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Circular Economic Opportunities for Greening SMEs – The Chinese Experience

(Background Paper for Plenary Session 6 of the Programme)

Final Draft

This background paper has been prepared by Prof.Jinhui Li and Xianlai Zeng, for the Eighth Regional 3R Forum in Asia and the Pacific. The views expressed herein are those of the author only and do not necessarily reflect the views of the United Nations.

CIRCULAR ECONOMIC OPPORTUNITIES FOR GREENING SMES – THE CHINESE EXPERIENCE

2018/5/30 Jinhui Li

Circular Economic Opportunities for Greening SMEs – The Chinese Experience

JINHUI LI

Foreword

On September 25th 2015, the United Nations countries adopted a set of goals to end poverty, protect the planet and ensure prosperity for all as part of a new sustainable development agenda 2030, by involving 17 Sustainable Development Goals and 169 targets. At least four goals which are Sustainable Cities and Communities, Responsible Consumption and Production, Industry, Innovation and Infrastructure, and Clean Water and Sanitation, are related to city and industry. On the other hand, a circular economy takes a holistic approach to the design and use of our products, materials, and resources to maximize their value before disposal. The four sustainable development goals have a strong link with the circular economy.

Owing to a significant amount and economic share of SMEs in the total enterprise, SMEs have absorbed much concern around the world, in particular for most developing countries. China has become the world's second-largest economy after 40 years' development of "wading across the stream by feeling the way (摸着石头过河)". A lot of experience and lessons on greening SMEs by circular economy approach can be summarized from this whole adventure. In February 2013, UNEP's 27th council meeting adopted a decision in promoting China's ecological civilization. I believe these will contribute to the economic development for other developing countries in regional sustainable development.

Invited by United Nations Centre for Regional Development, I prepared this document entitled *Circular Economic Opportunities for Greening SMEs – The Chinese Experience* with support of my teams in Basel Convention Regional Centre for Asia and the Pacific and School of Environment, Tsinghua University, especially Associate Professor/Dr. Xianlai Zeng. I hope it can extend the insight in theory and contribute to the industrial practice in near future.

If you have some suggestions and comments, please contact me at E-mail: jinhui@tsinghua.edu.cn; Tel: 86-10-6279-4351; Fax: 86-10-6277-2048.

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Contents

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On March 23th, 2018, we chaired one-panel discussion entitled *Circular Economy: Angel or Devil* in the 13th International Conference on Waste Management and Technology. The presenters shared their insights on circular economy, which were also helpful for this document.

Abbreviations and Acronyms

BAT: best available technology

BEPs: best environmental practices

CE: circular economy

CFC: chlorofluorocarbons

CNY: Chinese Yuan

CRT: cathode ray tube

E-waste: electrical and electronic waste

EoL: end-of-life

EoP: end-of-pipe

EPB: Environmental Protection Bureau

EPL: environmental protection law

GDP: gross domestic product

IP: industrial park

MDGs: Millennium Development Goals

MT: million ton

NDRC: National Development and Reform Commission

PCBs: printed circuit boards

PPI: pulp & paper industry

SDGs: sustainable development goals

SMEs: small and medium-sized enterprises

UNCRD: United Nations Centre for Regional Development

WEEE: Waste Electrical & Electronic Equipment

An Executive Summary

The rapidly rising global population, particularly in urban areas, and the close coupling between economic development and resource consumption have increased the rate of depletion of natural resources and deterioration of environmental quality. The circular economy has been regarded as the most effective solution for these problems around the world. It has gained momentum as a concept in both academic and policy circles, while circular business models have been linked to significant economic benefits over the years.

China, during the past nearly seven decades, was always striving to explore the road to sustainable development of economy and environment. Since the economic reform and open-door policy started in 1978, China set economic development as the central strategy to solve problems of backwardness and poverty. This strategy created an incomparable increase of gross domestic product, but at cost of dramatic resource consumption and serious environmental pollution. The dirty economy characterized with low resource recycling initially struck Chinese government around 2005. Meanwhile, China's nearly 1/5 of the world population is rushing to rapid urbanization, which was regarded as one of the largest issues human beings confront in the 21st century by Nobel laureate Joseph E. Stiglitz. China's rate of urbanization reached 56% in 2015 and will come up to 70% in 2030.

While the capacities of larger companies facilitate the adoption of and realization of benefits from circular business models, also small and medium-sized enterprises (SMEs) are increasingly aware of the benefits of closing loops and improving resource efficiency: saving material costs, creating competitive advantages and new markets are among the main reasons for Asian SMEs to take action. SMEs wishing to enter global value chains face different types of challenges for which they need practical, technical and legal advice and support. However, a couple of barriers have hampered the implementation of circular economy practices by SMEs that can originate, for example, from the SME enabling environment, such as national regulation and policy-making, from the market chain in which the SME operates, such as behavior of suppliers, and from lack of technical skills and economic incentive. On the other hand, China is promoting circular economy on a large scale, and many rich experience and lessons are coming into being.

Greening SMEs using circular economy philosophy generally involves two phases as cleaner production and waste recycling in supply chain. In the past three decades, cleaner production is realized mainly in the industrial park, and waste recycling is realized mainly in urban mining demonstrate base. These two actions are the core practical approaches of a circular economy to green SMEs. Driven by the regulation, policy, and technology development, some manufacturing SMEs has grown into industry park, eco-industry park, and circular-transformation of the industrial park to reach the green goal; some waste recycling SMEs has evolved from backyard workshop to urban mining demonstration zone and circular economy industry park to finalize the green development.

In the circular economy area, solving environmental problem linked with resource recycling is not only depended on the progress of science and technology, but also relied upon an integrity of regulation and policy. Many years' research from experiment to pilot has resulted in an emerging model of circular economy technology, characterizing with the identification of key process, integration of combined process, marketization of recycled product, and maintenance of regulation and policy.

The harsh situation also drives that circular economy should play an increasing role in supply-side structural reform and ecological civilization construction, which can provide the huge room of China's experience adopting. The experience needs to be urgently deepened and intensified in near future. Additionally, its leading in the theory and practice will enable that this integrated model is to be duplicated for other regions or countries.

Chapter 1: Introduction

1.1 The whole supply chain

In a forward supply chain, the customer is typically the end of the process. However, a closed-loop supply chain, or called the whole supply chain, includes the returns processes and the manufacturer has the intent of capturing additional value and further integrating all supply chain activities. Therefore, the whole supply chains include traditional forward supply-chain activities and the additional activities of the reverse supply chain.

Also, the whole supply chain is the circular economy supply chain, covering natural resource extraction, manufacturing, transportation, retail operations, product use, and end-of-life disposal (Figure 1). Comparing to the conventional supply chain and the forward logistics, the circular economy supply chain pays more attention on the reverse logistics, in particular on reduce, reuse, remanufacturing, recycling, and recovery, meanwhile reducing emission and resource consumption (Li et al., 2015; Zeng and Li, 2018).

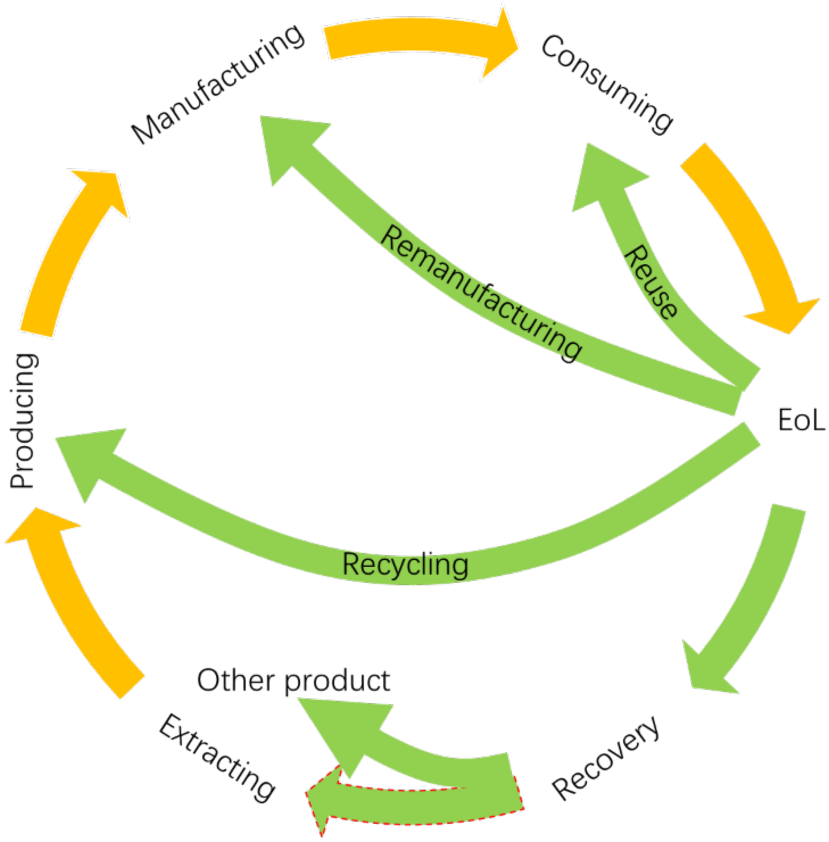


FIGURE 1 THE WHOLE SUPPLY CHAIN: THE FORWARD LOGISTICS AND THE REVERSE LOGISTICS

1.2 What are the SMEs?

SMEs stand for small and medium-sized enterprises. But what exactly an SME or Small to Medium Enterprise depends on who's doing the defining. There is no one united standard to classify the SMEs in the world. Depending on the country, the size of the enterprise can be categorized based on the number of employees, annual sales, assets, or any combination of these. It may also vary from industry to industry.

