2) Efficient material and cash flow of the intelligent collection

Figure 3.6 compares the material flow and cash flow in the intelligent collection and informal collection, system is comparatively efficient. Figure 3.6 (1) shows the material flow and cash flow in the informal collection where recyclables are traded and

transferred at least four times during the process from the generator to recycling plants. At every transfer step, a trade deal is made, and price rises, and the recyclable items need to be sorted according to the buyer's standard. Furthermore, the trade-for-cash nature of informal collection leads to low efficiency of the whole system. Every buying stakeholder in the system needs to prepare cash for trading. This exerts a high cash flow pressure on the higher buyer.

Figure 3.6 (2) shows the material flow and cash flow in the intelligent collection where both the recyclables transference and the trade frequency happen less than that of the informal collection. This is because, first, trade only takes place at two phases: the first phase, when recyclables are collected from the generator, and the last phase, when the recyclables are sold to the recycling plants. For any intelligent collection company that also invests in recycling facilities, trade only takes place at the first step. Second, material flow in intelligent collection system is more efficient than that of the informal collection, as the company normally establishes its own sorting center to take over the recyclables directly from the collectors. Besides, ICT devices in the intelligent collection can monitor the logistics and help to optimize the transportation system to save cost. The Spanish case mentioned in section 3.2.2 is an example. Third, trade of intelligent collection can take place in virtual currency and instead of cash. This brings less cash flow tension for the company. In a word, less trade and material transfer frequency help to increase the efficiency of intelligent collection.

Figure 3.6 Material flow and cash flow in the intelligent collection and informal collection

3) Accurate and traceable data of the intelligent collection

In the informal collection systems neither collectors nor traders, keep minimal statistics or records of their trade in recyclables, limited to only a cashbook of purchases and sales to monitor the change in profit. Therefore, this system provides little in the way of accurate statistical data for China's recycling industry. Researchers and policy makers only can reach such conclusions by estimation. Inaccurate data poses barriers to policy and planning for waste management and the development of the circular economy industry. From the government point of view, inaccurate data make policy planning difficult. From the business point of view, inaccurate data makes management unwieldy, as they cannot apply for subsidies, nor tax refunds, without accurate statistics data.

With the intelligent collection system, various ICTs tools help to identify, communicate and store a range of relevant data. First, the system can identify the

location and track the logistic routes of the recyclables. Second, the data is accurate, traceable and instant. The intelligent collection system records all information of recyclables from the moment they are handed over to the collectors. The server can provide a comprehensive statistical record of the recyclables collected at any moment in time.

Figure 3.7 illustrates that the server system of Income company displays the instant and accurate data of its intelligent collection system. It displays the locations and status of 5,000 PET bottle collection machines. Green spots show 4,577 machines are in good condition, red spots show 120 machines are in full stock, and yellow spots show 303 machines are not working. The system also presents statistics of the active users and real time PET bottles collected. It shows that 12,522 pieces of PET bottle being collected on that day, and lists the top 5 most active collection machines. Therefore, ICTs help to solve the problem of the data absent from the informal collection. Intelligent collection facilitates business management for the company; and supports better administration of waste management for the government.

Figure 3.7 Intelligent collection system monitors 5,000 PET bottle collection machines in Beijing

Source: Income company

4) Multi profit-making of intelligent collection

The organised nature of intelligent collection can help to develop the multi profit-making business model. The informal collection is a single linear profit-making system. As above Figure 3.6 (1) shows, stakeholders of the informal collection at every phase can only earn their profit from the price margin of trading with the next step. Such linear profit-making model of the informal collection is vulnerably affected by the price fluctuation of the resources market.

Intelligent collection is a multi network profit-making system. Figure 3.8 below shows the intelligent collection in China can earn profit from four sources. First, is the recyclables profit; similar to that of the informal collection, the collection company can make profit from the recyclables sold to the recycling plants. Second, there is the service

profit. This is the fee paid by the residents when the collector provides an extended service to the residents. In the HH collection pattern mentioned in section 3.1, the collectors can help to deliver the daily living goods and housework service when they carry out the door-to-door collection of the recyclables. The residents pay the service fee to the collection company directly. 8 of the 15 intelligent collection companies we interviewed had developed such extended service business under their intelligent collection system.

The third source is data profit. ICTs devices adopted in intelligent collection system provide the means to accumulate massive amounts of data of the recyclables being generated and also on residents recycling behavior, these data can be useful for the producers and retailers as they reflect the consumer behavior and their preference. The intelligent collection company can make a profit from mining the data for producer and retailer enterprises. For example, Income company monitors their thousands of PET bottle collection machines that track and analyze the beverage consuming behaviors and can make a considerable profit by reporting the information to the beverage producer.

The last source is policy profit. This refers to the policy anticipation and subsidy income the intelligent collection company can get from the government. The intelligent collection company can accumulate a massive recyclables database, full of information that is important to the government to enable it to make proper policy and take management action. Reporting data to the government can make policy anticipation of the waste management. More importantly, accurate collection data proves the waste reduction contribution of the intelligent collection that is supposed to enjoy subsidies

from the government. For example, Guangzhou municipality had released a policy to support a subsidy of 90 CNY per tonne of low-value recyclables collection to the intelligent collection company. This is because it contributes to the waste source separation and helps to save the public expense on the waste incineration.

Figure 3.8 Multi profit making model of intelligent collection

3.5 DISCUSSION

Section 3.4 reveals that intelligent collection in China has comparative advantages over the informal collection system regarding organization, trade, data accumulation, and profit-making sources. These advantages help to solve partially the social, environmental and efficiency problems associated with the informal collection. This renders the intelligent collection with the potential to assimilate the services of the

informal collection. According to interviews with the selected company managers, there are two approaches for such integration. One is depth integration, in which the intelligent collection company hires the experienced collectors from the informal sector, equips them with smartphones and intelligent devices, and trains them in the methods to carry out the intelligent collection. Any hired collector working as an employee in a company can now enjoy many social insurance and welfare benefits provided by the company. They can see their social status also rises. These are benefits that are absent for a collector in the informal sector. Thus, the integration approach would seem to bring satisfaction to both sides. The other integration approach is improved cooperation between the informal collectors and the companies. Informal collectors can join in the intelligent collection platform, receive collection orders from the intelligent collection server and carry out the door-to-door collections. Most companies we interviewed take the first approach and integrate many collectors from the local informal sector. For example, the HG company integrated 1,233 collectors from Hangzhou, and Income integrated 450 collectors from Beijing.

However, the degree of the integration is still limited, and two observations support this assumption. The first observation is that the informal sector in China is in a state of depression due to various social, economical and population factors. The younger generation is less willing to inherit the small collection business after the old generation collectors retire, given that this sector has a bad social image and a reputation for poor working conditions. The second fact is that the increasing meticulous city planning and management that leaves an ever-decreasing space for the informal collectors to make a living on collection in the city. For example, Beijing is about to

dismiss two million 'lower end industry' people in the latest version of its city planning. The 'lower end industry' includes the wholesale and retail elements of the large-scale free markets, as well as the recycling industry. Several recyclables trading markets were relocated in the remote suburban area or adjacent cities. This increased the informal collection transportation cost. The third fact is the falling price of secondary resources leading to depression of recycling industry and the demise of the collectors whose numbers have decreased as a consequence. According to the China National Recycling Resources Association, three million people in China's informal sector have left the industry since 2015. This has meant massive quantities of recyclable items have had to be dumped into incineration and landfill sites. For example, municipal waste collected that ended up at incineration and landfill sites in Beijing increased by 20% in 2016. This is attributed partially to the loss of informal collectors. Other factors include the shortages in the labor supply and a further decline of secondary material prices. Both these factors are fully recognised by the other author as threats to the future existence of the informal sector in China (Steuer et al., 2018).

The second observation is that the HM collection has become increasingly more applicable. This leaves less room for integrating the informal collectors by means of HH intelligent collection. Many companies started intelligent collection with the HH form by hiring collectors from informal sector to carry out door-to-door collection because HH form shared many similarities with the informal collection that the residents were used to and this was more acceptable to the residents at the beginning. However, the labor cost of HH form is much higher than the HM form, so many companies started to turn to HM collection. Besides, in China, the driving force behind residents recycling behavior

changing sees a move from recycling for financial reward to recycling for environmental protection perception. The cash rewards of the informal collection are losing their attraction to the residents. Instead, the HM form of the intelligent collection has become an interesting and convenient way to recycle. Therefore, we foresee that the degree to which intelligent collection will integrate the informal collection is limited. Intelligent collection is likely to only integrate a small number of informal collectors in the short term, and will very likely replace the informal collection system in the long run.

The rise in private companies operating intelligent collection in China is partly the result of China's government encouragement policy for start-up enterprise in the ICT area since Prime Minister Li Keqiang delivered this message at his speech on the 2015 summer session of World Economic Forum. The approaches of integration still need further exploration and verification of the market response. Also, the economics of the sustainable business model remains in question, as some challenges exist. First, in the current social and economic transition stage of China, people do not pay for their waste generation and collection but sell recyclables for money. This is different to the 'pay as you throw' situation common in developed countries. This leaves less opportunity for intelligent collection to survive. Second, although government recognizes the collection of recyclables does indeed bring benefits for waste source separation and reduction, a favorable subsidy policy is still just a trial in only Guangzhou city and remains under discussion in other cities. This hampers the intelligent collection companies to be able to continue their experimental business. Indeed, some companies have suspended their operations while they await a more substantial and favorable policy from the government.

In the long run, intelligent collection applications seem more promising in two areas. First, intelligent collection acts as a supplement to the formal MSW collection system and does provide a waste sources separation service. Since China president Xi Jinping addressed waste source separation and reduction on many high profile occasions, China's government has created the "Implementation Scheme of MSW Separation System" where 46 pilot cities are required to increase their collection and recycling rate of MSW to 35% by 2020. Local government will likely put more efforts and resources on this issue. Several key intelligent companies are exploring cooperation with local MSW collection systems to improve and achieve their waste separation and reduction target.

Second, the intelligent collection can be combined with the Extended Producer Responsibility (EPR) framework to establish exclusive collection system for special or high resource value waste, such as the WEEEs. In the recently released China EPR work plan, China's government will trial EPR for four products, Electronic and electrical product, vehicle, lead-acid battery, and paper-based beverage package. An intelligent collection platform for lead-acid battery has been trialled within the EPR framework in Shanghai (Wu et al., 2017). Besides, China has established 49 national urban mining pilots (Xue et al., 2017), and many WEEEs recycling plants are operated short of supply because they are collected mainly by the informal sector, and they often trade to illegal plants for a higher price (Chi et al., 2011). The intelligent collection system, combined with the EPR, may provide a solution for the high resource value wastes recycling and urban mining.

3.6 CONCLUSION

The application of ICTs in waste management has helped formulate an intelligent collection model. Intelligent collection in other countries is mostly only at a prototype or experimental stage and with input from public funds. However, many private companies that are operating intelligent collection for recyclables are springing up in China. Compared with the informal collection that has prevailed in past decades, current intelligent collection in China takes two forms: Human-human interaction collection (HH), and Human-machine interaction collection (HM). The intelligent collection has clear comparative advantages over the informal collection regarding the organization, trading and logistics, profit-making sources and massive data accumulation. These advantages render intelligent collection with the potential to integrate or replace the informal collection. One of the general integration approaches is to hire the old informal collectors as the new employees of intelligent collection companies.

The intelligent collection applications for waste management in some European countries is seen as a solution to achieve the newly assigned resource recycling goal under the EU Waste Framework Directive (Rada et al., 2013). In the current transitional status of China, the informal sector is in depression affected by various social, economical and city planning factors. It is foreseen that intelligent collection will assimilate the informal sector only partially in the short term, but will likely replace it in the long run. Intelligent collection in China is still in its early stages. A truly sustainable business model is not clear yet, as economic and policy challenges exist. In the future, intelligent collection application is promising in two areas. First, it can act as a

supplement to the formal MSW collection system helping to reduce the waste source generation and save public expense. Second, it can establish an intelligent collection platform for some high resource value waste items within the EPR framework and help ensure the quantity and quality collection for urban mining.

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CHAPTER 4: HOW URBAN MINING IMPACTS THE SUSTAINABLE DEVELOPMENT OF LESS DEVELOPED BUT EMERGING CITIES AND TOWNS: THE CASE OF JIESHOU IN CHINA⁸

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Abstract:

Normally, urban mining is based on the substantially accumulated social stocks and a large quantity of material flow in a developed city. But urban mining aggregation is also observed in some less developed cities or towns. It contributes major revenue to the city, creates jobs, promotes local industrialization and urbanization, while providing environmental and resource benefits to other cities. We define these locations as Urban Mining (UM) cities and towns. How does urban mining find its place in these less developed cities and towns? What are the driving forces and how do we ensure their sustainable development in the future? This paper takes Jieshou city of China as a showcase to investigate these questions with the help of interviews and material flow analysis methods. The results show that the development of UM towns in less developed regions is driven by various population, cultural and economic factors. Other drivers

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include the negative and positive feedback mechanisms induced by environmental and policy factors. However, urban mining also causes pollution. Therefore, the sustainable development of UM towns requires actions including: integrating the informal collection of waste streams with intelligent and internet tools to ensure quality and quantity of supply; upgrading the technology and equipment to reduce energy consumption and emission of pollution; and, expanding the manufacturing chain with new products to increase the total industrial output value and the economic contribution to the town. The Jieshou case provides lessons and experiences for other UM towns in the world, and shows an example of symbiosis between urban mining and urbanization.

Key words : Urban mining, Recycling, Urbanization, Sustainable development

4.1 INTRODUCTION

Urbanization creates a massive inflow of resources into the cities and towns. Their exploitation and utilization lead to an accumulation of final products and their waste streams in the cities. As a result, cities become a rich mine with high potential of resources (Jacobs, 1969). Urban mining is a metaphorical term, and often used to refer to the recycling of materials from urban society, as opposed to mining primary resources from nature (Brunner and Rechberger, 2004). It produces secondary resources and is proved to have a high potential for natural resource substitution and environmental benefits (Wen et al., 2015). Every city is at a different life cycle stage and exhibits much disparity regarding the urban mining potential and approaches (Brunner, 2011). Older cities, or cities with larger population and high consumption, have evolved large throughput flows of material input and output, thus have a higher potential of urban mining. The newly emerging cities are at an earlier stage of infrastructure construction that, nonetheless, have a massive resource input and is being transformed into the in-use stock of the city. In this case, the output flow is small and offers a lower potential for urban mining in the short term.

Most urban mining studies of cities take developed ones as their object and focus on the potential and approach of mining from the waste flow and stock. The in-use and hibernating stock has accumulated considerably in those cities with a long history (Johansson et al., 2013). For example, obsolete urban infrastructure and cables have a high content of metals resource. However, mining them needs specially-designed approaches (Krook et al., 2015). The waste flow generated from consumption also

provides significant potential for urban mining. Electronic waste (e-waste) from the universities are viewed as distinct urban mines. In the UK alone, 20 tonnes of valuable e-waste were stockpiled, and a further 87 tonnes were 'soon' to be available for exploitation (Ongondo et al., 2015). Together, these resources were valued at USD 11 million (Pierron et al., 2017). Exploiting these urban mines has driven the aggregation and industrialization of the recycling activities. This has led to the formation of specific industrial parks for recycling. For example, the Eco-town program in Japan had motivated the recycling plants to gather together in the urban area to recycle waste from the metropolis (Fujita, 2008). 170 recycling projects were operating in 26 Eco-Towns (Ohnishi et al., 2012), successfully propelling the industrial and urban symbiosis (Van Berkel, Rene et al., 2009).

However, some less developed towns and cities have had a chance to develop urban mining industry. In these cities, the accumulated urban mine stocks and flows are too small in quantity to justify supplying an industrialized and centralized urban mining industry locally, but they seek waste resources from other cities. They establish active collection networks, collect and process the urban mines from the surrounding cities and provinces, and even from further away internationally. The development of the urban mining industry in these cities/towns has contributed major economic revenues and employment. It has also stimulated rapid development of urbanization in these cities and towns. For example, Guiyu, the best-known e-waste dismantling town in South China, annually processes more than one Mt of e-wastes (UNEP, 2005). E-waste recycling has become a pillar industry in Guiyu and the source of household income for the local residents. By 2005, 5,500 family dismantling workshops were operated in Guiyu. This

employed about 60 thousand people, accounting for more than half of the population of the town. They generated an annual output value of nearly 1 billion CNY, accounting for more than 90% of the total industrial output value of the town, and contributed a tax revenue of 10 million CNY (Fang, 2011). But such extensive salvaging operations caused serious environmental pollution and health problems. Soil and underground water resource have become highly contaminated. This has posed a serious threat to the health situation, and even the birth rate (Xing et al., 2009; Xu et al., 2012).

Economically, the city/town is heavily dependent on the urban mining industry, but environmentally, pollution problem rises. This places its sustainable development in question. We call such city/town an 'Urban Mining' (UM) city/town. Urban mining contributes the environmental benefits of waste disposal and secondary resources supply to other cities and regions. It also helps to realize industrialization and urbanization in the city/town and shows the synergy between the urban mining and urbanization. UM cities/towns are common in the developing world experiencing unprecedented urbanization and industrialization process. In the past five years, China's government has selected 49 national urban mining basis pilots to promote and upgrade the urban mining industry in the country (Xue et al., 2017). Eight of the 49 pilots are based in the UM cities/towns. Other than that, there are also dozens of towns and counties in China sharing similar characteristics. This leads to our following research questions:

How does the urban mining industry find its place in UM cities/towns? What are the driving forces of the UM cities/towns? How to ensure sustainable development of the UM cities/towns?

In this paper, we attempt to give some definition of a UM city/town by selecting Jieshou as a typical case city from central China to explore the above questions using interviews and material flow analysis methods. This paper illustrates a typical UM city's development history and its driving forces. It analyses strategies for its future sustainable development, to provide a reference of lessons and experience for other UM cities/towns around the world. It contributes to both urban mining research and urbanization studies.

The paper is structured as follows: section one describes the UM town and the research questions. Section two introduces the profile of Jieshou, and analyses the driving forces. Section three recommends measures for Jieshou's sustainable development using a Pressure-State-Response analysis model. Section four discusses the relevance of the lessons and experience of Jieshou for other UM Towns. Section five concludes the paper.

4.2 UM CITY/TOWN FEATURES AND DRIVING FORCES: THE CASE OF JIESHOU

Our definition of a UM city/town refers to one city/town that is economically dependent on UM industry. It can be manifested by three indicators: 1) the quantity of urban mines assembled in the city/town dominates the surrounding provinces or regions,

2) the urban mining industry processes at least three types of urban mines, including metal and non-metal wastes, 3) the urban mining is industrialized and contributes to at least 50% of the city/town's total industrial output value. Many cities/towns in China satisfy these indicators. We take Jieshou as a case to illustrate its features and analyze the driving forces.

4.2.1 FEATURES OF JIESHOU AS UM CITY/TOWN

Jieshou is a middle-sized city of Anhui province in central China. As shown in Figure 4.1, it is located at the interface of the Yangtzing River Delta Economic Zone and the Central Plains Economic Zone. It lies 304 km distant to Hefei city, the capital of Anhui province, and 280 km to Zhengzhou city, the capital of Henan province. Jieshou has a total area of 667.3 km² with a population of 789 thousand. The urbanization rate is 49.5%, which is lower than the national average urbanization rate of 58.5% (NBS, 2018). Jieshou is an economically less developed city with its GDP per capita in 2015 only 2,515 USD, which is much lower than that of Anhui province (5,404 USD in 2015), ranking it in the last 20% of the total 600 cities nationwide in China.

Figure 4.1 Location of Jieshou in China

Jieshou is a typical UM city considering both the variety and quantity of urban mines, the dominant economic and revenue contribution by the UM, and the high degree of industrialization of the industry.

As for the variety and magnitude of the urban mines assembled, annually 2.8 Mt of lead-acid batteries, copper and aluminum scrap, and waste plastics are collected from a surrounding area of 500 km and transported in Jieshou. In 2015, Jieshou recycled 0.5 Mt of lead acid battery and produced 0.33 Mt secondary lead, which respectively accounted for 16% of the total waste lead-acid battery nationwide (3.1 Mt), and 20% of the total secondary lead produced nationwide (Figure 4.2). There are 2 Mt of waste plastics recycled annually in Jieshou, accounting for 9% of the total amount in China (Figure 4.3). This makes Jieshou the largest plastic waste assembling center in east China. Furthermore, Jieshou also recycled 100 thousand tonnes of copper and 200 thousand

tonnes of aluminum scraps, respectively accounting for 3.6% and 3.8% of nationwide quantity. This makes Jieshou one of 15 national secondary aluminum product bases in China.

Figure 4.2 Secondary lead Jieshou produced and their proportions in China.

Source: Jieshou Statistics Bureau, China Material Recovery Association

Figure 4.3 Waste plastic Jieshou recycled and their proportions in China

Source: Jieshou Statistics Bureau, China Material Recovery Association

From an economic perspective, UM is the pillar industry in Jieshou. As Figure 4.4 shows, the major industries in Jieshou include metal recycling, plastics recycling, textile and garment, food and brewing, machinery manufacture, bio-pharmacy, and others. The industrial output value of metal recycling and plastics recycling together account for a dominant 80% of the total local economic structure in Jieshou.

Figure 4.4 Proportions of Jieshou major industrial output value in 2014

Source: Jieshou Statistics Bureau

Furthermore, UM development in Jieshou is moving towards being industrialized and formed with four specialized UM industrial parks: Tianying, Xicheng, Guangwu, and Yawang. Their profiles are provided in Table 4.1. For example, in 2014, the four parks generated a total industrial output value of 29.8 billion CNY, contributed tax revenue of 926 million CNY and employed 30 thousand people. These 30 thousand people are directly engaged in the recycling operation. Around another 40 thousand people are engaging in UM collection in other cities and transportation for Jieshou. Thus, the UM industry in Jieshou provides 70 thousand jobs accounting for 10% of its total population.

Table 4.1 Economic contribution of four urban mining industrial parks in Jieshou

	Tianying	Xicheng	Guangwu	Yawang
Industrial output value (10 ⁸ CNY)	200.13	28.55	57.89	11
Tax revenue (10 ⁸ CNY)	7.15	0.4	1.55	0.16
Job created	10000	6000	10000	4000
Annual urban mines recycled	500 thousand tonnes lead-acid batteries	200 thousand tonnes aluminum and 100 thousand tonnes of copper	2 Mt of plastics	30-50 thousand tonnes plastics for ropes and strings

Source: Jieshou municipality

Therefore, Jieshou is a typical UM city and a regional hub, given its compliance with the definition and indicators above. A materials metabolism flow analysis of Jieshou reinforces the UM characteristics in the city (Figure 4.5). In 2014, the total amount of material input to the city was 7.064 Mt, of which 3.811 Mt were secondary resources, higher than the primary resources of 3.253 Mt. This character is significantly rare in city metabolism. The total output was 3.78 Mt, of which 3.25 Mt were UM products, consisting of 2.45 Mt of recycled materials and 0.8 Mt of recycled material sold to other places. Together, these account for 80% of the total output of the city. This further illustrates the dominant position of the UM industry in Jieshou.

Figure 4.5 Material metabolism of Jieshou in 2014 (unit: 10,000 tonnes)

4.2.2 DRIVING FORCES OF JIESHOU AS A UM CITY

The Jieshou case can be seen as a microcosm of UM development across China. A variety of social, economic, environmental and policy factors drove Jieshou to develop its UM industry in four stages (Figure 4.6). Stage 1 started in the 1980s when surplus rural labor began to engage in the low threshold and the labor intensive activity of collecting and recycling urban mine products in their family workshops. This primary recycling in small workshops caused a serious pollution problem. Subsequently environmental enforcement came into force and functioned as negative feedback intervention mechanism. UM operations step into the stage 2 of the up-down stage. Since 2005, various national circular economy and UM policies have driven Jieshou

government to intervene positively in its UM. As a result, four industrial parks were established, this is the main feature of stage 3. In stage 4, Jieshou started to consider the circular economy development for the whole city once based on the UM industry, and now moving toward a sustainable circular economy city. More details are given at the following subsection.

Figure 4.6 Urban mining development stages and their driving forces of Jieshou as UM town

4.2.2.1 Cultural factors

The collection of recyclables generated by households is the basis of UM development. In China, recyclable waste has a price in the market. The collector needs to trade or exchange other items with the generator. This requires the collector to have a trading awareness or culture to carry out the collection. A trading culture reputation has existed in Jieshou since at least the Song Dynasty (AD 960-1279). At that time, a handcraft industry of colored pottery developed in Jieshou (Figure 4.7). Today, the Jieshou colored pottery is listed as a national cultural heritage in China. Historically,

Jieshou people manufactured colored pottery and retailed them to adjacent towns using small carts as transport. An indigenous cultural and logistic trade network was accumulated incrementally as a tradition in Jieshou. This provides a good social, cultural basis for the development of UM collection. Nowadays, 40 thousand Jieshou people live in various other cities engaging in the UM collection business.

Figure 4.7 Handcraft of colored pottery produced in Jieshou

Source: Jieshou municipality

4.2.2.2 Population factors

The large rural population provided the labor basis for Jieshou to develop the labor intensive UM industry. Since 1978, when China adopted the economic reform policy and the household responsibility system, this increased the productivity of the farmers and liberated most rural surplus labors from the farmland (Putterman, 1993). Now, these farmers were no longer restricted to work on farmland only. They were

encouraged to take up small commodity processing and trade business to promote the social and economic development of the rural areas of China. Jieshou is located in central China, which is characterized by having a high population but little land and the household responsibility system liberated more labors than other areas. Jieshou people chose UM collection and recycling after they were liberated from the agricultural activity. Initially, they took advantage of indigenous pottery retailing experience and networks to engage in the collection of waste lead-acid batteries. Why lead-acid batteries? Because lead is one of the key ingredients to make color glaze of the pottery. Jieshou people were familiar with lead and its usage since a long time ago. They modified their pottery kilns to smelt and extract lead from the battery.

4.2.2.3 Economic factors

In recent decades, China has experienced the beginning and middle stages of its industrialization process. Metal resources have been in high demand as a result of the massive increase in construction, manufacture, and consumption. UM produces secondary material and provides an important supplement to the primary resource to feed all this increased market demand. This was the economic drive force for Jieshou to become a UM city. Since the 1980s, the colored pottery industry was in recession because the daily used products made of iron or plastics gradually replaced the pottery. Jieshou people started to recycle the waste lead-acid battery in their old pottery workshops. Incrementally, the workshops have aggregated and developed into a complete integral system. The system consisted of the collection, middleman, transportation, and recycling, all of which were carried by Jieshou people. Meanwhile,

people took advantage of the established collection system of the lead-acid battery to collect the cooper and aluminum scraps, as well as the plastics. Thus, more types and quantity of UM flowed and were transported to Jieshou. By the 1990s, 20 thousand Jieshou collectors were active in several provincial areas, and 200 household workshops were scattered across 80% of the Jieshou city area, forming a UM city.

4.2.2.4 Environmental factors

Environmental factors functioned as a negative feedback mechanism for the Jieshou UM city development. The acid-lead battery recycling workshops dispersed in most towns and villages in Jieshou, and used outdated technology and primary equipment. This caused severe pollution problems and affected people's daily life and health. Since the 1990s, acid-lead battery recycling workshops became "the difficulties of environmental governance, the focus of media attention and the hotspot of the public tip-offs," Once upon, they were listed as the primary monitoring objects by the provincial and national environmental authorities. (Jieshou-Government, 2011). Under this situation, in 1998, Jieshou government shut down all these small workshops, except for the 11 large ones, whose annual recycling capacity above 2,000 tonnes. The 11 large plants were relocated to place far away from the residential areas for collective pollution control by the government. The same action took place for the plastics recycling workshops too. However, this occurred in the period when China's economic growth was rapid, and market demand for raw and secondary materials remained strong. This tempted many small workshops owners to take the risk of going back into operation again soon after having been shut down. The UM industry in Jieshou was sustained in

this cycle of 'up and down' following the environmental enforcement actions taken by the government. During this time there was some hardship as Jieshou's industrial output value was greatly affected and dropped down. This was a rare experience against the nationwide status of rapid economy growth.

4.2.2.5 Policy factors

The national circular economy policy and the specific UM policy formulated a positive feedback mechanism for Jieshou UM city development. This provided a new driving force for its two recent development stages. Since the beginning of 21st century, China's government has put much attention and allocated more resources to circular economy initiatives through a variety of policy, regulations, programs, and subsidies (Mcdowall et al., 2017). These include the Suggestions on Speeding Up the Development of Circular Economy in 2005 (CCG, 2005), the Law for the Promotion of the Circular Economy in 2008 (CCG, 2008), the national 12th Five-years Plan (2011 to 2015), and the Circular Economy Development Strategies Action Plan in 2013 (CCG, 2013). Some circular economy pilots at corporate (micro), inter-firm (meso) and societal level (macro) have been selected and supported with tremendous financial aid (Geng and Doberstein, 2008; Geng et al., 2016; Mathews and Tan, 2016; Xue et al., 2018).

The national policy context has provided a significant new perspective for the local government. Jieshou has realized that using suppression intervention alone was not a good way to guard its UM industry. Instead, they thoroughly adopted the circular economy concept as a guide for its UM industry development, and took various actions: 1) compiling circular economy planning for the whole city of Jieshou, 2) allotting land to

establish the four specific industrial parks of Tianying, Guangwu, Xicheng and Yawang (see Table 4.1). 3) spending three billion CNY on the industrial park infrastructure construction and collective pollution control facilities. 4) allocating ten million CNY public funds as subsidy for technological innovation of the enterprises to reduce pollution emission. These actions have largely promoted the local UM industry towards normalized green development.

Meanwhile, Jieshou also actively applied for the national pilots and financial support. In 2007, the Tianying park was listed among the first batch of national circular economy pilots (Jiao and Boons, 2014) with the aim to promote cleaner production and resource recycling in the parks, meet the national target of energy saving and emission reduction, and foster complete industrial chain of lead-acid battery recycling. In 2010, Tianying was again approved as a national UM pilot. The measures to be taken to meet the seven requirements included: systematic waste collection network, proper industrial chain, large scale recycling materials, advanced equipment, shared infrastructure, collective environmental facilities, standard management, and operation system (Xue et al., 2017). The application process for these national credits has largely supported its stage 3 development, focusing on the industrial parks construction.

In 2013, the government of Jieshou expanded attention to the sustainability of the whole city. A circular economy city planning was compiled, and Jieshou was listed as the first batch of national circular economy demonstration cities to apply the circular economy approaches in all social and economic dimensions of the city (Wang, N. et al., 2018). Since then, Jieshou has stepped into stage 4, a thoroughly UM city that is

exploring the journey from a less developed city moving towards sustainable urbanization and industrialization via UM industry development.