Even in China, the standard of SMEs is also evolving. At least eight times updating has occurred since 1950s. The latest standard was given in 2011, involving sixteen industries and considering operating income, employee, and total assets (Table 1).

TABLE 1 CLASSIFYING STANDARD OF SMES IN CHINA

Industry	Middle-sized enterprise	Small-sized enterprise	Micro-sized enterprise

Animal husbandry and fishery	operating income: 5-200 million CNY	operating income: 0.5-5 million CNY	operating income: <0.5 million CNY
Common industry	Employees: 300-1000; and income: 20-400 million CNY	Employees: 20-300; and income: 3-20 million CNY	Employees: <20; and income: <3 million CNY
Construction	Income: 60-800 million CNY; and total assets: 50-800 million CNY	Income: 3-60 million CNY; and total assets: 3-50 million CNY	Income: <3 million CNY; and total assets: <3 million CNY
Wholesale	Employees: 20-200; and income: 50-400 million CNY	Employees: 5-20; and income: 10-50 million CNY	Employees: <5; and income: <10 million CNY
Retail	Employees: 50-300; and income: 5-200 million CNY	Employees: 10-50; and income: 1-5 million CNY	Employees: <10; and income: <1 million CNY
Transportation	Employees: 300-1000; and income: 30-300 million CNY	Employees: 20-300; and income: 2-30 million CNY	Employees: <20; and income: <2 million CNY
Warehousing	Employees: 100-200; and income: 10-300 million CNY	Employees: 20-100; and income: 1-10 million CNY	Employees: <20; and income: <1 million CNY
Postal Services	Employees: 300-1000; and income: 20-100 million CNY	Employees: 20-100; and income: 1-20 million CNY	Employees: <20; and income: <1 million CNY
Accommodation	Employees: 100-300; and income: 20-100 million CNY	Employees: 10-100; and income: 1-20 million CNY	Employees: <10; and income: <1 million CNY
Catering	Employees: 100-300; and income: 20-100 million CNY	Employees: 10-100; and income: 1-20 million CNY	Employees: <10; and income: <1 million CNY
Info. transmission	Employees: 100-2000; and income: 10-1000 million CNY	Employees: 10-100; and income: 1-10 million CNY	Employees: <10; and income: <1 million CNY
Software and info. technology services	Employees: 100-300; and income: 10-100 million CNY	Employees: 10-100; and income: 0.5-10 million CNY	Employees: <10; and income: <0.5 million CNY
Real estate development	Income: 10-2000 million CNY; and total assets: 50-100 million CNY	Income: 1-10 million CNY; and total assets: 20-50 million CNY	Income: <1 million CNY; and total assets: <20 million CNY
Property management	Employees: 300-1000; and income: 10-50 million CNY	Employees: 100-300; and income: 5-10 million CNY	Employees: <100; and income: <5 million CNY

Leasing and business services	Employees: 100-300; and total assets: 80-1200 million CNY	Employees: 10-100; and total assets: 1-80 million CNY	Employees: <10; and total assets: <1 million CNY
Others	Employees: 100-300	Employees: 10-100	Employees: <10

Note: http://www.gov.cn/zwgk/2011-07/04/content_1898747.htm; http://www.stats.gov.cn/tjsj/tjbz/201801/t20180103_1569357.html

1.3 Role and characteristics of SMEs

The role of SMEs in the global economy has long been recognized. The advantages associated with SMEs are those of entrepreneurial dynamism, internal flexibility, and responsiveness to changing circumstances. SMEs have played the vital role in economic development around the world. In the U.S., the total amount of the small-sized enterprises was approximately 25 million, accounting for 98% of all enterprises and creating more than 50% job vacancy. In the recent ten years, about 60-80% of the newly added job vacancy was provided by the small-sized enterprises. Its economic contribution always remains around 51% in the total GDP. In the EU, there is about 25 million enterprises, but 99.1% belongs to SMEs. In 2012, SMEs provided 67.4% job vacancy and created 56.9% economic contribution.

In China, since 2000s SMEs have experienced significant growth in terms of number and size (Figure 2). Until 2012, China had over 56 million SMEs (Li, 2013). Generally, SMEs contribute more than 60% of the nation's GDP, 50% of tax revenues, 70% of import and export trade, and 80% of urban employment. With respect to innovation, SMEs have contributed 66% of patents nationwide, 74% of technological innovations, and 82% of new products (Zhu et al., 2012).

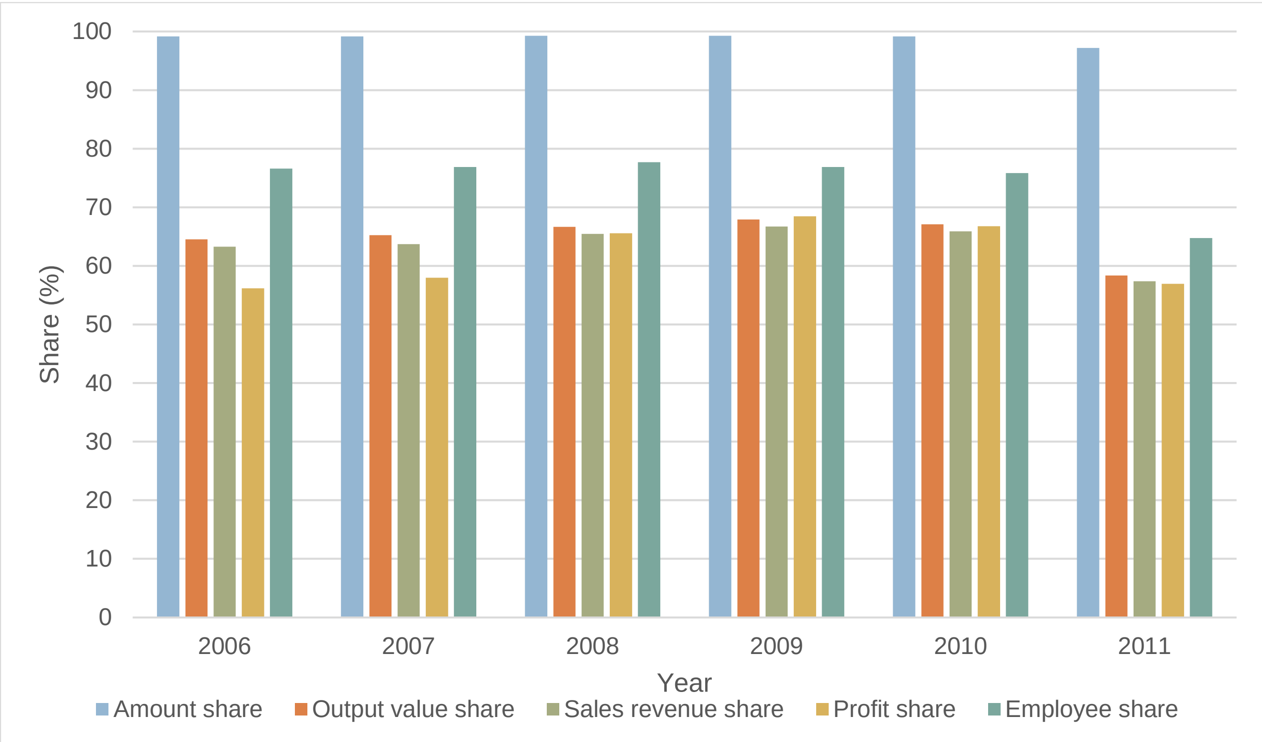


FIGURE 2 THE SHARE OF SMES IN TOTAL DESIGNED SIZE ENTERPRISES IN CHINA

Innovation is the vitality of enterprises. In the view of supply chain, innovation consists of product innovation and process innovation. Previous studies and experience indicate that the large enterprise prefer to improving the manufacturing process for one specific product, and that the SMEs prefer to changing the product more than the manufacturing process. For instance, the SMEs care more about the type of products so that they like to change the product in case of some problems from market. As a result, the manufacturing process is generally ignored by some SMEs, which easily causes the severe environmental pollution (Wen and Ma, 2013).

1.4 Environmental performance of SMEs

SMEs know much less about the environmental and social impacts of their production networks (O'Rourke, 2014). Around $4.7 trillion in environmental costs is externalized each year from global production systems (Trucost, 2013); and 6.4 billion tons of carbon dioxide emitted, more than 20% of global emissions, through production of traded goods (Davis, et al., 2011). Also, global production and consumption are consuming 50% more natural resources and services than ecosystems regenerate (Seuring, 2011; O'Shea, et al., 2013). With growth in populations and in per capita consumption levels, expanding consumer classes around the world and the production networks that support them are driving major ecological pressures.

SMEs are the main contributor of environmental pollution problem in China. In 2010, the total amount of SMEs in China accounted for 99.2% of total enterprises, and the gross industrial output value contributed 67% of total gross of all enterprises. However, the pollution generated from SMEs contributed over 70% of total industrial pollution (Fang, 2015). A huge amount of SMEs is concentrated on circular economy supply chain (Dai and Hao, 2014).

Chapter 2: Policy and technology drivers behind circular economy approach in greening SMEs

Circular economy actions are being motivated by four major drivers: (i) regulatory pressures (led by a mix of U.S. states and European Union legislation); (ii) competitive pressures (for both cost reductions and supply chain innovations); (iii) stakeholder pressures (particularly targeting brand reputations and demands for greater transparency); and (iv) risks from supply chain disruptions (brought about by regional resource shortages and extreme weather events) (O'Shea, 2013; Dauvergne and Lister, 2012).