4.3 CHALLENGES AND OPTIONS FOR JIESHOU TOWARDS A SUSTAINABLE UM CITY

Jieshou has leapt from an agricultural population intensive city to a UM city as a result of various factors. However, there are still challenges. First, there are environmental capacity limitations. Jieshou is a city facing a shortage of water supply. Its annual water resources per capita are only 303.5 m³. This is much lower than the national average of 2,100 m³ and the world average of 5,000 m³. The surface water and shallow ground water is badly polluted, According to the surface water quality standards of China (see appendix 1), both the surface water quality and the shallow ground water quality in Jieshou are classified as IV to V. Air pollution is also severe. Lead emissions from the lead-acid battery recycling are high. The national environmental authority sets a 330 thousand tonnes ceiling for total secondary lead production in Jieshou. Therefore, the environmental capacity cannot cope with the emissions from the growing UM activities.

The second challenge is what China's new social, economic trends pose to the traditional informal collection model. China is stepping into the late stage of industrialization. Intelligent technology has been applied in many sectors. Intelligent tools are being applied in waste management to formulate a new UM collection model: internet+ collection(Sun et al., 2018; Wang, H. et al., 2018). Meanwhile, the informal

collection is very likely to vanish in the future due to various social, technological and economic reasons (Steuer et al., 2018). This will pose a threat to the present collection model in Jieshou and affect the sustainability of its whole UM industry.

We adopt a Pressure–State–Response (PSR) model in this section to analyze the pressures and states and propose options for a coping strategy. The PSR model is used widely to evaluate resource utilization and sustainable development (Wolfslehner and Vacik, 2008). Its application in Jieshou situation is shown in Figure 4.8. We analyze three parts of the UM industry: collection, recycling, and utilization. The factors are the new challenges emerge from the three parts. The pressure indicators are the facts that influence the UM, the state indicators stand for its status at present, and the response indicators are the options we propose.

Figure 4.8 PSR analysis framework for Jieshou sustainable urban mining

4.3.1 COLLECTION: INTEGRATING INFORMAL COLLECTION WITH INTELLIGENT TOOLS

The collection is a fundamental part of urban mining. The UM aggregation and industrialization development in Jieshou was attributed to its unique collection model relying on its indigenous trading cultural and trading networks. 40 thousand Jieshou people live in other cities collecting the various UM products to supply the recycling plants in Jieshou. These people formulated a sophisticated business network through relative and folk relationship. This formulated a sufficient supply chain for the Jieshou UM industry. However, this collection model is also informal, sharing the same features of the informal collection generally where most collectors work on their own in the form of one-person and one-truck. Such unorganised collection is vulnerable and affected by market price fluctuation. Informal collectors are in the losing trend because the younger generation is less willing to inherit the small collection business once the older generation of collectors retires. Also, the increasingly meticulous city planning and management leave an ever-decreasing space for the informal collectors. So, we foresee that Jieshou will lose its population advantage of the collection. This element can no longer ensure the UM supply to the established four UM industrial parks in the future.

Meanwhile, intelligent collection and internet+ resource recycling model have been emerging in China and have received more favorable policies from national government and venture capital investors. There are now more than 50 intelligent collection businesses that have been operating for two or more years in China (Sun et al., 2018). Considering the fact that Jieshou has been the hub of various urban mines in its region and has its large number of affiliated collectors, we suggest the adoption of the intelligent and internet tools to establish online collection and trading platform of urban mines, and to attract the traditional collector to join in the new collection model

platform. This can reinforce Jieshou as a regional distribution center of UM. The intelligent tools also can be applied exclusively to the lead-acid battery collection and recycling under the Extended Producer Responsibility system. This integrates all stakeholders of the whole industrial chain, including the producer, retailer, collector and recycler to establish one producing-retailing-using-disposing-recycling platform that can ensure the quantity and quality collection of UM for Jieshou (Wu et al., 2017).

4.3.2 RECYCLING: UPGRADING THE TECHNOLOGY AND EQUIPMENT

In the four industrial parks, the urban mines processing and recycling technology and equipment remain much space for improvement, particularly while energy consumption and pollution is still a problem. For example, more than half the metal scrap recycling plants are still small businesses and unable to afford the automatic mechanical equipment for the pre-treatment of dismantling and sorting. Smelting equipment also has a high-energy consumption, but low resource recycling output. The plastic processing enterprises in Guangwu Park mostly use small-scale processing facilities to smash, clean and melt the waste plastics for granulated products. It is an energy intensive process, and the associated air pollution emissions are hard to control.

The straggling quality of the technical equipment causes extra pollution while Jieshou's limited environmental capacity is facing pressure with the increasing quantity of urban mines processed. We suggest that the government of Jieshou keeps investing in the construction and operation of pollution control infrastructure. They should urge for the integration of the enterprises to be able to introduce more advanced technology and upscale machinery equipment, which can help reduce energy consumption and

pollution emission. Other policy measures are also applicable. These include, for example, the elimination of outdated production capacity, stricter access thresholds for the industry, and to reward and subsidize technological innovation and investment in advanced equipment.

4.3.3 UTILIZATION: EXTENDING TO INDUSTRIAL CHAIN TO INCREASE OUTPUT VALUE

High-end utilization of recycled materials is absent in the four parks. This leads to a low output value of the park. Annually 2 Mt of waste plastic is input through Guangwu Park that leads to 1.8 Mt output. However, most of the outputs are low added value products, such as the plastics granulation, plastic basin, and slippers. Only 20% is high added value products, such as textile fibers. The output values per unit of urban mines weight in Guangwu Park are only 3,200 CNY per ton. This is much lower than its counterpart in other regions, such as Cixi, Beiling, and Dingzhou, where it is 7,000-10,000 CNY per ton. Annual inputs of metal scrap to Xicheng park are 300 thousand tonnes. Only 30-40 thousand tonnes output are manufactured products, and the rest are kept and sold as secondary materials. Tianying Park annually produces 330 thousand tonnes of secondary lead; only 36% of this remains in the park for new battery manufacture.

Therefore, UM in Jieshou takes the model of inputting waste, retaining pollution and outputting the materials. The industrial output value is rather low, as well as its contribution to the local economy. We suggest introducing manufacturing plants for high products, based on the secondary materials that are recycled in the park. This will

increase the proportion of high added value products and the total industrial output value. Taking the Tianying Park as an example, we draw options for several lead-based, high value, product chains and recommend the introduction of manufacturing plants for Uninterrupted Power Supply batteries, lead carbon batteries, radiation protection boards and more (see appendix 2).

4.4 DISCUSSION

Driven by the same social and economic factors mentioned in section 4.2.2, many other UM cities/towns in China have been, and are, in the similar situation as Jieshou. Table 4.2 lists several typical UM cities/towns and their profiles. For example, Gengche town is one less developed town in Jiangsu Province. Here, plastics recycling contribute to 85% of the local industrial output values and the public revenue, and 30 thousand people, almost 70% of the town population engaged in the industry (Zhang, 2010). Similarly, the UM industry is the pillar industry in Yujiang city and contributes 54% of the local revenue (Zhao, 2011).

Table 4.2 Some typical UM cities/towns in China and their economic contribution

Typical UM city/town	Population (10 ⁴)	Area (Km ²)	Urban mines assembled	Quantity (10 ⁴ tonne)	GDP contribution	Jobs (10 ⁴)
Yujiang city	38.5	932	Waste plastic	200	54%	3
Miluo city	73.5	1669	Metals scraps, Waste plastic	157	43%	4
Wenan city	50.0	1028	Waste plastic	200	93%	10
Ziya town	2.5	60	Metals scraps, rubbers	150	45%	2
Guiyu town	13.9	52	E-waste	150	90%	6
Gengche Town	3.5	35	Waste plastic	300	85%	3
Dazhou town	7.3	64	Metals scraps	200	90%	3

Source: data collection from various sources

UM development in these cities/towns also causes obvious problems. First, is pollution. Wen'an, in Hebei province, a city 150 km from Beijing, became the largest waste plastic assembling site in north China. But it also "turned from a bucolic agricultural region into a bustling, crowded, and dirty, stinky, noisy environment" (Minter, 2013). Manually dismantling imported WEEEs in Guiyu of Guangdong Province caused severe environmental problems, and even poor health and high neonatal mortality (Song and Li, 2014; Xing et al., 2009; Xu et al., 2012). Second, is the low industrial efficiency problem. Most of the UM plants use outdated technology and equipment and can reclaim only part of the input waste substance. Thus the total recycling rate is rather low. Further manufacturing, based on the recycled materials is absent, causing the total output value of UM to remain low.

The environmental authorities have recognized the severe pollution problem and taken increasingly strict action, including the clamp down on small plants. However, while elimination of the UM industry can stop the pollution emission, it will also stop local economic growth, and even put challenges on the municipal waste management system in the other cities. For example, after many plastic recycling workshops of Wen'an were shut down, the plastic waste being generated in Beijing had nowhere to go and was sent to the incineration and landfill site. This put much pressure on its waste management system capacity and increased the public expense as well. Therefore, we should seek a more sustainable UM development for these UM cities/towns instead of rough intervention, to promote local urbanization and industrialization, while also formulating an urban symbiosis at the macro social level.

Jieshou as a typical UM city, its development can be viewed as a microcosm of the wider UM development in China. It provides lessons and experiences for other cities/towns in China and the other developing world. The experiences include: 1) establishing industrial parks as a basis for enterprise integration and collective pollution control, 2) taking advantage of national support policy for circular economy by applying to become a national pilot, 3) providing direct guidance and subsidies to promote technological innovation and integration to reduce the emission of pollution. Our recommendations to Jieshou's future development are also applicable to other similar cities/towns in China.

4.5 CONCLUSION

Urban mining is normally feasible and operated in social and economically developed cities. But some of China's less developed cities/towns with limited stock and flow can develop the UM industry as their pillar industry and become a UM city/town. UM development in these cities/towns can support their own urbanization and industrialization while offering urban symbiosis benefits to others. Jieshou, as a typical UM city, is a microcosm of UM development in China, and a showcase for sustainable development of other UM cities/towns. The main conclusions are:

1) Being a UM city/town includes these main features: the quantity of urban mines collection in the town dominates in the surrounding provinces or regions. The UM industry processes at least three types of urban mines, including metal and non-metal wastes. The UM is industrialized development and contributes to at least 50% of the total industrial output value of the city/town.

2) The development of UM city/towns in less developed regions in China is driven by population, cultural, and economic factors, and the negative and positive feedback mechanisms induced by environmental and policy factors. At the beginning stage, surplus labor liberated from rural areas with a rich trading culture engage in recycling activity in family workshops. This can drive massive urban mines assembling in the city/town. At a later stage, improved environmental standards and strict enforcement, as well as the encouragement by the circular economy policy, can drive the UM city/town to take more proactive actions, including: establishing specialized UM

industrial parks, merging the small workshops, introducing advanced technology and equipment, and collectively controlling the pollution.

3) Such UM cities/towns also face challenges in the collection, recycling and utilization part of UM industry. Supporting the development toward a sustainable UM city/town requires these actions: integrating the informal collection by intelligent and internet tools to ensure quality and quantity supply of the urban mines, upgrading the technology and equipment to further reduce the energy consumption and pollution emission, and extending the manufacture chain to increase the total industrial output values and its economic contribution to the town.

CHAPTER 5: A PRELIMINARY REVIEW OF THE URBAN MINING PILOT BASES PROGRAM IN CHINA⁹

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Abstract

Waste recycling helps to establish a circular loop of resource flow between production and consumption, achieving a certain symbiosis between the industrial and urban sector. Since more and more resources are accumulated in the urban sector, urban mining as a form of waste recycling in a massive way becomes an outstanding way to achieve industrial and urban symbiosis. In 2010 China initiated a national Urban Mining Pilot Bases (UMPB) program with the objective of developing the recycling industry and relieving environmental and resource constraints. This study aims to provide a policy review of the program. We find that the UMPB program was developed from past circular economy policies, and attains legal assurance from current laws and national plans. But this did not formulate a perfect governance context for its implementation. A

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multi-ministerial cross-management network led to policy conflicts, and recycling-oriented legislation remained absent. These became the main barriers for the good implementation of those urban mining pilots. Comparing with the eco-town program in Japan, it shows that both programs share some similarities of partial policy objectives, but also show variety in the scope of urban symbiosis due to the different problems they focus on and the slightly different policy objectives under the different economic and social development phases.

Keywords: Urban mining, Urban symbiosis, China, Recycling industry.

5.1 INTRODUCTION

Resource supply is an international issue for many countries in the process of urbanization and industrialization. UNEP predicted that the global demand for in-use metal stocks would be increased by 3-9 times if the total world population were to enjoy the same levels of use as industrialized countries (UNEP, 2010). China's outstanding economic growth pattern is resource intensive, having become "the world's factory." Ministry of Land and Resources (MLR) report shows that China's external dependence on imported iron, copper, and aluminum are up to 51.2%, 72% and 47.9% respectively (MLR, 2016).

Recycling is regarded as one important solution to ease the resource depletion in many countries. Recycling rates of 18 metals are estimated exceeding 50%, and those of glass, plastic and other packaging materials even higher than 90% (Graedel, 2011b). Moreover, recycling can also save energy and avoid environmental pollution compared with virgin resource exploitation. Such extraction of secondary resources from urban metabolism is named as urban mining (Krook, 2010; Krook and Baas, 2013). Since urban theorist Jacobs noticed that the cities would become a huge, rich and diverse mine of raw materials (Jacobs, 1969), urban mining has become a metaphorical term for resource recovery from the techno-sphere. Literature suggests that urban mining has various denotations in different contexts. A broader concept includes the landfill mining, mining the tailings, the slags, the dissipations, the hibernations and in-use stocks (Johansson et al., 2013). The urban mining potential of copper and iron will attain 8.1 and 711.6 Mt respectively in 2040. The substitution rate (secondary metals substituting

primary metals) can increase by 25.4 percent and 59.9 percent compared to the status in 2010 (Wen et al., 2015).

In 2010, the Chinese government initiated a national program to establish 50 national Urban Mining Pilots Bases (UMPB) in China. In its official notification, urban mining is defined as recycling waste materials from the major seven waste stream, including the electronic equipment, cables, communication facilities, vehicles, household appliances, electronic products, packaging and scraps (NDRC, 2010). These are obviously classified as end-of-life products of in-use stock. The so named bases are often referring to as industrial parks hosting large scale waste recycling plants including pre-treatment, processing and products manufacturing. In this process, massive resources are recovered from waste and transited into secondary materials and even new products. In 2012, 29 bases recycled 24 Mt of waste and produced 16 Mt of secondary materials with a total market value of 247 billion CNY¹⁰.

Such massive waste recycling establishes a circular loop of material flow between production and consumption, between industry and urban to enable symbioses emerging in the urban sector. The urban symbiosis concept is first introduced by Van Berkel, taking the Japanese eco-town case as an example (Van Berkel, R. et al., 2009), and was followed by several more publications on the same subject (Dong et al., 2014; Geng et al., 2010). Contrary to the intensively studied industrial symbiosis (Chertow, 2000, 2007; Golev et al., 2014; Shi et al., 2010; Van Berkel, 2004), the study of urban

¹⁰ Equivalent to 35.9 billion USD at an exchange rate of 1 USD to 6.88 CNY on 23 May 2017.

ymbiosis is still at an early stage. This paper aims to bring the Chinese urban mining bases case into this rarely studied field, and answers the following question:

What are the typical features as a massive urban symbiosis policy that the Chinese urban mining bases program represents, and to what extent can it be improved?

Data was collected and analyzed by reviewing documents from government and by interviewing policy makers and the pilot bases managers. The paper is organised as follows: after this introduction, section two profiles recycling industry in China, section three introduces the urban mining programs including the management frameworks and the progress of its implementation. Section four presents a policy analysis including the policy evolution and governance context and analyzing those with the help of the Governance Assessment Tool (Bressers et al., 2016). Section five compares the UMPB program with the Japanese eco-town program, and conclusions are in section six.

5.2 DEVELOPMENT OF CHINA'S RECYCLING INDUSTRY

Since the 1980s, some farmers began to engage in recyclable waste resources collection and recycling by establishing recycling workshops in their backyards. They traded and collaborated with each other, gradually cultivated a leading industry in the county, contributing to the local economy and employment. For example, the plastic waste recycling industry in the Gengche town in the Jiangsu province accounted for 80% of the GDP in (Zhao, 2011) total. It also created jobs for the surplus rural labor force of the towns, 70% of the residents of Gengche town worked on waste collection and recycling business, and people from adjacent towns also joined in the industry,

altogether 60,000 jobs were created (Zhang, 2010). Table 5.1 lists some typical recycling industry township/county in China.

Table 5.1 Some typical township or county recycling industry aggregations

Town/county	Recycling industry	Recycling amount per year (10 ⁴ tonnes)	Workers involved (10 ⁴)
Wen'an, Hebei	plastic	200	10.0
Jieshou, Anhui	plastic, lead acid battery	200	5.0
Dazhou, Henan	metals	380	4.5
Guiyu, Guangdong	imported WEEEs	220	6.0
Ziya, Tianjin	imported hardware	150	2.0
Gengche, Jiangsu	plastic	300	3.0

Source: data collection form various sources

The spontaneously developed recycling industry in towns bear some problems. Firstly, there is no layout plan for the household workshops, the wastes are randomly piled up in the open air, and dismantled and processed with poor equipment, imposing environmental and health risk to the workers and local residents. Wen'an in Hebei province, a county 150 km from Beijing, became the largest waste plastic assembling site in the past 20 years but also turned from a bucolic agricultural region into a bustling, crowded, and dirty, stinky, noisy environment (Minter, 2013). Manually dismantling imported WEEEs in Guiyu of Guangdong Province caused severe environmental problems, and even poor health and high neonatal mortality (Song and Li, 2014; Xing et al., 2009; Xu et al., 2012)。

Secondly, recycling in China is mainly driven by market forces and economic profits. Waste metal and paper/cardboard have higher market value and leading to high

collecting and recycling rates, while waste plastic and glass have lower recycling rates, and the collecting and recycling of waste Compact Fluorescent Lamps remain deficient due to little profits and the absence of regulations. Thirdly, because most recycling plants can not afford advanced technology and equipment, they often only reclaim high value metals and discard the compound metals and the difficult to separate ones, resulting in the overall recycling rate staying very low. The WEEEs reclaim rate is only 30% in China, while that of European countries can be as high as 75%. These are not helpful for resource saving and circular economy development set by the central government. Thus Low-end recycling industry needs improvement.

5.3 URBAN MINING PILOT BASES (UMPB) PROGRAM IN CHINA

In 2010, the China National Development and Reform Commission (NDRC) and the Ministry of Finance jointly initiated the UMPB program. The objective stated in the official document is “to implement the Circular Economy Promotion Law, to promote the recycling industry development and help to relief the resource and environmental bottleneck constrains in China.” The goal is to support 30 (later upgraded to 50) national urban mining pilot bases. Through this process, it intends to promote the key waste streams recycling at a large scale with high value production, to develop and spread advanced recycling technology, and to explore the urban mining model and policy mechanism. For this purpose, the program prescribes seven requirements for an ideal urban mining base: systematic waste collection network, proper industrial chain, up-

large scale recycling of materials, advanced equipment, shared infrastructure, collective environmental facilities, and a standard management and operation system.

The prediction of the urban mines' potential and waste stream tracing as well as the spatial distribution of the recycling plants needs in-depth research, but some studies indicate that it is quite promising. The urban mining potential of copper and iron will attain 8.1 and 711.6 Mt respectively in 2040. The substitution rate (secondary metals substituting primary metals) can increase by 25.4 percent and 59.9 percent compared to the status in 2010 (Wen et al., 2015).

5.3.1 SELECTION OF THE PILOT BASES

The pilot bases are selected from the recycling industry parks, and only those parks with annual recycling capacity above 0.3 Mt are eligible to make an application. The selection process consists of four steps: 1) provincial DRCs recommend of local applicants, 2) the applicants draw up and submit their national urban mining pilot base action plans according to the guideline issued by NDRC. The guideline sets a unified format for the action plans, and emphasizes the park's status quo analysis, the target of recycling capacity, and the newly added waste recycling facilities investment projects to achieve the target. 3) NDRC invites experts to evaluate the action plans following certain rating rules, and selects the top scoring applicants as national urban mining pilot bases. The Ministry of Finance will provide subsidies to support the investment of new facilities and equipment as well as collection system. The management procedure of pilot bases selection is illustrated in Figure 5.1.

Figure 5.1 Selection procedure of urban mining pilot bases

PDRC: Provincial Development Reform Commission; NDRC: National Development Reform Commission; MOF: Ministry of Finance

5.3.2 PROGRESS AT PRESENT AND SOME FIRST OBSERVATIONS

During 2010-2015, NDRC called for five batches selection, in total 140 recycling industrial parks made application and only 45 were selected as the national urban mining pilot bases. The 45 selected urban mining pilot bases information are shown in Table 5.2. The overview shows that their total planning area is 275.8 Km², and total planned annual waste recycling capacity is 68.3 Mt. China in total recycled 210 Mt domestic and imported recyclable resources in 2012; the total recycling capacity of 45 urban mining pilot bases can account for one third of this amount, and shows some significance regarding the scale.

Further scanning of these pilot bases shows some disparities between the pilots regarding the planned area and recycling capacity. This is related with their various historic development foundations and with future goals. The Nr. 1 Tianjin Ziya pilot was a town focused on imported hardware waste dismantling and now targets to become a comprehensive industrial park, including dismantling and recycling of WEEEs, waste vehicles, cables, plastics, and cardboards, with a total processing capacity of 3.4 Mt. The planned pilot area also includes the agricultural and residential areas, in total 135 km², and a new town. The Nr. 2 Anhui Jieshou pilot is developed from an acid lead battery recycling aggregation. It is a specifically urban mining industry park focusing on a single waste stream. Due to the national total emission control limitation policy of SO₂, the pilot cannot plan more than 0.5 Mt of capacity.

Table 5.2 Profile of the 45 approved national urban mining pilot bases

Nr	Name	Planned area (km ²)	Total investment (billion CNY)	Recycled in 2012 (10 ⁶ tonne)	Planning capacity (10 ⁶ tonne)
1	Tianjin Ziya	135	19.8	1.53	3.4
2	Anhui Jieshou	10	10	0.48	0.5
3	Hunan Miluo	18	17.8	1.57	4.0
4	Guangdong Qingyuan	2.7	0.7	0.49	1.2
5	Sichuan Xinan	3.3	0.9	1.03	1.9
6	Qingdao Xintiandi	5.0	1.0	0.37	0.9
7	Zhejiang Ningbo	1.4	5.0	0.4	0.6
8	Shanghai Yanlongji	0.1	0.8	0.49	0.8
9	Guangxi Wuzhou	6.7	15	1.5	1.8
10	Jiangsu Pizhou	4.3	2.0	0.4	0.9
11	Shandong Linyi	1.5	1.1	1.2	3.0
12	Chongqing Yongchuan	2.5	1.5	0.88	0.9
13	Zhejiang Tonglu	8	1.5	1	1.0
14	Hubei Gucheng	10	2.4	1.63	2.8
15	Daliang Eco-park	12	18	0.7	1.9
16	Jiangxi Xinyu	4.2	2.5	2.0	3.3
17	Hebei Tangshan	1.1	0.7	0.65	1.0
18	Henan Dazhou	10	10.6	2.3	3.5
19	Fujian Huamin	2.3	1.3	0.4	0.3
20	Ningxia Lingwu	6.7	9.0	1.0	2.1
21	Beijing Lvmeng	0.3	1.0	0.75	1.3
22	Liaoning Donggang	8.2	6.0	0.45	0.9
23	Foshan Yingjia	0.8	2.9	0.58	1.3
24	Anhui Chuzhou	3.8	2.5	0.2	1.0
25	Xinjiang Nanjiang	0.8	1.5	0.4	0.6
26	Shanxi Jitianli	2.7	1.5	0.2	0.5
27	Heilongjiang Dongbu	3.8	0.5	0.37	0.6
28	Hunan Yongxing	4.2	20	0.53	1.4

29	Jilin Gaoxin	2.0	1.3	0.5	0.8
30	Hubei Gelinmei	0.4	4.2	-	1.6
31	Jiangxi Yingtan	10	3.5	-	1.8
32	Jiangsu Rudong	16.6	6.5	-	1.5
33	Zhejiang Taizhou	4.4	10	-	3.0
34	Hebei Zhonghang	0.7	3.3	-	0.3
35	Sichuan Baohe	3.3	5.0	-	1.7
36	Henan Luoyang	5.9	3.5	-	0.3
37	Guiyang Baiyun	2.2	2.8	-	1.4
38	Fujian Haixi	0.9	3.4	-	2.0
39	Fujian Xiamen	0.4	0.4	-	0.4
40	Shandong Yantai	3.2	2.5	-	5.0
41	Inner Mongolia Baotou	20	26	-	0.8
42	Gansu Lanzhou	14.1	3.2	-	0.8
43	Xinjiang Kelamayi	30	9.0	-	0.5
44	Heilongjiang Haerbin	5.5	5.9	-	2.0
45	Guangxi Yulin	2.0	0.5	-	1.5
Total		390.8	248.4	24	68.3

Source: data collection from several sources

Figure 5.2 shows the locations of the 45 pilot bases, mainly located at the east coastal and middle region of China. Two factors explain this. First, the industrial development and population are concentrated in the eastern and central regions, leading to high demand for waste generation and processing as well as for resources. This favours the development of the labor-intensive recycling industry, especially in the provinces of Anhui, Henan, Hebei with a large population. Secondly, coastal areas hold many harbors, though which the waste resources get imported or smuggled in, thus favors the growth of dismantling and recycling industry in the costal area. Several urban

mining pilots like Tianjin Ziya and Guangdong Qingyuan are developed on such importing and dismantling of wires and cables, WEEEs, and waste metals.

Figure 5.2 Location of 45 national urban mining pilots bases

However, the selection of the 45 urban mining pilots was only based on their industry development planning. It hasn't considered the location distribution issue. Because the inputs for an urban mining pilot are the recyclable waste resources from nearby cities, the waste generation and supply is much related to the local economic development level, and the consumption habits of the people. Urban mining pilots cannot be located too nearby each other, to avoid waste supply competition problems. Figure 5.2 shows that there are seven pairs of pilots located nearby each other, their transportation distances are under 200 km. If they focus on similar recycling streams, there must be a potential risk of competition for waste supply. Table 5.3 compares the

seven adjacent pilots' similarities and finds that three adjacent pairs of pilots bear such problems.

Table 5.3 Mutual distances of seven pare pilots are less than 200 km.

Adjacent pilots	Distance	The similarity of their recycling industry
Xiamen &Quanzhou	100 km	Same recycling industry, but different waste resources, middle similarity.
Yongchuan &Neijiang	112 km	Both are comprehensive recycling industry parks, high similarity.
Jingmen &Xiangyang	124 km	Different waste streams focused on, low similarity.
Beijing Tianjin Tangshan	125 km	Three are comprehensive recycling industry, high similarity
Nantong & Shanghai	128 km	One comprehensive and the other is specific glass recycling park, low similarity
Taizhou & Ningbo	174 km	Middle similarity
Linyi & Xuzhou	198 km	Middle similarity

In summary, some first observations on the 45 urban mining pilots are : 1) the 45 urban mining pilots bases accounts for one third of the total collected and imported recyclable resources, thus have a high significance. 2) There are many disparities between the pilots in terms of the planned capacity and scale, some are targeting to become a comprehensive recycling industrial park, and some are focused on specific waste streams. 3) The selection of the urban mining pilots has neglected the geographical distribution issue, resulting in seven pairs of pilots that are located within 200 km from each other, and some of them have a similar industry planning, thus leading to a high risk of waste resource competition in the future. The overall management of these urban mining pilots should coordinate the capacity planning among the pilots.

5.4 THE POLICY ANALYSIS

This section presents a policy analysis of the UMPB program. We firstly review other relevant policies and find the policy evolution path, and then profile its policy network which featured with a multi-ministries cross-management system. Finally, we apply governance contextual analysis tool to find the supportiveness of the current governance structure for the program.

5.4.1 POLICY EVOLUTION OF THE URBAN MINING PROGRAM

The urban mining program is an important initiative for developing the circular economy in China. Review of circular economy relevant policy suggests that the urban mining initiative is not isolated, but is built upon other policies. It also shows that the driving forces of waste recycling management in China are moving from environmental and recycling angles to resource strategies concerns. The circular economy concept was first officially introduced by the Ministry of Environmental Protection (MEP) in 2002, but soon included in the profile of NDRC authorities. Table 5.4 lists all circular economy relevant policies since then.

Table 5.4 Relevant national circular economy policies and programs

National programs	Year started	Ministry in charge	Policy Focus	Results so far
Eco-industrial park	2003	MEP	Recognize eco-industrial parks	26 were accomplished, 59 were in the application procedure
Circle zone management initiative	2004	MEP	Improve environmental management of waste recycling assembling area	19 Pilots were selected
The circular economy demonstration program	2005 2007	NDRC	Key industries, industrial parks, province, and cities.	178 demonstration projects were accomplished.
Urban mining pilot bases program	2010	NDRC	Supports 50 pilots bases	45 pilots selected
Industrial park circularized development program	2012	NDRC	Supports 100 industrial parks to implement circular economy projects	67 industrial parks were selected
Circular cities demonstration program	2013	NDRC	Supports 100 cities	First batches 40 cities were selected

Source: Data collection from several sources

In 2004, Ministry of Environmental Protection (MEP) initiated a circle zone management for the assembling area of imported waste recycling workshops (mainly wastes of electric wire, cable, machinery, and equipment). The objective was to improve the environmental management in the area. 19 Pilots were selected, instruments to

monitor imported waste licenses and total control, as well as environmental technology planning was introduced to improve in total 627 enterprises.

In 2005 and 2007, NDRC with other five ministries jointly initiated two batches of circular economy pilots, in total supporting 178 pilots to practice waste reduction, recycling and recovery projects (Jiao and Boons, 2014). Among these pilots, some waste recycling projects were included in the first batch such as renewable resource collection and recycling, waste metals recovery, WEEE, and remanufacturing. The second batches list several renewable resource recycling industrial parks, e.g., Tianjin Ziya and Anhui Jieshou, which were naturally selected as urban mining pilot bases in 2010.

The above two initiatives addressed different issues of recycling. The Circular Economy Pilots explored various circular economy models at wide-ranging fields and industries. A total of 178 pilots including enterprises, industrial parks, provinces and cities, of which 9 circular economy pilot parks were further selected as pilots in urban mining pilot bases program in 2010. The circle zone management initiative targeted on environmental issues of the recycling companies. There are only 19 pilots but 10 of which were also selected as urban mining pilot bases later. 16 UMPBs enjoyed the circle zone management policy or circular economy pilots before they were listed as urban mining pilot bases (see Table 5.5).