2.1 China's adventure on industry development, environmental improvement, and circular economy

Since initiating market reforms in 1978, China has shifted from a centrally-planned to a market-based economy and has experienced rapid economic and social development. GDP growth has averaged nearly 10 percent per year—the fastest sustained expansion by a major economy in history—and has lifted more than 800 million people out of poverty. China reached all the Millennium Development Goals (MDGs) by 2015 and made a major contribution to the achievement of the MDGs globally. Although China's GDP growth has gradually showed since 2012, it is still impressive by current global standards. In 2016, China's GDP surpassed 70 trillion CNY (Figure 3). With a population of nearly 1.4 billion, China is the second largest economy and is increasingly playing an important China has been the largest contributor to world growth since the global financial crisis of 2008. These achievements are majorly relied on over 40 million SMEs around China.

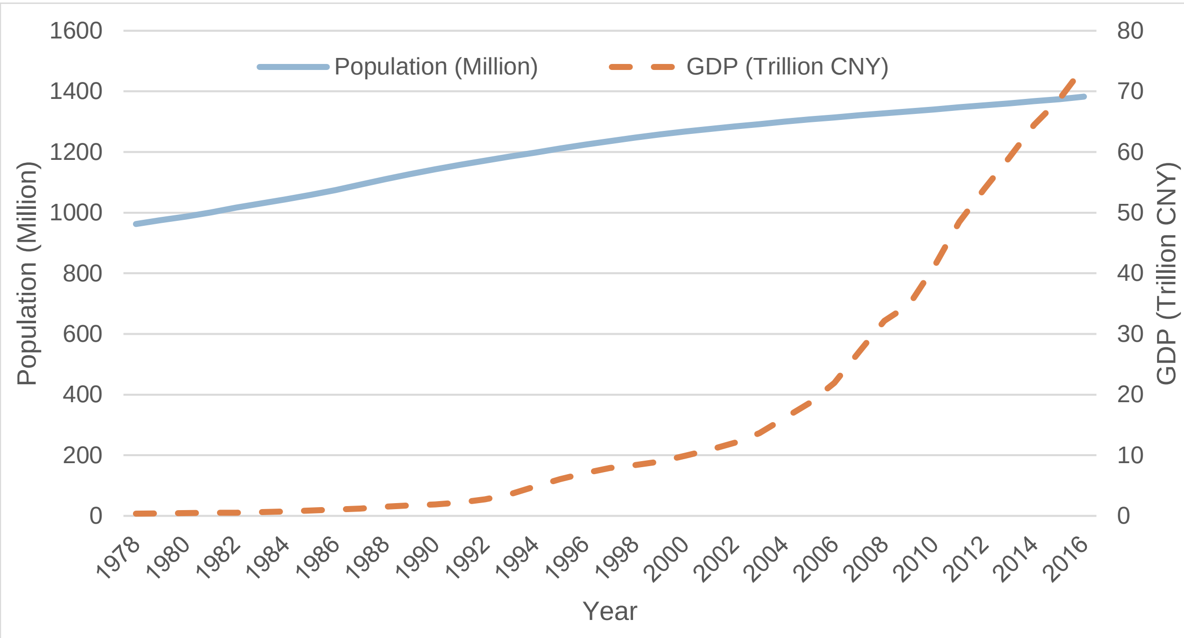


FIGURE 3 GROWTH OF CHINA'S POPULATION SIZE AND GROSS DOMESTIC PRODUCTS

Note: Data source from China Statistics, http://www.stats.gov.cn/tjsj/

In China, greening SMEs using circular economy philosophy generally involves two phases for cleaner production and waste recycling in supply chain. More special, cleaner production is realized mainly in industrial park (IP), and waste recycling is realized mainly in urban mining demonstrate base. These two actions are the core practical approaches of circular economy to green SMEs. In this chapter, we will address them to outline the policy and technology along the adventure.

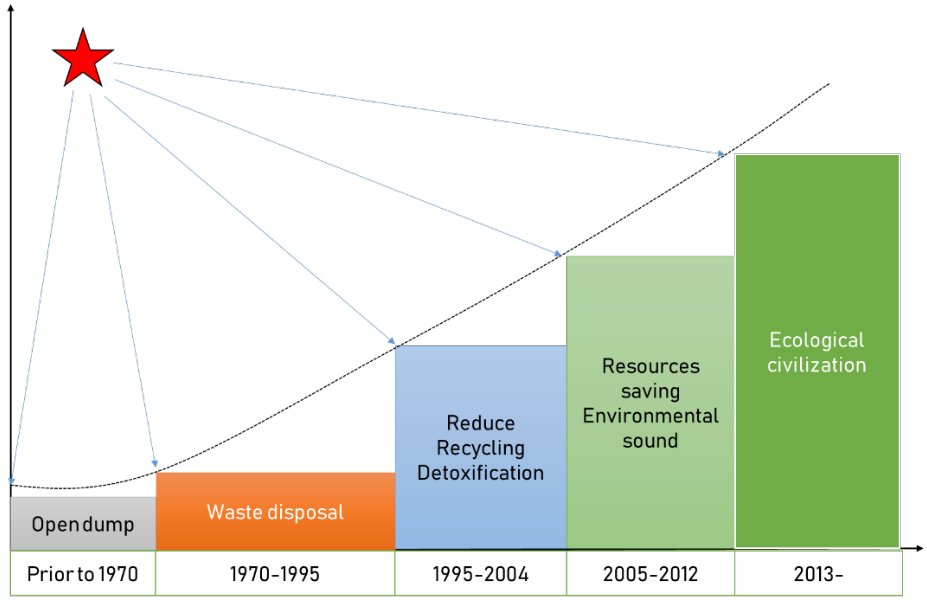


FIGURE 4 CHINA'S ADVENTURE OF INDUSTRY AND POLLUTION CONTROLLING

(1) Before 1970

In order to improve circular economy subject to resource efficiency and waste recycling, the SMEs is gathered and scaled up, known for IP. The traditional IP can be tracked back to 1950s. But the IP was characterized with the leader by the national enterprise in remote place. They had no the relevant facilities and single industry type so that they were the mixed industry with labor and intensified land between pollution and non-pollution. There was no legislation system on environmental protection and waste recycling. Almost all the industrial waste and municipal solid waste were disposed with open dump without environmental consideration. Additionally, there was lack of technical process for waste recycling and circular economy (Figure 4).

(2) 1970-1995

In this era, especially after 1980, China's economy was rapidly revived. In 1979, Environmental Protection Law (trial run) was implemented so that the legislation system of environmental protection started to establish and environmental protection was regulated as one national policy. But the philosophy of "pollute first, then clean up" dominated. As a result, waste disposal with simple landfilling was popular without some efficient recycling (Figure 4). Five economic special economic zones and 14 open cities emerged with a couple of economic development zones. Modern IPs were established with feasible land plan and environmental plan. More and more environmental pollution occurred in the cities.

(3) 1996-2004

China's environmental problems are also spilling over into other countries, while other countries affect China's environment through globalization, pollution and resource exploitation. China is already the largest contributor of sulphur oxides and chlorofluorocarbons to the atmosphere. A factor exacerbating many environmental problems in China is that, as a 'world factory', China exports products but consumes natural resources and leaves pollutants behind (Liu and Diamond, 2005). On April 1, 1996, Solid Waste Pollution Prevention Law was enforced so that waste recycling and safety disposal were regulated. In August, 1996, the environmental policy of "one controlling and two meets" were released by State Council: all the industrial source should meet the emission standard, the fifteen types small enterprises should be closed, covering about 84,000 small electroplating, small papermaking, and small chemical plant. Until Dec., 31, 2000, 97.7% of industrial sources met the emission standard, and 93.6% of priority pollution enterprises realized the requirement of emission standard (Su, 2006).

In 2002, China promulgated the SME Promotion Law, which emphasizes SMEs' scientific and technological innovations and upgrading. In 2004, China amended the constitution to grant non-state-owned firms a legal status. Since most SMEs are non-state-owned, such a legislative move shows China's broad acknowledgement of the importance of the private sector, which in turn is conducive to the further development of SMEs.

Regarding the IPs, they had established more strong link with the city, and served more functions like housing, entertainment, and trade. In 2002, 49 national economic development zones obtained the GDP of 311 billion CNY and their total industrial output value reached 78.7 billion CNY. With the updating of global industry structure, IP was transformed into high-tech development zone. In 2000, 53 high-tech zones had gained 794.2 billion CNY with the annual increasing rate of 60% in the year of 1990-2000.

(4) 2005-2012

China's economy, dominated by polluting, low efficiency industry, is gradually being replaced by a circular economy that applies the principles of "reduce, reuse, and recycle" and uses one facility's waste as another facility's input. In 2005, China State Council initially issued the requirement of circular economy development, and formulated Outline of the National Program for Long - and medium - term Scientific and Technological Development (2006-2020). Later, China released Circular Economy Promotion Law in August 2008, Thus, it is almost consensus that fulfilling circular economy can solve the problem of economic growth and resource shortage. By the end of 2010, there was 83 national high-tech development zones and 107 national economic development zones. All the provinces, almost all the cities and counties has established industrial parks.

With respect to the IP, in order to further improve the performance of circular economy, in March 2012 National Development and Reform Commission (NDRC) and the Ministry of Finance released the opinions on the promotion of circular-transformation of IPs.

(5) 2013-update

On January 1, 2015, a new environmental protection law (EPL) took effect in China. It is the nation's first attempt to harmonize economic and social development with environmental protection. The EPL is perceived as the most progressive and stringent law in the history of environmental protection in China. It details harsher penalties for environmental offences — for example, for acts of tampering and falsifying data, discharging pollutants covertly and evading supervision. It contains provisions for tackling pollution, raising public awareness and protecting whistle-blowers. It places more responsibility and accountability on local governments and law-enforcement agencies and sets higher standards for enterprises. Totally, more than 100 environmental laws and policies have been enacted since the 1970s.