Table 5.5 Some urban mining bases are developed from the circular economy pilot and circle zone management pilots

Nr.	Urban mining pilot bases	Approved as urban mining pilot bases	Approved as circular economy pilots	Approved as circle zone pilots
1	Tianjin Ziya	2010	2007	2007
2	Anhui Jieshou	2010	2007	-
3	Hunan Miluo	2010	2005	-
4	Guangdong Huayuan	2010	2005	-
7	Zhejiang Ningbo	2010	2007	-
9	Guangxi Wuzhou	2011	-	2010
15	Dalian Eco-park	2011	-	2012
18	Henan Dazhou	2011	2007	-
22	Liaoning Donggang	2011	-	2010
28	Hunan Yongxin	2012	2007	-
31	Jiangxi Yingtan	2013	2005	2009
32	Jiangsu Rudong	2013	-	2011
33	Zhejiang Taizhou	2013	-	2008
40	Shandong Yantai	2014	-	2007
41	Inner Mongolia Baotou	2014	2005	-
45	Guangxi Yulin	2014	-	2008

Source: Data collection from several sources

The urban mining program has the dual objectives of industrial development and reducing environmental and resources constrains, but its resource strategy is more obvious as it sets an annual capacity threshold of 0.3 Mt for the applicants. Figure 5.3 illustrates the policy evolution path of urban mining policy. It shows the driving forces of waste recycling management in China moved from environmental and recycling angles to resource strategies at UMPB program, and then to a integration of three aspects in

2013 when NDRC initiated 100 circular pilot cities program to promote comprehensive circular economy development of industrial, agricultural, society sectors in cities (NDRC, 2013). Till then, China is moving forward to a more comprehensive urban symbiosis stage.

Figure 5.3 Policy evolution path of urban mining policy

5.4.2 THE GOVERNANCE OF IMPLEMENTING THE UMPB PROGRAM

The urban mining policy has evolved from the previous relevant circular economy policies but is also supported by a more comprehensive policy framework. Together they define the policy network (see Figure 5.4). The term policy network is here not confined to the relevant actors, but also the policies, institutions, and resources that form the context of the policy implementation. This is also labelled as the “governance” context (Bressers and Kuks, 2004).

Figure 5.4 Legal framework of UMBP program

Firstly, at the regulation level, the Circular Economy Promotion Law promulgated in 2009, provides a regulation basis for all circular economy planning and pilot programs including the urban mining program (Su et al., 2013). Secondly, at the planning level, the 12th national Five Years Plan (FYP) sets the target to increase resource productivity by 15%. This is the first time for China that a FYP sets the target on resources and recycling. Following that, the NDRC has drawn up a circular economy development strategy and action plan, which lists major tasks such as the top 10 Circular Economy (CE) pilot projects, 100 CE pilot cities and 1000 CE pilot enterprises and parks. The urban mining pilot bases program is emphasized in the plan. There are other special plans that also support and embody the urban mining program (Table 5.6).

Table 5.6 Several 12th FYP special plans reinforce the urban mining pilot bases program

	Ministry in charge	Special Plans	Main tasks listed in the plans relevant to urban mining and resource recycling
2011	State council	12 th FYP action plan for energy saving and emission reduction	100 resource comprehensive utilization bases 80 waste collection pilot cities 50 urban mining pilot bases 5 remanufacture assemble area 100 food waste management pilots
2011	NDRC	Guidelines for comprehensive resource utilization of 12 th FYP.	Increase renewable resource collection rate to 70%. Increase secondary cooper, aluminum and lead production to 40%, 30%, 40% of the total production respectively.
2012	Ministry of science and technology	12 th FYP special plan of waste recycling technology projects	Priorities filed include: resource recycling technologies of metals, WEEEs, polymer, and electric machine remanufacturing.
2012	State Council	12 th FYP special plan of energy saving and environmental industry development	Support 50 urban mining pilot bases; Support waste collection, recycling industrial chain, environmental pollution remediation infrastructure, and platform, large scale, and high value resource recycling.
2012	State Council	12 th FYP special plan of national strategic emerging industries development	Support some urban mining pilot bases, and improve the recycling technology and equipment manufacture level of waste metals, rubble, tire, battery, etc. al.
2012	State Council	12 th FYP special plan of energy saving and emission reduction	Implement key projects of comprehensive resource utilization, waste collection, urban mining, remanufacture, food waste management, industrial park circular reform, technology spreading.

2013	State Council	Circular economy development strategy and short term action plan	Top 10 pilot projects: waste collection pilots, 50 urban mining pilot bases. 100 CE pilot cities; 1000 CE pilot business/industrial parks.
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Lastly, the urban mining program also receives financial support. The Ministry of Finance established a circular economy fund, to support projects in six sectors, which include: urban mining pilot bases program, food waste management, industrial park circularity transition, remanufacture, cleaner production technology promotion, and circular economy infrastructure. The fund provides 10% of the total investment ratified in the urban mining pilot bases action plan as subsidy. About 4 billion CNY has been ensured for the urban mining pilot bases; every pilot base can receive an average of 0.1 billion CNY for the projects construction.

However, while the current urban mining policy framework looks sufficiently supportive in terms of policy and planning context and resource allocation, there are still some issues to be improved.

The single urban mining pilot bases program covers seven major types of waste. It tries to establish a comprehensive platform for waste recycling. Comparing with the EU waste management legal framework (see table 5.7), the EU sometimes deploys specific directives to regulate specific waste management streams. But the target of China's urban mining policy is not the waste itself but industrial park, which provides a platform for large scale and high value recycling production. Therefore, it also needs other policy mechanism such as pollution control, recycling licenses, industry access,

waste collection system, financing and industry chain cultivation et al. Because different wastes are under different ministry's jurisdictions, this leads to a complex urban mining policy network consisting of multiple ministries and multiple waste streams (see Figure 5.5).

Table 5.7 Legal framework of China UMPB and EU waste management

Waste streams covered by China UMPB program	Corresponding EU directives
Electronic equipment	Directive on WEEE (2002/96/EC)
Cables	Directive on WEEE (2002/96/EC)
Communication facilities	Directive on WEEE (2002/96/EC)
Household appliances	Directive on WEEE (2002/96/EC)
Electronic products	Directive on WEEE (2002/96/EC)
Packaging and scraps	Directive on Packaging and Packaging Waste (1994/62/EC)
End-of-Life Vehicle	Directive on End-of-Life Vehicle 2000/53/EC

Figure 5.5 A complex urban mining policy network consisting of multiple ministries cross-management

MOF: Ministry of Finance; MEP: Ministry of Environmental Protection; NDRC: National Development and Reform Commission; MIIT: Ministry of Industry and Information Technology; MOFCOM: Ministry of Commerce.

In this multi-ministerial cross-management network, policy conflicts occur in many cases. The collection, recycling, and pollution control parts are under different ministries' jurisdictions. Some planned recycling facilities can be hindered by license applications from other departments, and even undermined due to short supply of waste resources.

The absence of a specific waste management law is another shortage in the current governance context of implementing the urban mining policy. Particularly waste collection is not supported by regulation but only relies on free market mechanisms. This

leads to several problems. Waste streams can be transported more than 500 km to the highest price buyer while nearby plants are in short supply, thus eco-efficiency is not assured.

Currently, the policy effects of the urban mining pilot bases program are not coordinated with the waste WEEE policy. Since 2012, the Ministry of Environmental Protection initiated a waste WEEE recycling and management program. A fair WEEE fund and management system has been established, and 106 WEEE dismantling enterprises are listed to receive subsidies. However, only a few enterprises are located in the current 45 urban mining pilot bases, therefore the two policies have little mutually supportive influence on one another.

All in all, the current urban mining governance context only provides a platform for the urban mining recycling activities, some policy conflicts still occur, special regulations are absent, so inter-ministerial coordination and policy integration is needed to develop an overall institutional design for urban mining in China. Consequently, specific recycling oriented regulations are in need to assure sufficient waste supply for the urban mining industry development. Lastly, coordination between ministries and policy integration are needed to implement the urban mining pilot bases policy goal of resolving resource bottleneck constraints.

5.4.3 ANALYZING THE SUPPORTIVENESS OF THE GOVERNANCE CONTEXT

Above we have shown that the urban mining policy, in fact, originates from many policies and with many governmental stakeholders. It attempts to harmonize those in an

over-all platform. Bressers and Kuks (2004) state that under these conditions two criteria determine the degree to which the governance context, including the network context, is supportive for the implementation. The criteria are defined by the questions that they pose to the five dimensions of governance (administrative levels and geographical scales, actors and networks, problem perspectives and goal ambitions, strategies and instruments, and responsibilities and resources for implementation):

1. *Extent*: are all elements in the five dimensions that are relevant for the policy or project that is focused on taken into account? Or are essential ones lacking?

2. *Coherence*: are the elements in the dimensions of governance reinforcing rather than contradicting each other?

Sufficient extent and coherence together form genuine policy integration. Just having sufficient extent, being complete, is not enough. However: lack of extent can be one of the sources of lack of coherence.

In later theoretical development and empirical studies two extra criteria were added:

3. *Flexibility*: are multiple roads to the goals, depending on opportunities and threats as they arise, permitted and supported?

4. *Intensity*: how strongly do the elements in the dimensions of governance urge changes in the status quo or in current developments?

For each of the five dimensions of governance, the four criteria mentioned above can be applied, which forms a matrix. This matrix forms the core of the *Governance*

Assessment Tool (GAT)(Bressers et al., 2016). Together, the questions in each cell shed light on the degree of supportiveness or restrictiveness of the governance context towards the implementation of policies and projects. Note that not the implementation and success of the program itself is evaluated, but the degree to which the governance context is supportive for such success.

While the early assessment of the governance context as described in the sections above does not provide detailed information on all the twenty separate cells, it is possible to systematically analyse the governance context for the implementation of the urban mining pilot bases program with the criteria of the Governance Assessment Tool.

Extent: high level of involvement, but some elements are still lacking

The selection process involved both upper and lower levels in a sort of top-down bottom-up interaction. Also, the potential bases themselves were involved. This selection process has however not resulted in an optimal geographical spread of pilot sites. Among the problem perspectives obviously such geographical scope has been missing.

The absence of a specific waste management law is another shortage in the current policy governance context. Particularly waste collection is not supported by regulation but only relies on free market mechanisms. This leads to several problems, as waste can be transported more than 500 km to the highest price buyer while nearby plants are in short supply, thus eco-efficiency is not assured, and extra unnecessary

pollution is likely. While reducing these was an important purpose of the national program, these shortages affect the core of the policy.

Coherence: both reinforcing and contradicting forces

On the positive side, the urban mining pilot bases program is very well embedded in the general Circular Economy policies, laws and plans of China. Equally positive is that the development of those policies and plans goes consistently into the direction of more comprehensive strategies, for instance with the recent 100 circular city pilots program.

On the other hand, the broad scope of the program, involving various waste streams and stages of processing, also creates coherence issues. It requires a multi-ministerial cross-management network while the collection, recycling, and pollution control parts are under different ministries' jurisdictions. They are not always geared towards mutual cooperation. As a consequence, in many cases, policy conflicts occur.

While the geographical distribution of the pilots is not optimized, it is possible that in some cases competition for waste streams occurs, leading to transports and pollution hazards.

While the waste WEEEs policy is not coordinated with the urban mining pilot bases program, only a few enterprises are located in the current 45 urban mining pilot bases. Thus the potential for reinforcing of the two programs is underused.

Flexibility: the test is yet to come

The criterion of flexibility is an important governance asset in situations in which the field develops in a dynamic way, and thus adaptive responses to these changes are

required to keep the original goals feasible. It can be predicted that such developments are bound to occur in the future. One might think of technological developments in waste separation and processing, or of developments in the supply of waste streams and demands for materials due to technological and economic forces like the gradual transition towards a service oriented economy. As the implementation of the program is still under development the test whether it is capable of allowing and supporting a sufficient degree of flexibility to the bases to cope with such changes while keeping the objectives up, is yet to come.

Intensity: high level of policy support

While the urban mining pilot bases program is one of the spearheads of the circular economy policy turn that China is pursuing, even supported by the 12th FYP, it has a high level of policy support that makes it difficult to ignore. The sheer size of the effort to create a nationwide innovative system testifies this. Whether the level of finance (10% subsidy) is sufficient to enable the pilots to flourish remains to be seen. Probably solving the issues mentioned under extent and coherence is as important as that and will also require continuously strong high-level policy support.

Highlights

The systematic analysis of the governance context above confirms the picture of the previous section. While the intensity of the program is quite high, the institutional organization created a medium level of extent and coherence. Whether flexibility will prove sufficient is too early to tell. Actually this picture is not uncommon for an innovative program. By its nature, it has to obtain a position among many existing and

more established policies and government organizations. Only an open eye for its remaining inconsistencies and a continuation of its high level support can make the situation develop into an even more supportive governance context, for instance by taking the measure mentioned at the end of the previous section.

An open mind includes a desire to learn from previous examples. Therefore, the next section will compare the Chinese program with a program that Japan started already in the late nineties.

5.5 COMPARISON WITH THE ECO-TOWN PROGRAM IN JAPAN

Facing a similar waste and resources problem as China did later when developing economically, Japan initiated its eco-town program in 1997 with two aims: to extend landfill site life and to revitalize local industry. Local governments formulated eco-town plans and submitted them to the ministries for approval and endorsement. Ministries provided grants to local authorities to execute the town planning, community recycling, and outreach activities, and subsidies to private companies to invest in the recycling projects (Van Berkel, R. et al., 2009). During 10 years of operation, 26 eco-towns are endorsed, 205 projects were invested in and started in operation. The eco-towns are classified into three types: promotion of environmental industries, treatment of wastes, and community development. The projects are mainly focused on plastic recycling as the largest waste stream, and food and electronic waste recycling (Ohnishi et al., 2012). The program has been proven successful. It not only contributed to diversification and sophistication of recycling technologies such as metal recovery and high grade recycling options for plastics, but also had a broader impact as eco-towns are regarded as

industrial recycling clusters with extensive cooperation among different companies in Japan's Second Fundamental Plan for Establishing a Sound Material- Cycle Society (OECD, 2011). Table 5.8 summaries comparative information between Japan's eco-towns program and the urban mining bases program in China.

Table 5.8 Comparison between Japan's eco-town program and China's urban mining program

	Japan Eco-town program	China Urban mining program
Time	1997-2006	2010-2015
Policy objectives	<ul style="list-style-type: none"> -stimulating new industrial development; -addressing waste management issues. 	<ul style="list-style-type: none"> -stimulating new industrial development ; -help relief environmental and resource bottleneck.
Ministries in charge	<ul style="list-style-type: none"> -Ministry of Environment (MoE), -Ministry of Economy, -Trade and Industry (METI) 	<ul style="list-style-type: none"> -National Development and Reform Commission (NDRC)
Legal bases	<ul style="list-style-type: none"> -Basic Law for Establishing the Recycling Society; -National planning; -Specific laws (2002-2003) 	<ul style="list-style-type: none"> -Circular Economy Promotion Law as general law; -12th FYP and specific plans; -Absence of specific laws.
Result	<ul style="list-style-type: none"> -26 eco-towns endorsed; -205 projects(170 were recycling and recovery projects in operation, of which 61 received subsidies) 	<ul style="list-style-type: none"> -Target to support 50 bases, 45 are already recognized, and 5 more to come.
Investment and subsidies	<ul style="list-style-type: none"> -Grants to local government for planning execution activities, 50% of project costs in the range of 3–5 million JPY/year (30–50,000 USD/yr.) for a 3 to 5-year period. -Subsidy to companies for recycling plants at averagely 36% of the investment (total investment 1.65 billion USD), total subsidy 59 billion JPY(approximately 590 million USD) spent. 	<ul style="list-style-type: none"> -No grants to local authorities, ; -Total projects investment is 192.3 billion CNY (approximately 32 billion USD). Subsidy is 10% of total investment in every urban mining base, 4 billion CNY (approximately 666 million USD) ratified for 45 bases.
Project types	<ul style="list-style-type: none"> -Software projects of the community and outreach activate. -Plants projects include plastic recycling projects as the largest group and food and electronic waste recycling projects 	<ul style="list-style-type: none"> -Software projects include waste collection system and waste information platform projects. -Other major projects include recycling plants of waste metals,

		electronics, vehicles and tires, plastics, etc.; no food waste stream.
Effects and impacts	<ul style="list-style-type: none"> -It contributed to recycling technology development. -Eco-towns are recognized as industrial recycling clusters with extensive cooperation among different companies in the Second Fundamental Plan for Establishing a Sound Material-Cycle Society. 	<ul style="list-style-type: none"> -It is still early to do program evaluation, but some effects already occur. The program helps to upgrade recycling technology and equipment, integrate waste collection systems and the industrial chains in some bases. Assembling and up scaling waste recycling also generates environment impacts.