In industrial practice, circular-transformation of IPs was one of the major circular economy construction demonstration programs in the 12th Five-Year Plan issued by the China State Council. It comprised of 7 major tasks to transform traditionally high resource and energy intensive production into high efficiency and low pollutant production. By 2017, 129 industrial parks had been approved for circular-transformation of IPs by NDRC.

2.2 Regulation and policy in greening SMEs

Historically, the attitudes as regulation and policy of government to SMEs have varied considerably: at the initial phase, SMEs were motivated to promote the economic progress. When the environmental problems came out from SMEs, the government set regulation or law to control their manners. Regulation and policy server as the lever to adjust and green SMEs in recent decades. Main regulations and policies can be seen at Table 2.

TABLE 2 EXAMPLES OF POLICIES, GUIDANCE AND REGULATION FOR CIRCULAR ECONOMY PUBLISHED DURING 2005-2016

NO.	Title	Year	Source

1	Opinions on Accelerating Growth of Circular Economy	2005	The State Council
2	Recovery and Management measures on renewable resources	2007	The State Council
3	The Regulation for the Administration of collection and Treatment of Waste Electrical and Electronic Equipment (Chinese WEEE)	2008	The State Council
4	Notice on demonstration base construction of Urban mining	2010	National Development and Reform
5	12th five-year plan of Mineral resources saving and comprehensive utilization	2011	The Ministry of Land and Resources
6	12th five-year plan of Major industrial solid waste comprehensive utilization	2011	The Ministry of Industry and Information Technology
7	Implementation plan of comprehensive utilization of crop and straw during 12th five-year plan	2011	NDRC, the Ministry of Finance, the Ministry of Agriculture
8	The opinions on the promotion of circular-transformation of Industrial parks	2012	MDRC, the Ministry of Finance
9	Comprehensive utilization of resources guidance during 12th five-year plan	2012	NDRC
10	Circular economy development strategy, and the recent action plan	2013	The State Council
11	Action plan of Energy development strategy （2014-2020）	2014	The State Council
12	Opinions about Pushing the Construction of Ecological Civilization	2015	The State Council
13	Guide Plan for Circular development (Draft open to public advice)	2016	NDRC

Before China making a clear definition of urban mining in 2010, policies are established for renewable resources and circular economy. The Chinese government initiated the establishing of venous industrial parks in 2006 and the development of renewable resources industry was seen as an important part of circular economy in the 11th five-year plans. The subsequently proposed major measures to create a resource-saving and environment-friendly society further reveal the determination of the country on sustainable development and renewable industry. Base on pilot cities on recycling renewable resources and venous industry parks, industry chain was gradually formed composing collection, transport, sorting and treatment in many areas, which show a potential for the building of a national urban mining and industrial development pattern.

To promote the scale-up and industrial development of urban mining industry, to elevate the utilization level of urban mining, the NDRC and Ministry of Finance issued the notice for establishing national pilot bases for urban mining in 2010 to cover the shortage of lacking natural resources and to alleviate the tense on resources and environment for socio-economic development. This notice defines the concept of urban mining and means the government formally acknowledge and accept urban mining, and direct plan the layout of pilot bases, which is a major shift of national view and strategy on resources. By July 2017, 43 national pilot bases had been established shown in Figure 5. The present regional distribution of national pilot bases shows a pattern of more locating in southeast and less in northwest, which is closely related to regional economic development level. A dense distribution of pilot bases around coastal areas can be attributed to easy importation of renewable resources. Regional centers aggregating a large amount of resources are formed around the existing waste materials exchange market. These bases mainly located in 3 regions, including those in Circum-Bohai Sea Region to utilize renewable resources home and abroad, the ones in Yangtze River Delta region to produce high-value-added products relying on technology advantages, and the ones in Central Region to comprehensive develop urban mines under the background of the regional economy.

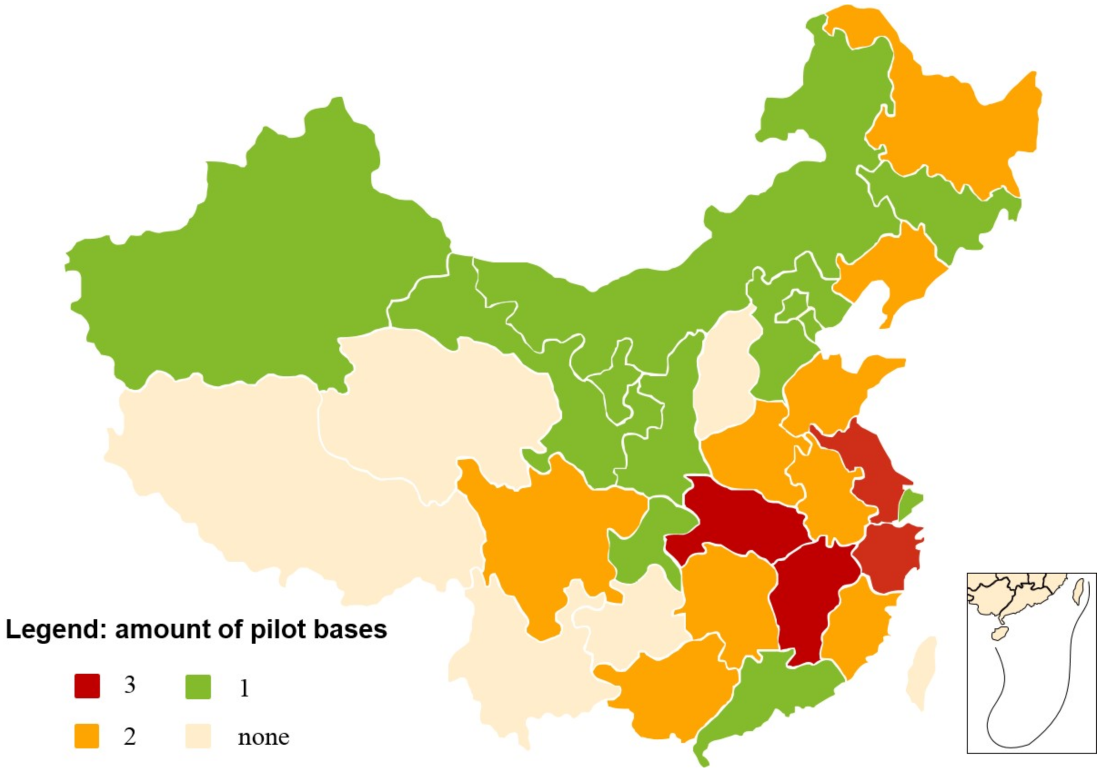


FIGURE 5 DISTRIBUTION OF URBAN MINING DEMONSTRATION BASES IN CHINA

Urban mining industry is considered as an important strategic emerging industry in the national development plan of strategic emerging industries during the 13th five-year period issued by the State Council in Nov. 2016. It is required to promote urban mining and the utilization on wastes with low recycling value. In April 2017, 14 ministries and commissions joint issued the Action Plan for Circular Economy Development targeting an improvement of resource productivity of 15% than 2015, and a recycling rate of 54.6% for main kinds of wastes. The building of a new strategic guarantee system on resources is one of the main objectives in this action plan.

2.3 Technical process in greening SMEs

Technical process is the hard motivation to green SMEs. Its dynamic evolution is ignited with the development adventure of IP and urban mining base in mesoscopic level (Figure 6). We will address the detailed cases to illustrate the technical process in Chapter 3.

With the circular economy, this technical strategy includes (1) design devices for disassembly, (2) materials for substitution, (3) manufacturing processes that enable the use of recycled materials, (4) fabrication efficiency, (5) technology interventions to enable e-waste recovery, (6) methods to collect and separate e-waste components, (7) technologies to digest and recover RESE, and (8) technologies to separate commercially desirable, high-purity outputs (O'Connor, 2016).

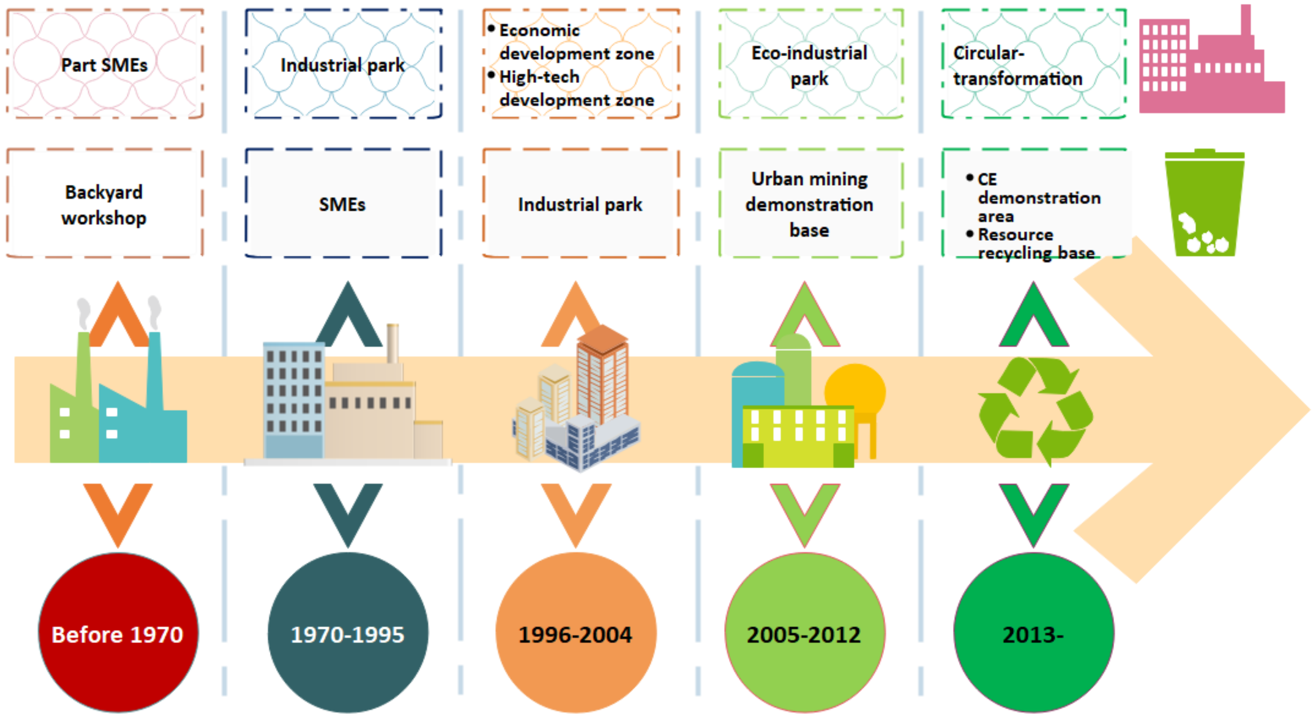


FIGURE 6 EVOLUTION OF GREENING SMES TO IP AND URBAN MINING BASE

Chapter 3: Learning from Chinese experience assess the future perspectives of circular economy in greening SMEs in Asia-Pacific

3.1 Improving resource efficiency and recycling rate in China

3.1.1 RESOURCE EFFICIENCY PERFORMANCE

On Dec., 27, 2016, Chinese government released *Assess Indicator System of Circular Economy Development* (2017 edition). Two main indicators were presented as resource productivity (or efficiency) and waste recycling rate. Resource productivity is the quantity of good or service (outcome) that is obtained through the expenditure of unit resource. This can be expressed in monetary terms as the monetary yield per unit resource. It is commonly used in sustainability measurement as they attempt to decouple the direct connection between resource use and environmental degradation.

Higher resource productivity means that a higher GDP can be generated using less resource, raw material and energy. Resource productivity has been significantly increasing since 2005. Resource productivity of coal grew from 1450 US$/t in 2005 to 1800 in 2010 (Figure 7). From 2011 to 2015, the energy consumption per GDP decreased by 2.0%, 3.6%, 3.7%, 4.8%, and 5.6% respectively (NBS, 2016a). According to the newest report, energy consumption for the first half year decreased by 5.2% compare with energy consumption in 2015 (NBS, 2016c). In terms of water resource productivity, water consumption for generating 10,000 CNY GDP declined 70% in the last decade (Figure 8). Higher energy efficiency can reduce the coal consumption when generating the same GDP, and therefore make contribution to carbon emission reduction.

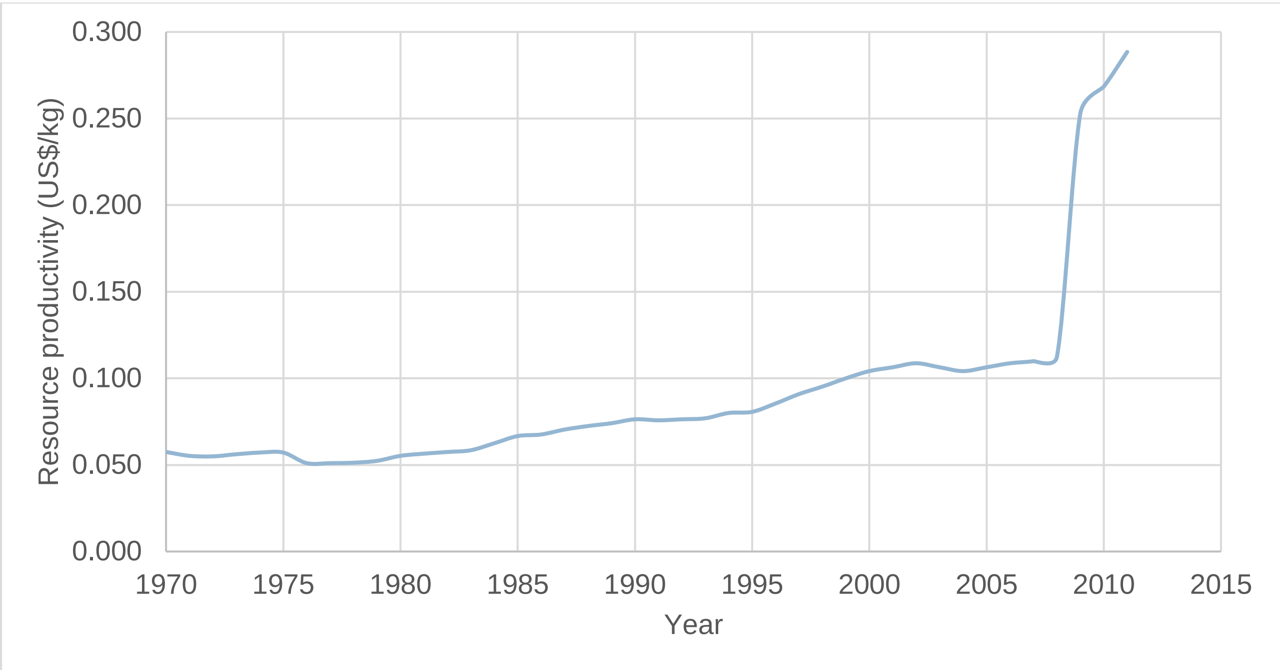


FIGURE 7 EVOLUTION OF RESOURCE PRODUCTIVITY IN CHINA

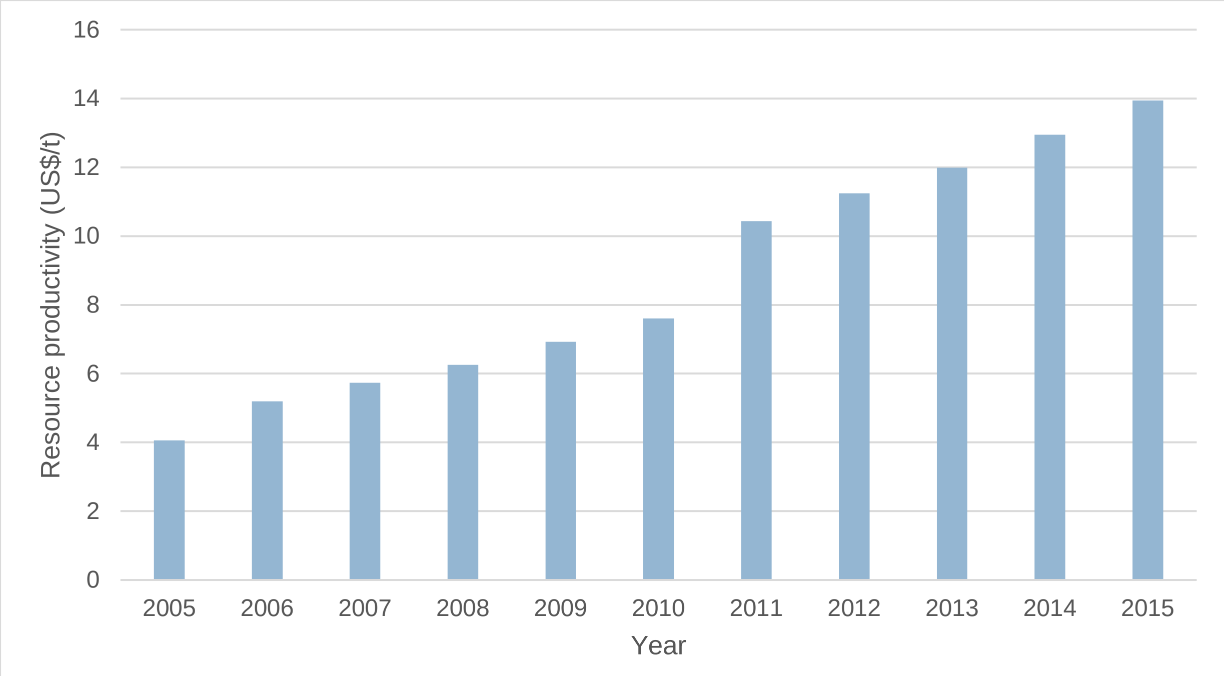


FIGURE 8 RESOURCE PRODUCTIVITY OF WATER IN THE YEAR OF 2005-2015

3.1.2 RECYCLING RATE PERFORMANCE

Along the supply chain, circular economy consists of clean production, resource utilization, waste recycling, and sustainable consumption, which is characterizing of reduce, reuse, and recycling (called as 3R). Recycling is the most substantial part in developing circular economy. In the past years, China put much endeavor on recycling of waste and renewable resources. Main concerned renewable resources involve iron and steel, non-ferrous metals, plastic, paper, tire, e-waste, end-of-life vehicle (ELV), boat, battery, and glasses.