Source: Eco-town program information is adapted from(Fujita, 2008; GEF, 2005; Sato et al., 2004; Van Berkel, R. et al., 2009)

Although the eco-town program targets at the city level, while the urban mining program is targeting at industrial park level, it is still worthwhile to compare the pair, as both programs support the same category of recycling projects: recycling waste from urban life. This makes them sharing a similarity in terms of urban symbiosis. The total capacity of eco-towns’ recycling projects is almost 2 Mt per year, and China’s urban mining bases planned capacity is 66 Mt per year. Other similarities include that both programs share the same objective to bloom the recycling industry development, and share the same national policy background of striving for a circular society.

Still, both programs also present diversities of the urban symbiosis, these include:

1) Recycling projects in the eco-town program are mainly focused on the municipal waste recycling such as plastics, food waste, and electric waste, while China’s urban mining bases program supports the recycling plants of electronic equipment and products, cables, vehicles and tires, packaging, etc. Municipally generated food wastes are not included but covered by another national initiative. This is related to the different

policy objectives between two programs. The eco-town program is to extend the service life of landfilling site and to cultivate local industry, while the urban mining program is to promote the recycling industry development for resource and environmental concerns.

2) The slight difference in policy background and policy objectives also causes that the scope of urban symbiosis in both programs is different. Recycling projects in the eco-town program are mainly processing waste from local and nearby cities. The recycling boundaries of China's urban mining bases can extend to provinces at 500 km away. Moreover, some recycling plants in Japan are facing a shortage of waste supply because of exporting to Chinese plants. The scope of urban symbiosis in China has a larger scope than Japan. But eco-efficiency of both large and small scope urban symbiosis need further study.

3) Several factors contribute to the success of the eco-town program, but the recycling-oriented legislation is conceived as a most important one to assure sufficient supply of waste to the recycling plants (Van Berkel, R. et al., 2009). The Waste Management Law (2003) sets aims and objectives for waste management. The Law for Promotion of Effective Utilization of Resources (2001) designated key products and industries for resource saving. Besides, the Law for Promotion of Sorting, Collection and Recycling of Containers and Packaging (2000), the Law for Recycling of Specific Kinds of Home Appliances (2001), the Construction Materials Recycling Act (2002), the Food Recycling Law (2003) and the Domestic Automobile Recycling Law (2003), all set very specific recycling goals (Morioka et al., 2005). These recycling-oriented legislations are still absent in China's legal framework.

In summary, the similarity between the eco-town program and the urban mining program is based on their joint focus on urban symbiosis. The differences between both programs indicate their different background and different policy objectives. Industry development for resources is the core feature of China's urban mining program, and waste management is attached to the eco-town program. This leads to different results of small scope urban symbiosis in Japan and large scope urban symbiosis in China. And it is too early to conclude which one is more eco-efficient.

The eco-town program is a proven success, for contributing to recycling technology diversification and sophistication, and while being recognized in the later Japan Second Fundamental Plan for Establishing a Sound Material- Cycle Society. While it is too early to evaluate the urban mining program, already some obvious effects are appearing. Firstly, it helps technology and equipment upgrading. Jieshou, a specialized waste Lead-Acid Battery recycling park, discarded hand-dismantling equipment and deployed the most advanced automatic production line, vastly improving the efficiency and reducing environmental and health risks. Secondly, it promotes extending of industrial recycling chains. Many bases planned facilities for a new production by using recycled materials. Also, some bases expand the waste resource collection systems to ensure waste supply for the recycling plants. All these improvements are attributed to the urban mining program that provides a platform and subsidies for massive resource recycling. Last but not least, the environment effect is obvious when the technology and equipment are upgraded and when waste recycling quantities are increased.

5.6 CONCLUSION

Urban symbiosis taking recycling as main activity links efficient material flows between production and consumption, the industry sector and urban sector. China's urban mining pilot bases program promotes the recycling industry developing toward large scale, advanced technology and high value recycling practice to help to relieve environmental and resource bottleneck constraints. The current 45 pilot bases, with a planned 6,600 Mt per year of capacity, indicate that a massive urban symbiosis effort is taking place in China.

This paper provides a preliminary review of the urban mining pilot bases profile by analyzing its policy evolution path and the policies in which it is located. It finds that China's urban mining bases program is developed from past circular economy policies, including the circular economy pilot program and circular zone management program. It shows that the driving forces of waste recycling management in China is moving from an environmental and recycling angle to resource strategies. The program attains legal assurance from the circular economy promotion law and support from the national 12th FYP and specific plans, as well as subsidies from the circular economy fund. But this does not yet create a perfect governance context for its implementation. On the contrary, a multi-ministerial cross-management network is currently implementing the urban mining pilot bases program. In this network, incoherencies create, policy conflicts occur, and recycling-oriented legislation is absent, thus becoming main barriers for the urban mining program and especially its waste collection requirements.

Comparing with the eco-town program in Japan, the urban mining program shares the partial policy objective to promote industry development. But waste management and environmental amenity is another driving force for the eco-town program, while optimizing the resource strategy is for the urban mining program. This leads to the differently focused recycling projects and recycling area boundaries between the two programs. Therefore, China's urban mining program is regarded as a large scope urban symbiosis program and Japan's eco-town as a local scope urban symbiosis. Such difference is attributed to the different problems they attack and the slightly different policy objectives under different economic development phases. The resulting eco-efficiency of both forms is a future study subject.

It is too early to evaluate the urban mining program, still some obvious effects are already appearing. The recycling technology and equipment improved, industrial recycling chains extended up to collection part and down to production part, and environmental effects are observed. As it stimulates massive recycling activities, the urban mining pilot program will help with environmental and resource constraints. However, more inter-ministerial coordination and policy integration is needed to develop the governance context into a top institutional design for sustainable urban mining in China.

CHAPTER 6: CONCLUSION

This chapter concludes the thesis and consists of three sections. The first section elaborates the main findings of this study. To do so, the four-dimensions of the sustainable UM framework and the key issues will be again presented briefly, and the four sub-questions that this thesis studied will be answered one by one. The second section will reflect on the applicability of the theoretical framework developed in this study. It will discuss the usability of the framework, its limitation, and further development. The final section will touch on policy implications of this study for policy makers in China, and its application to other developing countries, as well as the developed countries.

6.1 MAIN FINDINGS

The goal of this thesis was to answer the overall research question, which was: What are the multiple attributes of urban mining and the relevant focal points embodied in the resource, environmental, economic, and social dimensions? And what the corresponding management and policy mechanisms towards sustainable urban mining?

To deliver this objective, the study design consisted of five steps. Firstly, a conceptual analysis framework is developed in Chapter 1. The framework consists of four dimensions of sustainable UM including the resource, the environmental, the economic and the social dimension. For each dimension, key focal points are identified. These make up a four-dimensional sustainable UM framework, and led to the sub research

questions of this study. The questions in the resource and environmental dimensions have been answered by previous teamwork research that I was involved. Therefore, this doctoral thesis is designed to focus on answering the remaining questions in economic and social domains to complete the picture. In step 2, sub research question 1 in the economic dimension is answered in chapter 2. In step 3, sub research question 2 in the social dimension is answered in chapter 3. The study is supplemented by introducing a case study and policy assessment in step 4 and step 5. In step 4, a UM city case study is presented in chapter 4. This case study consolidates the resource, environmental, economic and social dimensions of UM in one place. It answers sub question 3 of this thesis. Chapter 5 provides results of step 5. It touches upon the policy aspect and reviews the sufficiency of national legislation and policy for sustainable UM development in China. In a word, the overall question of sustainable UM in China is answered sufficiently by answering the key questions in the four dimensions of UM framework followed by an integrated case illustration and policy assessment at the national level. The following section will manifest the main findings of this study.

6.1.1 FOUR DIMENSIONS OF SUSTAINABLE UM IN CHINA

The literature review showed that the concept of UM was initially posed to deal with resource harvesting from the material social stocks that had accumulated in the cities. The most research took the single dimensional paradigm and only focused on exploring the resource potential of UM, but urban mines actually have various distinguishing environmental, economic and social attributes and each with their own key focal points. Therefore, we need to build a multi-dimensional paradigm for

sustainable urban mining, and key focal points in each dimension need to be explored in order to answer the overall question of sustainable UM in China.

In the resource dimension, the fundamental questions were to explore how much resource potential of UM could generate and to what extent the UM resource might substitute for the primary resource supplies. The previous teamwork published in the *Journal of Industrial Ecology* answered this question. We selected copper (Cu), aluminum (Al), lead (Pb), and iron (Fe) as the key UM resources in China. We assumed three economic development scenarios: business-as-usual (BAU) scenario, low resource (LR) scenario, and strengthened recovery (SR) scenario. We constructed a predictive model based on the stock analysis model, material flow analysis, and life distribution model to analyze the key metals' demand, recycling, and stock in the three scenarios. Firstly, we portrayed the metabolic status of four metal resources from sector data from 2010. Under the BAU scenario, from 2010 to 2040, the UM potential of Cu, Fe, Al, and Pb will continue to increase. The stock of Cu increases from 3.3 to 8.1 Mt, Fe from 223.5 to 711.6 Mt, Al from 9.3 to 37.0 Mt, and Pb from 5.5 to 12.1 Mt. When we considered the metals resource reserve and demand we found that primary Pb in China will be used up in 10 years and Cu and Fe in 30 years. Meanwhile, UM can provide a stable supply to substitute for the primary resource supply. The potential UM of Cu and Fe will exceed the amount of imports in 2030 and become the main source of the domestic supply. By 2040, the substitution rate of Cu and Fe will be achieved, 25.4% and 59.9% respectively. Under the strengthened recovery scenario, the result looks more promising. Therefore, UM can play a key role in stabilizing resource supplies for the ongoing economic growth that China continues to experience.

The paper also partly answers the question in the environmental dimension. UM of the four metals generates substantial environmental benefits in terms of the energy saving, water consumption, solid waste discharge and Sulphur dioxide (SO₂) emission. Recycled Fe and Al are significant for energy saving and SO₂ emissions reductions. In the 2020 BAU scenario, the two metals can save 96.3 and 32.0 Mt of standard coal, respectively, and reduce 141.5 and 148.4 Mt of SO₂ emission. Recycled Cu saves 1,305.5 Mt of water and reduces 1,255.9 Mt of solid wastes. The UM potential of key metals and their environmental benefits lay down an important foundation for the next steps of this research.

This thesis is designed to answer questions mainly in the economic and social dimension. For the economic dimension, location optimization is identified as the key focal point in the framework. The generation of urban mines is more complex than that of natural mines as they are dynamic according to the urban population, consumption and economic development degree, while these features also change over time. The proper location of UM facilities can help the UM industry achieve efficiency nationwide, particularly given that China's government has initiated a national policy to select 50 national UM pilot bases and support them with industry upgrading. The location selection of these 50 bases has become a practical question. Therefore, the first sub research question in this thesis was:

Sub question 1: How to optimize the location of UM pilot bases to achieve maximum coverage of GDP and population under the social and economic circumstances?

To answer this question, an AHP method was used to establish a database of the total 287 municipality level cities in China. This database includes the city data of population, economic development, urban mines social stocks, UM industry development, and the local market demand for secondary resources. Normalization of the data generated a city index rank list that indicated a city's potential to locate a UM pilot base. 160 cities were taken for the optimization selection in the second step because their index was above the average normalized result. Following that, a maximal covering location model was constructed with the objective to achieve maximum coverage of the population and GDP. The model used a 0-1 linear programming method with a 200 km set as the economically serving distance condition. Applying the optimization model in the GIS software resulted in a matrix of 0-1 linear programming of the 160 candidate cities. The matrix showed the dynamics between the numbers of cities being selected as UM bases and the percentage of GDP and population coverage. When only one city is selected, a maximum of 16.7% GDP and 7.2% of the population can be served. Every additional city added in, the coverage of GDP and population sharply increased until the number of added cities reached to 20. When the city number reached to 40, GDP and population coverage reached a peak of 97.1% GDP and 94.9% respectively. Beyond that, adding one more city did not provide any additional coverage of GDP and population. This result implied that 40 urban mining bases could theoretically provide maximum GDP and population coverage for China if the only domestic urban mines stock were considered. Considering an additional 50 Mt urban mines were imported to China annually, the decision of 50 national UM pilot bases by the government was reasonable. However, when the study was finished, 28 pilot bases

have been officially selected by the central government, 22 are remained to be decided. A second optimization was carried out with the 28 bases location as a fixed precondition. This resulted in a list of 22 cities as the candidate city for the remaining national UM bases selection. The process illustrated useful methods for location optimization of UM recycling facilities to achieve maximum coverage of service, and sufficiently answered the sub research question in the economic dimension.

In the social dimension, the collection of urban mines is identified as the focal point. Those recyclable wastes generated from household and commercial places are scattered in their distribution. Therefore, the efficient collection is important for a sustainable UM system. In China, recyclables collection and recycling have been carried out predominantly by the informal sector, which is facing several challenges. First, they cause obvious environmental pollution and pose threats to human health. Second, the quantity and price of collections fluctuate in the market and makes the supply of urban mines unstable for the UM recycling facilities. Third, the stringent intervention of the informal sector can cause abrupt challenges to the municipal waste management. Therefore, sustainable UM necessarily requires the stable and optional collection to integrate or replace informal collection. Meanwhile, more and more ICTs and IoTs tools are being applied in waste management and generating a new collection-intelligent system. More than 50 private companies have now engaged in the intelligent collection in China, They have explored various approaches to integrate the informal collection. Therefore, the second sub research question to be answered in this thesis was:

Sub question 2: Can the new intelligent collection integrate informal collection to ensure a sustainable supply of urban mines in China?

To answer this question, the 15 most successful intelligent collection cases in China were selected as research objects. A quality research method was employed to identify the forms and features of the intelligent collection, and their comparative advantage over informal collection systems. The results showed that intelligent collection companies in China operated in two forms: human-human interaction collection (HH) and human-machine interaction collection (HM). HM refers to the collection by machine. The machine is a cabinet embedded with ICTs devices, such as sensors, barcodes, and data communication devices. People may input recyclables into the cabinet and earn credit to spend on online shopping or to top up their public transportation commune card. The HH collection refers to the collection by a collector with the assistance of ICTs. People may book collection orders via smartphone to get their recyclable wastes collected at a preferred time and location and earn credits in return. HM collection is most applicable for standard waste items collection in public spaces. HH collection is more applicable for all recyclables in residential areas. Most intelligent collection companies use HH collection at the beginning and take on the HM collection model at a later stage.

Compared with the informal collection, the intelligent collection has four advantages. First, the intelligent collection is a more organised collection system operated by the company. This feature requires the intelligent collector to keep regular interaction with each household and to give the collection legitimacy. It also helps to

eliminate the potential cause of social and health problems often associated with informal collection systems. Second, material flow and cash flow is efficient in the intelligent collection system, given the assistance of ICT devices. Trade takes place less frequently in the intelligent collection, and ICTs can help to optimize the logistics of the waste transportation. Trade in intelligent collection uses virtual currency instead of cash. This poses less tension between the collector and middleman as are found with the informal collection. Third, the intelligent collection can generate accurate and traceable data of urban mines generation and disposal. This helps both the business and government with their management and policy making. Fourth, the intelligent collection has multiple sources of profit making. These include the profit from selling the recyclables, providing household service at the collection, mining the big data, and applying for subsidy for their waste source separation service. Therefore, the intelligent collection can be an alternative collection of urban mines to integrate the informal collection in the short term. All the intelligent collection companies we have investigated employ collectors from the informal sector. This is the general approach leading to informal collection integration. In the long run, the intelligent collection is very likely to replace the informal collection, particularly as the informal sector is in depression due to the various social, economical and population generation factors. For a sustainable UM future enjoying stable urban mines supply, the intelligent collection as new collection model under the new social and economic trend in China cannot be neglected. Intelligent collection within the Extended Producer Responsibility framework is very promising to ensure a quantity and quality collection of some high resource values urban mines.

6.1.2 SUSTAINABLE UM CITY

UM development in China has become a large-scale industry that recycles wastes and generates significant amounts of secondary resources, as well as manufacturing materials for many new products. The development of a UM industry in one city can help to achieve urban symbiosis at the micro level, and contribute to the city's industrialization and urbanization. It consolidates the four dimensions of UM attributes in one place. This leads to the third sub research question in this thesis:

Sub question 3: How does the UM industry development impact the host city industrialization and urbanization and ensures its sustainable development?

To answer the question, a typical city Jieshou in China was selected as a case study to illustrate the integrated features of UM development in China. Jieshou is a middle-size city in central China with a population of less than one million. Its economic development ranks amongst the last 20% of the total 600 county level cities of China. Jieshou is a typical UM city because of the high variety and quantity of urban mines assembled in the city, the high degree of industrialization of the UM industry, and the dominant economic and revenue contribution by the UM industry to the city. There are annually 2.8 Mt lead-acid batteries, copper and aluminum scraps, and waste plastics assembled in the four specific recycling industrial parks of the city for recycling and processing. These four UM industrial parks generated 20% of the total secondary lead in China, 3.6% of copper and 3.8% of aluminum production in China. The UM industry contributes 80% of the city's total industrial output value and provides about 70,000 jobs. UM is a pillar industry of the city. Material metabolism analysis of Jieshou was carried.

The results revealed that 54% of the input materials to the city are urban mines, and 80% of the output is recycled materials. This is a significantly rare case in the urban metabolism.

Jieshou is a microcosm of UM development across China. The UM industry finds its dominant place in Jieshou; it is driven by a variety of social, cultural, economic, environmental and policy factors. Historically, Jieshou people manufactured colored pottery and retailed them to the adjacent towns using small carts as transport. Consequently, an indigenous cultural and logistic trade network evolved incrementally as a tradition in Jieshou. In 1978, China implemented the economic reform policy and the household responsibility system. This liberated most rural surplus labors from the farmland. Jieshou people took advantage of the indigenous pottery retailing experience and networks to engage in the collection of waste lead-acid batteries. Jieshou selected this special waste because lead was one key ingredient in the production of colored pottery they were familiar with over hundreds of years in their manufacturing of the colored pottery products. In more recent years, fast economic growth in China provoked a high demand of secondary resource and, then, led to the UM flourishing development. In 1990, more than 200 lead recycling household workshops were in operation in Jieshou. However, the primary recycling equipment and technology caused severe environmental pollution problems. Jieshou government intervened strongly by shutting down the small recycling workshops and relocating the large ones to specific places for collective management and pollution control. This negative feedback mechanism was not effective until the circular economy policy was introduced in 2000s as a positive feedback mechanism. The Jieshou government adopted the circular economy approach as the

guiding principle for its UM development strategy. It took a series of actions under the national supporting policy schemes. In 2013, Jieshou decided to expand the circular economy concept to all sectors of the city in its search for a circular economy city pilot. This has driven Jieshou toward implementing a sustainable development model.

However, the UM industry in Jieshou is not yet perfect and still faces many challenges, including the limits of the environmental capacity and new social trends in collection section. A Pressure–State–Response (PSR) model was constructed to analyze the three sections of the UM industry in Jieshou. In the collection part, the informal collection is facing a general depression as the social and economy circumstance changes, and as new intelligent collection model emerge. In the recycling part, high-energy consumption and environmental pollution problems remain due to the outdated processing equipment. In the utilization part, low-end products still dominate and result in a relatively low output value of the industry. Therefore, supporting a development toward a sustainable UM city/town requires the following actions: integrating the informal collection by intelligent and internet tools to ensure quality and quantity supply of the urban mines to the city; upgrading the technology and equipment to reduce the energy consumption and pollution emission further within the constraints of the local environmental capacity; and, extending the manufacture chain to more high end products to increase the total industrial output values and UM industry's economic contribution to the town.

Jieshou as a typical UM city, its path can be viewed as a microcosm of a wider UM development in China. It provides lessons and experiences for other cities/towns in

China and the rest of the developing world. The experiences include: 1) establishing industrial parks as hubs for enterprise integration and collective pollution control, 2) taking advantage of national supporting policy of circular economy by applying for entitlements as a national pilot and financial subsidy, 3) providing direct guidance and subsidies to promote technological innovation and industry integration to reduce the pollution and increase productivity. These are also applicable to other similar cities/towns in China and other developing regions.

6.1.3 SYSTEMATIC UM POLICY

Sustainable UM development requires sufficient policy support. China's government officially adopted the circular economy concept into its national policy scheme in 2005, and further initiated special UM Pilot Bases Program in 2010. Are the policy and legislation governance sufficient for UM sustainable development in China? This leads to the fourth sub research question of this thesis:

Sub question 4: Is the current legislation and policy setting sufficient for sustainable UM development in China?

To answer this question, a preliminary review of the UM Pilot Bases Program (UMPB) and a contextual analysis was done. In China, many and various UM industrial parks are developed driven by similar factors as in Jieshou. Their development levels are widely different. China's government initiated the UMPB program to upgrade the UM recycling industry and to relieve resource and environmental bottleneck constraints. The UMPB program defined UM resources as the ferrous metals, non-ferrous metals,

precious metals, plastic, and rubber from the eight major types of wastes (electronic equipment, cables, communication facilities, vehicles, household appliances, electronic products, metal and plastic packaging, and scraps). It intended to select 50 recycling industrial parks as national UM pilot bases. It prescribed seven requirements for listed pilots: systematic waste collection network; sufficient industrial chains; large amounts of recycling materials; advanced recycling equipment; shared industrial infrastructure; collective environmental facilities; and, standard management and operation systems. At the time of finalizing this thesis, 49 national pilots had been selected. Their total recycling capacity would account for one third of all recycling in China. Generally speaking, the UMPB program illustrated a high relevance and significance to the recycling industry in China.

The UMPB program was launched with a good policy basis. These include several relevant policies targeting the management of recycling industry. The Circle Zone Management Initiative in 2004 by the Ministry of Environmental Protection (MEP) intended to tackle the environmental problems of imported waste recycling plants. The 2005 Circular Economy Pilot Program by the National Development and Reform Commission (NDRC) intended to promote material recycling and resource saving in industrial parks. The UMPB program by NDRC in 2010 then turned to address the resource potential and enhance the recycling industry. All these three programs, in turn, provided the basis for the Circular Economy Pilot City program later initiated by NDRC in 2013. This policy integrated the environmental, recycling and resource issues together at a city level. A review of the policy development path reveals that the UM policy is

clearly part of the national circular economy scheme and embraces interaction with each of the other policies.

Meanwhile, the UMPB program is also supported by a favourable context of a larger policy framework as follows: the China 12th National Five Years Plan set resource saving target as a national goal; the Circular Economy Fund allocated subsidy for UMPBs; the China Circular Economy Promotion Law lays down a legislation foundation, while various other special national planning initiatives for environment, energy saving, and recycling industry provide specific roadmaps and key guidelines. Therefore, generally speaking, the policy context does provide sufficient support in terms of policy and planning context and resource allocation to the UMPB program.

However, challenges remain. Firstly, different waste streams are under different ministry's jurisdictions, and thus also the collection, recycling and pollution control are under different ministries' jurisdictions. This leads to a multi-ministerial cross-management network where policy conflicts inevitably occur in many cases. Secondly, the absence of a waste management law and coordination with the WEEE policy caused unstable waste supply to the UMPBs. Therefore, specific recycling oriented regulations are needed to ensure sufficient waste supply for the urban mining industry development. In conclusion, coordination between ministries and policy integration is needed to support the sustainable development of UMPBs.

6.2 FUTURE RESEARCH QUESTIONS

The four-dimensional sustainable UM framework offers a theoretical base for a country or region to develop UM for environmental and resource benefits. This thesis and the previous study mentioned attempted to answer the fundamental issues in every dimension. However, some other issues remain that deserve further exploration in the future.

For the resource dimension, the resource potential estimation for China as already accomplished is a just static result. It answers the general question of resource potential, but not yet down to the specific cases. For example, we need to forecast the UM resource potential availability every year and in every province or city in order to make practical planning of the UM facilities and symbiosis with other industry production. It would be more interesting and useful for planning if the urban mines distribution in different provinces and years could be visualized through the assistance of some software, such as the ArcGIS platform (Guo et al., 2016). Therefore, an additional research question in the resource dimension could be: *How to simulate and visualize the spatial and yearly distribution of key urban mines at provincial or city level?* This information would enable one to track the metabolism flow of key resources in different sectors and geographic places, which is significantly important for the resource stability strategy of a country.

In the environmental dimension, it is easy to calculate the environmental benefit of one UM recycling with a known coefficient under the best available technology of recycling. It is also not difficult to solve the negative environmental externality of the UM

industry by investing in equipment upgrading and pollution control. But there is a trade-off issue between recycling for resources and recycling for the environment. Reclaiming some resources from the urban mines comes at a high environmental cost, and environmental benefits can be at the cost of resource depletion. We can regard this situation as a recycling dilemma. Neither the environment benefits nor the resource benefits and economic return, can become the only indicator to judge the sustainability of recycling. Therefore, the future research question could be: *to what extent the different materials of the urban mines can be recycled, to ensure the balance between its various attributes?*

This is also related to an additional issue arising in the economic dimension. UM is currently driven by the economic benefit and operated in a relatively open market. When secondary resources are in high demand in the market, most recyclable wastes can be collected for resource harvest. When the market is down, low value wastes will be left in the municipal waste streams for the public disposal facilities, and this increases the public cost of waste management. In this case, we should systematically evaluate and compare the cost and benefits between sending the low value waste to UM facilities and to incineration or landfilling facilities. An economic policy tool should be designed to keep a stable balance between the UM and waste management system. Therefore, the future research question could be: *what economic policy tools should be introduced to ensure sufficient collection and recycling of low value waste in order to avoid this being sent to incineration and increasing the public cost and environmental cost of waste disposal?*

In the social dimension, the collection remains as the core issue. Due to time and funding constraints, this thesis only discussed the potential of the intelligent collection to integrate the informal collection to ensure a stable supply of urban mines. There are other collection approaches applicable for different urban wastes. For example, lead-acid batteries can be collected through an EPR system; some WEEEs can be collected via the “old exchange for new” scheme, cardboard and papers can be collected at generation source; and, beverage packages normally are sorted and collected at the pre-treatment part at the waste disposal site. And there are also some pilot projects on the integration of recyclables collection with the MSW collection system in China. Various collection approaches are applicable for different features of specific urban mines. *What collection approaches should a sustainable urban mines collection system include and integrate to achieve efficiency of the system?* This is the question for next steps of research on collection.

Surely, recycling of materials is not the only option for circular economy instead of the product reuse, remanufacturing and refurbishment (Korhonen et al., 2018). Recycling indeed is a kind of the end of pipe solution for resource saving. Because of entropy, recycling will ultimately lead to unsustainable resource depletion, pollution and waste generation. Regardless of what any cradle-to-cradle concept may claim (McDonough and Braungart, 2002), recycling alone cannot build a fully “closed” loop material usage system. Therefore, to achieve circular economy in a sustainable sense, reducing resource usage and simplifying the materials at the product design stage is important. Product designers and materials scientists need to invent forms of materials to meet both the purpose of high product performance, while also maintaining high

recycling potential (Graedel, 2011a). These are research questions that extend beyond the UM system itself.

6.3 POLICY AND MANAGEMENT IMPLICATIONS

This study has direct policy implications for UM development in China and was designed to provide suggestions and recommendations for China. Chapter 2 answered the question of number and locations for selection of national UM pilot bases. This directly supported the government decision making in the selection process. It also illustrated a useful method for UM recycling facility location planning for other regions and countries. This study has demonstrated the comparative advantages of the new intelligent collection model and its integration potential over the informal collection. Intelligent collection conforms to the new social and economic trends in China but is still in its early development stage. China's government will show a clear gesture of support for this innovation by releasing the favoring policy. The case study of the UM city of Jieshou proved how the national supportive policy drove this less developed city toward a circular economy and sustainable development model via developing the UM industry. The in-depth policy assessment of UM policy scheme in China has shown that two aspects of the policy development are the most urgent to overcome key barriers hampering the UM industry. One is the coordination among different ministries each having jurisdiction for the same waste stream. Second is the integration mechanism with the waste management system that can enhance the collection of urban mines, for example, the integration of recyclables collection and the MSW collection system will increase the efficiency of both systems.

China's story has implications for other countries. Population, economic, and cultural factors drove some less developed China cities to develop their UM industry as a means to industrialize and urbanize. The same factors and market demand for secondary resources can be found in other countries in the developing world. For example, in India, manufacturing, and production are facing severe resource bottlenecks, which will be further enhanced with the growing demand for materials. When no official UM facilities are planned and constructed in a city, UM recycling relies on the informal sector. They also face environmental pollution and low end equipment problems (Arora et al., 2017). Successful experience and lessons from China can provide examples for India at the beginning of their UM development. These can even help the industrial park experiment and recycling technology and equipment in India to leap forward to sustainable UM.

Lastly, China has taken a series of actions to prohibit the import of many kinds of recyclable wastes from developed countries. This has had two instant effects. First, many UM facilities that were heavily reliant on import wastes now have no stable supply. They have been forced to either seek a domestic supply source or move to adjacent developing countries to continue their operations. These new locations can use China's successful experiences to avoid the same environmental and social problems experienced in China. The second direct effect is massive wastes piling up in European countries and America. This has driven them to seek a proper UM management solution, instead of dumping to other developing world countries (Carbonnel, 2018). Part of China's experience also is applicable to these countries. Furthermore, EU countries have acknowledged the economic and environmental contribution of circular economy

approaches and are incrementally adopting this in business and policy plans. Studies show that the overall impact of the circular economy in the Netherlands is estimated at EUR 7.3 billion annually, creating 54,000 jobs (Hoogendoorn et al., 2013). In the UK, the circular economy could create 200,000– 500,000 gross jobs (Mitchell and Morgan, 2015). The EU has set a range of recycling targets for various wastes. For example, 55 percent of plastic packaging wastes must be recycled by 2030. China's experience is also applicable to EU countries achieving their circular economy targets, whether they intend to recycle the waste in their home county or send them to other counties, such as Malaysia and Vietnam. Some authors state that UM is just the old content of waste management in a new envelope (Baccini and Brunner, 2012). If we notice the UM development switch among the developed and developing countries, UM is more than just waste management, it even highlights the non-renewable resources metabolism and the environmental and social influence at an international scale. Sustainable development of UM in one country, or coordination among different counties, can help them to achieve urban symbiosis and circular economy on an international scale. Therefore, UM is clearly an important contributor and approach toward the sustainable development for a better world.