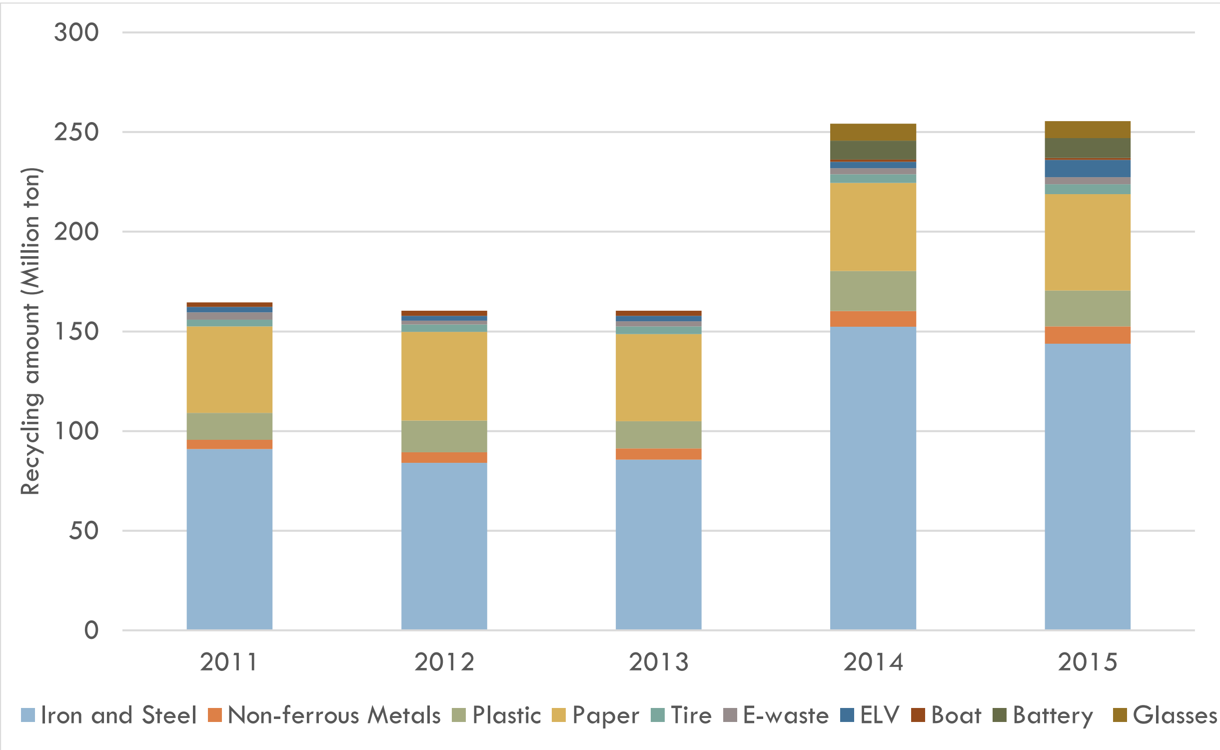


FIGURE 9 RECYCLING VOLUME OF 10 MAIN RENEWABLE RESOURCE FROM 2011-2015 (MILLION TON). NOTE: DATA SOURCE FROM MINISTRY OF COMMERCE.

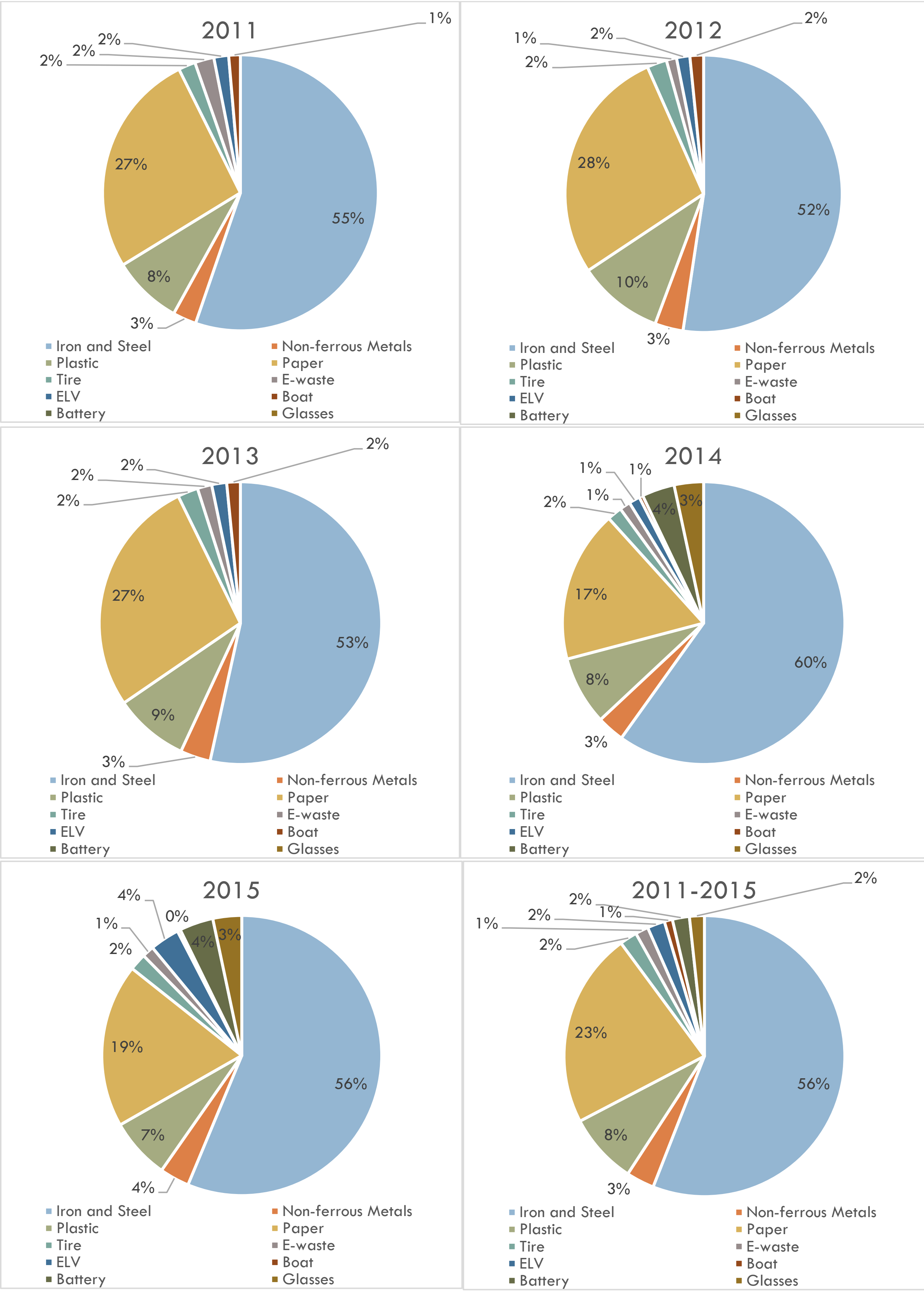


FIGURE 10 RECYCLING STRUCTURE OF 10 MAIN RENEWABLE RESOURCE FROM 2011-2015 (MILLION TON). NOTE: DATA SOURCE FROM MINISTRY OF COMMERCE.

3.2 Greening manufacturing process: case study of pulp and paper industry

3.2.1 WHY FOR PULP & PAPER INDUSTRY CONCERN AS CASE STUDY?

Paper and paper products are important resources for socioeconomic development. Pulp & paper industry (PPI) comprises companies that use wood as raw material and produce pulp, paper, paperboard and other cellulose-based products. China has become the world largest paper and paperboard producer. China produced 107.1 million tons of paper and consumed 103.52 million tons of paper in 2015 (China Paper Association, 2017). In 2014, there were nearly 3000 paper manufacturing companies in China that produced 0.1 billion tons of paper and paperboard, occupying 25% of the world total production (Yu, et al., 2016).

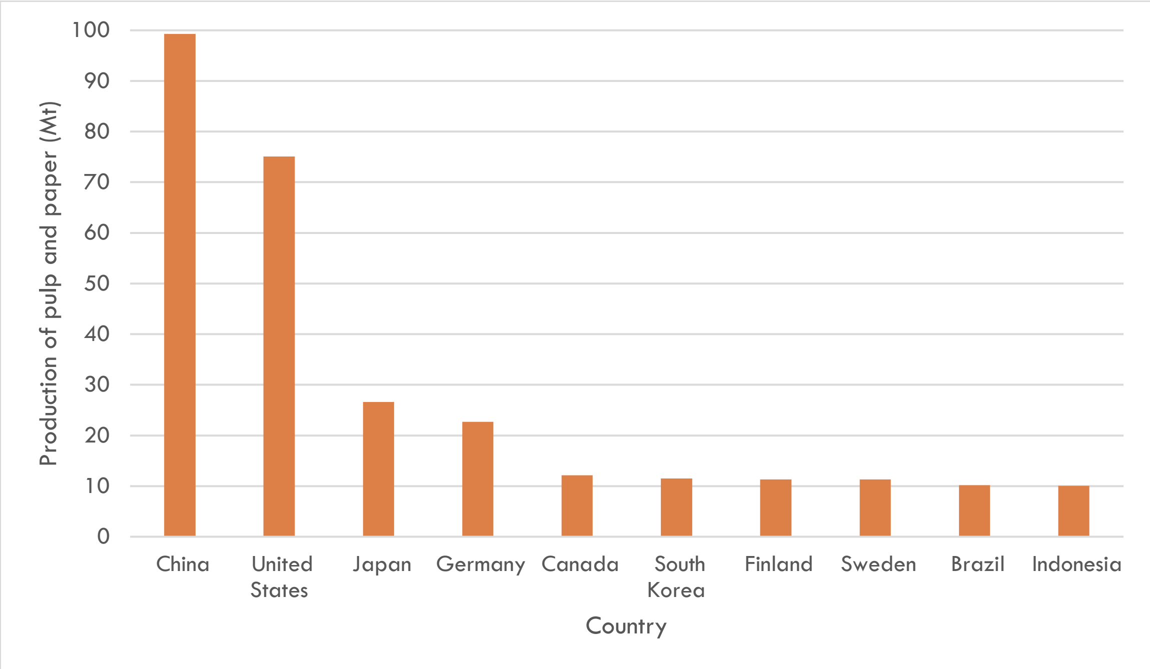


FIGURE 11 PRODUCTION OF PULP AND PAPER IN 2011 (MT). SOURCE: HTTPS://EN.WIKIPEDIA.ORG/WIKI/PULP_AND_PAPER_INDUSTRY

Generally, PPI is energy and raw materials intensive, with high capital costs and long investment cycles. The industry has an excellent track record in resource efficiency and innovation. Thanks to its knowledge of wood fiber, PPI is at the forefront of developing innovative products alongside more traditional products. It is a pioneer in making the EU low-carbon bioeconomy an industrial reality.