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APPENDICES

Appendix 1:

Selection of key indicators from the China Environmental quality standards for surface water (GB 3838—2002) unit: mg/L

Indicator		I	II	III	IV	V
DO	≥	7.5	6	5	3	2
COD	≤	15	15	20	30	40
BOD ₅	≤	3	3	4	6	10
NH ₃ -N	≤	0.15	0.5	1.0	1.5	2.0
Total P	≤	0.02	0.1	0.2	0.3	0.4
Total N	≤	0.2	0.5	1.0	1.5	2.0

Classification of Water type:

I : Water sources and national nature reserves.

II : Class I protection zones for drinking water sources, protection zones for valuable fish and spawning grounds.

III: Class II protection zones for drinking water sources, general protection zones for fish and swimming area.

IV: General industrial water zones and water recreation areas where no direct contact with humans occur

V: Agricultural water zones and scenic water areas

Appendix 2:

2. 1 Material flow analysis of the lead-acid battery recycling in Tianying industrial Park

2.2: Recommendation of high value lead based production for Tianying park

SUMMARY

As society and economies grow with the increasing industrialization and urbanization, more and more non-renewable resources are exploited and accumulate in the urban areas as social material stocks. Mining these social stocks, on the one hand, provides secondary resources that can partially substitute for the primary resource supply and help slow down damage to ecosystems. On the other hand, they can generate environmental benefits. Furthermore, urban mining has become an industry offering economic benefits to the city. Urban mining is making its own contribution to sustainable development, but the research on the subject mostly focuses on the resource potential estimation, while a systematic UM theory remains under development. Practically, China's government has acknowledged its benefits and put forward a specific national program to promote the UM industry and facilitate its upgrading to release a resource bottleneck in China. Will the social, economical and policy developments in China stimulate or restrict the sustainable development of urban mining? This is becoming a core question to be answered.

To achieve the objective, this doctoral study started by exploring the key attribute of urban mines, and the core issues associated with them. Together, these led to the formulation of a four-dimensional sustainable UM framework to serve as the theoretical background to this study. In the resource dimension, resource potential estimation and their substitution of the primary resource supply is the key issue. In the environmental dimension, positive and negative environmental benefits of UM are the key issue. A

previous teamwork study the author was involved in explored the resource and environmental questions in China. It calculated copper (Cu), aluminum (Al), lead (Pb), and iron (Fe) metrics as these cover the four key metals UM potentials. It found that the stock of Cu is set to increase from 3.3 to 8.1 Mt, Fe from 223.5 to 711.6 Mt, Al from 9.3 to 37.0 Mt, and Pb from 5.5 to 12.1 Mt. By 2040, the substitution rate of Cu and Fe (UM supply over the primary supply) will achieve 25.4% and 59.9% and exceed the imported amount to become the main source of domestic supply. Urban mining of the four metals also generates substantial environmental benefits, in terms of the energy saving and reductions of water consumption, solid waste discharge, and Sulphur dioxide (SO₂) emissions.

In the economic dimension, the key question is location optimization of the 50 national UM pilot bases the China government would like to support. Because urban mines generation are scattered given a wide range of demographic and economic factors, the location of UM facilities is and will be a key issue. A maximal covering location model combining a 0-1 integer programming method was constructed and applied on the ArcGIS platform. Results showed that 40 UM bases are sufficient to achieve maximum coverage of GDP and population. Considering an additional 50 Mt urban mines were imported to China annually, the decision of 50 national UM pilot bases by the government was reasonable. The government has already selected 28 bases with 22 ones to go. A second optimization process resulted in a list of 22 cities as the best candidates for these UM bases.

The key issue in the social dimension is the collection and integration of informal collection. The informal sector has already caused well-known environmental and social problems. Meanwhile, a new collection model had emerged in China with the assistance of ICTs and IOTs tools and, already, more than 50 private enterprises are now engaged in the intelligent collection. Intelligent collection in China takes two forms: Human-human interaction collection, and Human-machine interaction collection. Both forms apply barcode, sensor, GSM/GPRS and ICT tools. The intelligent collection has a good potential to integrate informal collection, as it has four comparative advantages. These include: 1) it is organised collection with legitimacy, 2) its material flow and cash flow is more efficient, 3) it harvests accurate and traceable big data, 4) it is a multi-source profit-making business model. In practice, the current intelligent collection companies in operation employ collectors from the informal sector. Considering the new social and economic trends in China, it is easy to foresee that intelligent collection can integrate the informal collection, not so easily in the short term, but might replace it in the long run. UM management should make advanced planning of its strategy to apply intelligent collection in ways that can ensure a stable waste resource supply.

This study further illustrated the four-dimensional issues in one UM city as a micro case study to explore how UM industry development in one city can impact its industrialization and urbanization and help contribute towards sustainable development. This study defined a UM city/town as one where the UM industry contributes the major economy and revenue to the city. Jieshou is a typical UM city. It is a microcosm of UM development across China and shares similar features with many other UM towns and cities. Driven by the population, cultural, and economic factors, Jieshou people took on

UM recycling, and this has become a pillar industry in Jieshou. Metal recycling accounts for 80% of Jieshou's industrial output value. Environmental and policy factors have acted as negative and positive feedback mechanisms and have further driven Jieshou to develop toward a circular economy city as its latest ambition. Jieshou's experience includes: 1) establishing UM industrial parks for industry upgrading and collective pollution control, 2) taking advantage of national support policy to become a national pilot, and 3) providing direct guidance and subsidies to local UM technological innovation and integration.

Lastly, an in-depth policy assessment in China for UM brought the study back to the macro level, and its results can formulate specific policy advice for the core question of this thesis - sustainable UM development in China. UM policy in China was developed on the basis of a previous policy of circular economy and has now become an important pillar of the national circular economy policy schemes. UM development generally in China has sufficient policy support with the elements of national planning, legislation, and finance subsidy. But the governance of UM exists in a multi-ministerial cross-management network, and thus policy conflicts happen. Coordination between ministries and policy integration are needed to promote sustainable UM development.

The four-dimensional framework is an initial attempt; many more extensive issues remain to be explored in every dimension. This includes the simulation and visualization of the UM potential based on GIS platform, economic policy instrument designs for the efficient household recyclables resources collection, and many other collections system designs. This study constructs a theoretical four-dimension

framework for sustainable UM analysis and strategy planning. Practically it provides specific policy advice for China government decision-making about the UM industry. The experience and lessons of China are also applicable for other developing counties, and for the EU counties with their circular economy targets.

SAMENVATTING

Terwijl samenleving en economie groeien door toenemende industrialisatie en urbanisatie worden steeds meer niet-hernieuwbare grondstoffen geëxploiteerd en raken deze opgeslagen in het stedelijk gebied als maatschappelijke voorraden. Mijnbouw van deze voorraden kan enerzijds secundaire grondstoffen opleveren die gedeeltelijk primaire grondstoffen kunnen vervangen en de schade aan ecosystemen vertragen, en bovendien milieuvoordelen bieden. Verder kan stedelijke mijnbouw ook een bedrijvigheid worden die economische voordelen biedt aan de stad. Stedelijke mijnbouw levert haar eigen bijdrage aan duurzame ontwikkeling, maar het onderzoek naar dit onderwerp richt zich doorgaans alleen op het inschatten van de mogelijk omvang van de grondstoffen die gewonnen kunnen worden. Een systematische “urban mining” (UM) theorie is nog in ontwikkeling. In de beleidspraktijk heeft de Chinese overheid de voordelen al onderkent en een specifiek nationaal programma ingesteld om de UM industrie te verbeteren en de grondstoftekorten in China te verminderen. Hoe zou een duurzame stedelijke mijnbouw kunnen worden ontwikkeld? Dit werd de kernvraag om te beantwoorden.

Om dit onderzoeksdoel te bereiken, start dit proefschrift met het exploreren van de sleuteleigenschappen van stedelijke mijnen, en de hoofdpunten die deze kenmerken oproepen. Tezamen formuleren deze een UM kader met vier dimensies, dat als de theoretische achtergrond van deze studie dient. In de grondstofdimensie is de inschatting van het grondstofpotentieel en de mate van mogelijke vervanging van de

aanvoer van primaire grondstof het kernpunt. In de milieudimensie zijn de positieve en negatieve gevolgen van UM het kernpunt. In een voorafgaande studie, waarin de auteur deel uitmaakte van het onderzoeksteam, zijn de grondstof- en de milieuvragen onderzocht voor China. De studie berekende het potentieel voor koper (Cu), aluminum (Al), lood (Pb) en ijzer (Fe), vier belangrijke metalen. De voorraad aan Cu zou toenemen van 3.3 naar 8.1 Mt, Fe van 223.5 naar 711.6 Mt, Al van 9.3 naar 37.0 Mt, en Pb van 5.5 naar 12.1 Mt. Tegen 2014 zou een vervangingsgraad van Cu en Fe (UM aanbod versus primaire grondstof) bereikt kunnen zijn van 25,4% en 59,9%, meer dan de invoerhoeveelheden, en zou de voornaamste bron van binnenlandse aanvoer zijn geworden. Stedelijke mijnbouw van de vier metalen zou ook aanzienlijke milieuvoordelen bieden in termen van energiebesparing, waterconsumptie, afvoer van vaste afvalstoffen en zwaveldioxide (SO₂) uitstoot.

De deelstudie in de economische dimensie werd ontworpen om de vraag naar de optimalisatie van de locaties voor UM pilot bases in China te beantwoorden. Omdat het verzamelen van de UM grondstoffen verspreid is langs demografische en economische lijnen, is de juiste plaatsing van verwerkingsfaciliteiten een kernvraag. Een locatiemodel met maximale dekkinggraad werd ontwikkeld met de 0-1 integrale programringsmethode en toegepast op het ArcGIS platform. De resultaten lieten zien dat 40 UB bases voldoende zijn om een maximale dekkinggraad te verkrijgen van BNP en bevolking. Omdat de Chinese regering al 28 bases had geselecteerd, met nog 22 in de planning, hebben we ook een tweede optimalisatie uitgevoerd die resulteerde in een lijst van 22 steden die het beste voor een van deze bases in aanmerking zouden komen.

In de sociale dimensie is de inzameling van de grondstoffen het kernpunt. Hoe daarbij de informele sector te integreren in een duurzame aanpak was daarbij een grote vraag, omdat bekend is dat de huidige informele sector milieu- en sociale problemen veroorzaakt. De opkomst van een nieuw model van inzameling met de assistentie van ICT en IOT hulpmiddelen kan worden waargenomen in China en meer dan 50 privé bedrijven zijn nu al betrokken in deze “intelligente inzamelingsaanpak”. De intelligente inzameling neemt in China twee vormen aan: mens-mens interactie inzameling en mens-machine interactie inzameling. Beide vormen maken gebruik van een streepjescodes, sensoren, GSM/GPRS en andere ICT hulpmiddelen. Intelligente inzameling heeft een goed potentieel om de informele inzameling in zich op te nemen omdat het vier comparatieve voordelen heeft: 1) het is een georganiseerde vorm van inzameling met legitimiteit, 2) de stofstromen en geldstromen zijn efficiënter, 3) het levert accurate en herleidbare gegevens op, en 4) het is een op verschillende bronnen berustend winstgevend bedrijfsmodel. Huidige operationele intelligente inzamelingsbedrijven gebruiken in de praktijk de diensten van inzamelaars uit de informele sector. Gegeven de nieuwe sociale en economische trends in China kan worden voorzien dat op de korte termijn de intelligente inzameling de informele inzameling kan integreren en op de lange termijn zou kunnen vervangen. Het UM management zal op voorhand een strategie moeten ontwikkelen om intelligente inzameling toe te passen om een stabiele aanvoer van grondstoffen te verzekeren.

De studie illustreert vervolgens de hoofdpunten van de vier dimensies in een specifieke UM stad als kleinschalige casus, om te exploreren hoe de ontwikkeling van UM bedrijvigheid in een stad invloed heeft op industrialisatie en urbanisatie en op

duurzame ontwikkeling. Deze studie omschrijft een UM stad als een plaats waar de UM bedrijvigheid een grote bijdrage levert aan de economie en de plaatselijke inkomsten. Jieshou is zo'n typische UM stad. Het is een microkosmos van UM ontwikkelingen die overal in China plaatsvinden en deelt overeenkomstige kenmerken met veel andere UM steden. Gedreven door bevolkingsfactoren, culturele factoren en economische factoren zijn de bewoners van Jieshou begonnen met UM recycling en dit werd een basisbedrijvigheid in Jieshou, de metaalrecycling is goed voor 80% van de waarde van de industriële opbrengsten. Milieufactoren en politieke factoren functioneerden als negatieve en positieve feedbackmechanismen die Jieshou verder de kant op dreven om als uiteindelijke ambitie een circulaire stad te worden. De ervaringen van Jieshou omvatten: 1) de inrichting van UM bedrijventerreinen om de recycling te verbeteren en een gemeenschappelijke aanpak van vervuiling mogelijk te maken, 2) de voordelen plukken van het nationale ondersteuningsbeleid om daarmee een nationale pilot te worden, 3) het bieden van rechtstreekse begeleiding en subsidies aan lokale UM innovatie en integratie.

Ten slotte bracht een analyse van het UM-beleid in China de studie weer terug naar het macroniveau en resulteerde in specifieke beleidsadviezen met betrekking tot de kernvraag van dit proefschrift, duurzame ontwikkeling van UM in China. Het UM-beleid in China werd ontwikkeld op basis van het eerdere beleid aangaande circulaire economie en werd een belangrijke zuil in nationale beleidsschema's inzake circulaire economie. Daardoor heeft de ontwikkeling van UM in China in het algemeen voldoende beleidssteun ondervonden met elementen van nationale planning, wetgeving en financiën. De governance van UM berust echter bij een multi-ministerieel netwerk met

kruisende managementlijnen, waardoor beleidsconflicten voorkomen. Coördinatie tussen de ministeries en beleidsintegratie zijn nodig om de duurzame UM ontwikkeling te bevorderen.

Het vier-dimensies kader is een eerste poging, er zijn nog veel meer issues die in elke dimensie kunnen worden geëxploreerd, zoals de simulatie en visualisatie van het UM potentieel met behulp van een GIS platform, het ontwerp van economische instrumenten om de efficiënte inzameling van recyclebles van huishoudens te ondersteunen, andere ontwerpen voor inzamelingssystemen, enzovoorts. Theoretisch heeft deze studie het vier-dimensies kader voor de analyse en strategische planning van duurzame UM geconstrueerd. Praktisch verschaft het specifiek beleidsadvies aan de besluitvorming van de Chinese regering over de UM industrie. De ervaring en lessen vanuit China zijn ook van belang voor andere ontwikkelingslanden, alsook voor de EU landen met hun doelstelling van circulaire economie.

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