But PPI contributes to air, water and land pollution and discarded paper and paperboard make up roughly 26% of solid municipal solid waste in landfill sites. Pulp and paper generates the third largest amount of industrial air, water, and land emissions in Canada and the sixth largest in the United States. Worldwide, PPI is the fifth largest consumer of energy, accounting for four percent of all the world's energy use. However, the entire paper and printing sector contributes less than 1% to the global greenhouse gas inventory due to the very high use of renewable energy, mostly biomass.[1] PPI in China also has adverse impacts on resource demands and pollutant emissions while PPI uses more water to produce one ton of product than any other industry.

3.2.2 GREENING PERFORMANCE OF MANUFACTURING PROCESS IN RECENT DECADES YEARS

After the establishment of new China, China's PPI has experienced six decades' adventure. A significant evolution occurred from scratch, from small to big, from weak to strong, from coarse to fine, and from traditional to modern. At least five phases can be divided from the experience of China's PPI (Cao, 2009).

[1] https://en.wikipedia.org/wiki/Environmental_impact_of_paper

(1) Basic phase for three years' rehabilitation and the first-five year (1949-1957)

A few PPI companies were established so that the added yield of paper & paperboard was 0.338 million tons. The yield of paperboard grew from 0.108 million tons in 1949 to 0.911 million tons in 1957 with the annually increasing rate of 30.6% (Figure 12). The self-sufficiency ratio of product was raised from 79.3% in 1950 to 95.3% in 1957. But there was no any legislation system for manufacturing and environmental protection, and there was lack of technology for cleaner production and waste recycling.

(2) Zigzag progress for three years' great leap forward and the second-five year (1958-1965)

The policy of "two legs working" was adopted so that numerous small PPI companies were created with the small, crude, and group characteristics. The added 1850 companies resulted in a sudden growth of the national yield of paper and paperboard from 1.22 million tons in 1958 to 1.80 million tons in 1960, with the annual increasing rate of 21.5% (Figure 12). The distinct problems were black, rough, and thick of paper in the years. At the duration of 1961-1965, China entered into the adjustment period of national economy. The PPI enforced the policy of "adjustment, strengthen, enrich, enhance" so that some crude PPI companies were closed, stopped, combined, or changed. In this duration, although most PPI companies just discharged their pollutants while manufacturing, no significant pollution occurred owing to few pollutants. But there was also no any legislation system for manufacturing and environmental protection, and there was lack of technology for cleaner production and waste recycling.

(3) Wandering stage for ten years' disturbance and the year of 1977

The year of 1966-1976 was the ten years' disturbance of the Great Proletarian Cultural Revolution. PPI went down without professional and proper management, and the yield declined in 1967 and 1968. In the ten years, total yield grew from 2.09 million tons to 3.41 million tons with the annual increasing rate of 5% (Figure 12). After the disturbance, PPI were boosted again and in 1977 the yield reached 3.77 million tons. But there was also no legislation system for manufacturing and environmental protection, and there was lack of technology for cleaner production and waste recycling. The awareness of environmental protection was raised at the start.

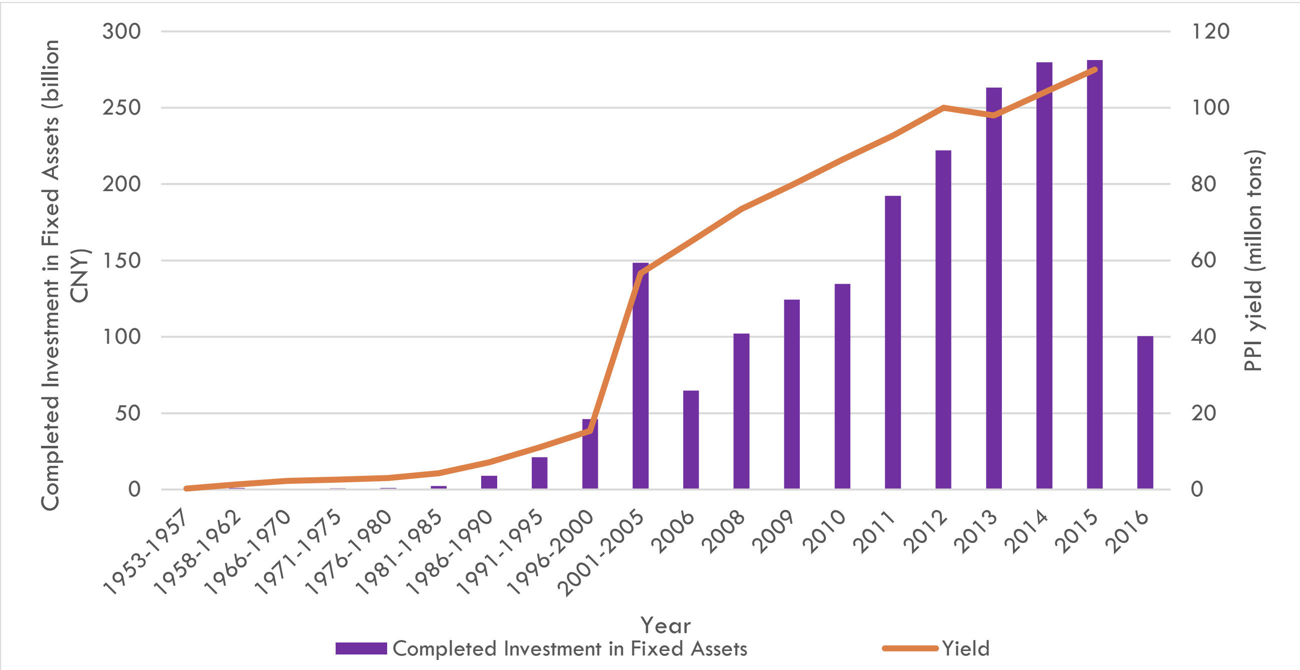


FIGURE 12 PPI INDUSTRY IN CHINA SINCE 1953

(4) Rapid progress stage the year of 1978-2008

National priority of work was transmitted in 1978. Thus, PPI entered into the new development stage. The reform and opening-up provided some opportunities. This duration could be regarded as the largest increase, the rapidest development, and the best quality for China's PPI. The yield grew from 4.39 million tons in 1978 to 79.8 million tons in 2008 with the annual increasing rate of 10.2%, which was over 6-7 percent of global increasing rate (Figure 12).

With obsolete technology, equipment, and management, the Chinese PPI is recognized as being one of the most highly polluting sectors. Its plants discharged 3,214,000 t/a of COD in 1995, accounting for 41.8% of the overall industry pollution load of China (Ren, 1998). Non-wood pulp and paper companies are of particular concern, as most of them are SMEs. Efficiency of resource usage at these SMEs is extremely low compared with the international average.

Almost all the PPI companies belong to SMEs. In this phase, especially in the year of 1978-2000, the rapid progress of PPI heavily relied on simple duplication and expanding from big cities to all cities around China. This linear economy is characterized with high consumption, high input, and high pollution. To protect the environment and resource, a couple of laws, regulations, and standards have been formulated and make up of China's legislation system. In 1978, the piece of protecting the environment and natural resource was listed in China's Constitution Law. And in 1979, China's Environmental Protection Law was initially enforced on trail, with the focus on the end-of-pipe (EoP) treatment for waste water, waste air, and solid waste. In 1980s, the framework of legislation system came into being and enabled three principles: Prevention first, combining prevention; polluter pays; and enhancing environmental management. Water Pollution Prevention Law and Air Pollution Prevention Law were implemented. In 1990s, three great transformations for manufacturing industry, i.e. PPI, were proposed as transformation from EoP to comprehensive controlling, transformation from single concentration controlling to the combined controlling with concentration and total amount, and transformation from decentralized governance to the combined governance of decentralization and convergence. Solid Waste Pollution Prevention Law was enacted. After 2000, the life cycle management was realized and translated into some new laws, typically for Cleaner Production Promotion Law and Circular Economy Promotion Law. All the measures are summarized here and shown in Table 3.

TABLE 3 THE MAIN MEASURES FOR REDUCING ENVIRONMENTAL IMPACT OF CHINA'S PPI.

Time	Laws, regulations, standard, and measures related to PPI
1994	Six paper companies were selected as the first batch of pilots for cleaner production audit and training in the program of UNEP
1995-1996	• Fifty-four cleaner production projects were implemented in these 6 companies. • Guide of Cleaner Production for Paper and Pulp Making Industry (on trial) was completed.
1996-1997	The second batch of pilots for cleaner production audit and training was initiated in 9 paper companies.
1998-1999	The third batch of pilots for cleaner production audit and training was initiated in 12 paper companies.
2005	The National Environmental Protection Control Standard for Imported Solid Wastes as Raw Materials e Waste and Scrap of Paper or Paperboard (GB 16487.4-2005)
2006	• Evaluation Indicator System of Cleaner Production for Pulp and Paper Industry (on trial) • Cleaner Production Standard - Process of Bleached Alkali Bagasse Pulp in Paper Industry (HJ/T 317-2006)
2007	Cleaner Production Standard - Production of Bleached Soda Straw Pulp and Paper Industry (HJ/T 339-2007) Cleaner Production Standard - Production of Kraft Chemical Wood-Pulp and Paper Industry (HJ/T 340-2007)
2008	The National Discharge Standard of Water Pollutants for Pulp and Paper Industry (GB3544-2008)

2009	*Circular Economy Promotion Law*
2009	Cleaner Production Standard - Waste Paper Pulping (HJ 468-2009)
2011	The National 12th Five Year Plan for Environmental Protection listed PPI as a key industry for water consumption and pollution reduction. The 12th Five Year Plan for Pulp and Paper Industry was issued by the NDRC, the Ministry of Industry and Information Technology and the State Forestry Administration. The National Standard of Water Saving Enterprises e Pulp and Paper Making Industry (GB/T 26927-2011)
2012	Revised *Cleaner Production Promotion Law*
2012	The Technical Specifications for Pulp and Paper Industry Wastewater Treatment (HJ 2011-2012) was published by the Ministry of Environmental Protection.
2015	Revised *China's Environmental Law*
2015	The Action of Water Pollution Prevention Plan issued by the State Council of China has required PPI to reduce water pollution. The Indicator System of Cleaner Production for Pulp and Paper Industry was jointly issued by the NDRC, the Ministry of Environmental Protection and the Ministry of Industry and Information Technology. This integrated indicator system has replaced the one on trial published in 2006 and the cleaner production standards of HJ/T317-2006, HJ/T 339-2007, HJ/T 340-2008 and HJ 468-2009.
2016	Revised *Solid Waste Pollution Prevention Law*
2016	The National 13th Five Year Plan for Environmental Protection listed PPI as a key industry for water consumption and pollution reduction. Assess Indicator System of Circular Economy Development (2017 edition)
2017	Environmental Protection Regulation of Imported Waste Paper or Paperboard Environmental protection control standard for imported solid wastes as raw materials-Waste and scrap of paper or paperboard (GB 16487-2017)

TABLE 4 SOME SMES' INTERNAL CHANGES IN RESPONSE TO REGULATION REFORM (WANG ET AL., 2011)

Name	Environmental investment [a]	Cleaner technology adoption[b]	Environmental management
Huatai	0.8 Billion Yuan	● Alkali recovery system ● Water recycling system ● Close all straw pulp production line, and change to wood pulp and waste paper pulp; ● COD<60 mg L^{-1}	ISO14001
Sun	1 Billion Yuan	● Water recycling system ● Forestry-pulp-paper integration project ● COD<60 mg L^{-1}	ISO14001
Chenming	1 Billion Yuan	● Grey water treatment system ● Sulfur removal system ● COD<50 mg L^{-1}	ISO14001
Quanlin	N/A	● Straw pulp waste liquor hazard-free treatment ● COD<100 mg L^{-1}	ISO14001
Bohui	0.66 Billion Yuan	● Active carbon absorption system; ● Water recycling system; ● COD<50 mg L^{-1}	–
Yataisenbo	N/A	● Flocculation-air flotation treatment system ● COD<70 mg L^{-1}	ISO14001

Many technical processes in PPI companies have been developed towards cleaner production and circular economy (Table 4). Driven by the laws and technology, despite of rapid increase in yield and total energy consumption, the average energy consumption has been declined since 1985 (Figure 13). In 1985, it was over 2 tons' standard coal per ton yield, but went down to 0.75 in 2000 and around 0.5 in 2008. Over 2000 companies has been shut down, eliminating ten million tons yield.

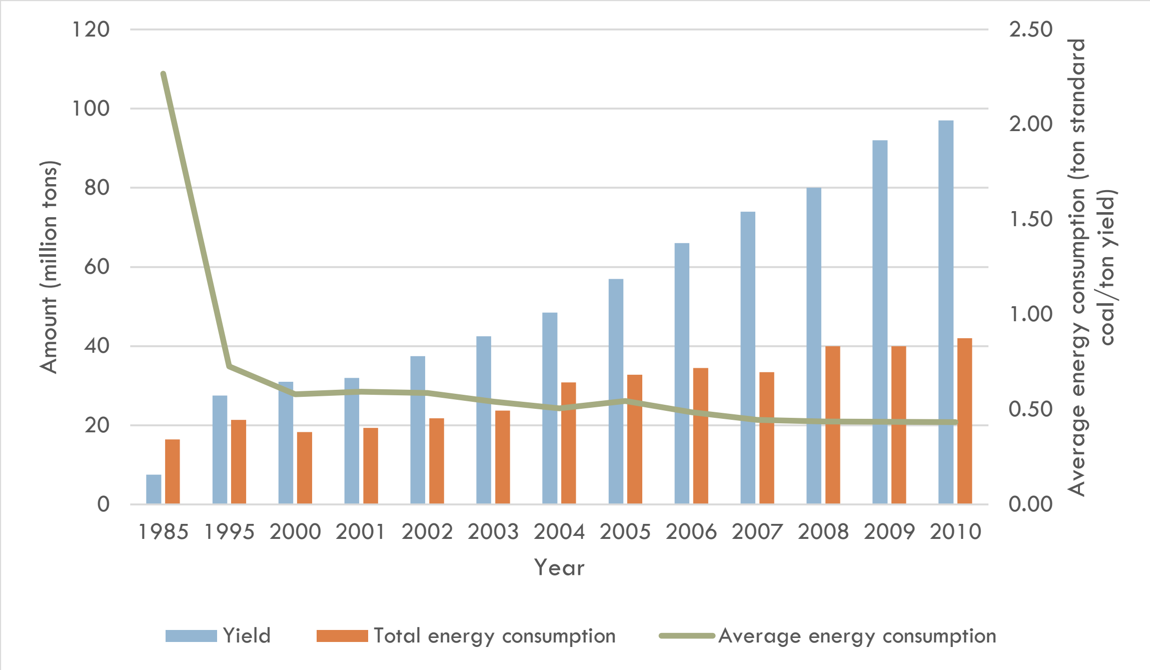


FIGURE 13 PAPER AND PAPERBOARD IN 1985-2010: YIELD AND ENERGY CONSUMPTION

(5) Ecological civilization stage (2009-update)

In the last decade the Chinese government has realized the need to create not just a prosperous and technologically sophisticated society but an "ecological civilization (restructuring the economy to achieve man-nature, production-consumption harmony)" based on its cultural and religious traditions. Instead of setting a specific target for the economic growth in his report to the 19th National Congress of the Communist Party of China, President Xi Jinping proposed an ambitious blueprint of ecological civilization. To achieve this goal, China's economic development must transition from "quantity first" to "quality first." China also plans to accelerate the process of environmental protection (Xiao and Zhao, 2017).

China's PPI has come into a new period stage with reaching its peak. On September 21, 2009, China Paper Association and China Technical Society of Paper Industry chaired the Green Development Forum of China's PPI. Thirty-four advanced companies released the green development declare. Many laws, regulations, and standards have been revised or enacted (Table 3). For instance, Circular Economy Promotion Law was initially enforced in 2009, and Cleaner Production Promotion Law was revised in 2012. On January 1, 2015, a new environmental protection law (EPL) took effect in China, which is perceived as the most progressive and stringent law in the history of environmental protection in China. It details harsher penalties for environmental offences — for example, for acts of tampering and falsifying data, discharging pollutants covertly and evading supervision. It contains provisions for tackling pollution, raising public awareness and protecting whistle-blowers. It places more responsibility and accountability on local governments and law-enforcement agencies and sets higher standards for enterprises (Zhang and Cao, 2015). And in 2016, Assess Indicator System of Circular Economy Development (2017 edition), with two main indicators of resource efficiency and recycling rate, was released to formalize the practice of circular economy.

In the technical level, many processes of manufacturing and waste recycling have been developed and upgraded in recent years. The cleaner production and resources recycling have been strengthened substantially. They are illustrated in Table 5.

TABLE 5 TYPICAL CIRCULAR ECONOMY PRACTICES: CLEANER PRODUCTION AND RESOURCES RECYCLING

NO	Item	Content	Goal	Standard

1	Upgrading process for chemical pulp	Using low-energy consumption cooking, oxygen delignification, and free chlorine bleaching process	Reducing 80% emission of AOX, 30 m^3 water/ton pulp, and altering annual 2 million tons pulp	• Each wood pulp process can generate over 0.1million tons • Each bamboo pulp process can annually yield over 51,000 tons • Non-wood pulp can annually yield over 34,000 tons
2	Comprehensive utilization of non-bleaching straw pulp and its product	Using low-energy consumption cooking, oxygen delignification, and residue water recycling process	5% increase of achieved pulp, saving water of 30 m^3/ton pulp	• Each newly-built line can yield over 0.1 million tons. • Each altered line can annually yield over 34,000 tons
3	Altered process of alkali recovery	Using evaporation and combustion process of high solid content black liquor, and new filter process of green liquor and white liquor	30 tons alkali recovery from 50,000 tons of annual yield of pulp, generating 570 tons steam, and reducing 70% of pollution load	The chemical pulp system can annually yield 50,000 tons
4	Anaerobic digestion and its gas utilization	Anaerobic digestion for high content waste water, and biogas power generation	One kg BOD generates 1 m^3 biogas, and reducing 70% of pollution load	Waste pulp can yield over 0.1 million tons for each line
5	Combined heat and power	Improve energy efficiency using combined heat and power	The combined heat and power project with over 6 million watt can save 15,000 standard coal	Over 1.5 million watt

Dirven by laws and technical process, the PPI has achieved the significant economic benefit and environmental benefit. Although the total water consumption is about 12 billion tons, the discharging waste water has been declined from 4 billion tons in 2009 to 2.5 billion tons in 2014. Water resource efficiency was improved from 40 CNY/ton water in 2009 to 60 CNY/ton water in 2014 with the annual increasing rate of 10% (Figure 14). Currently, there are 4764 SMEs of PPI in China. Most of them localizes in Guangdong, Zhejiang, Hebei, Sichuan, and Fujian. Meanwhile, Guangdong is leading in the number of the production lines, followed by Zhejiang, Hebei, and Hunan (Figure 15(A)). Regarding the waste water generation from PPI, Zhejiang has an amount of 717 Mt, followed by Guangdong, Shandong, Henan, and Hebei. The rank of COD generation in provinces has the same pattern as the waste water generation. Zhejiang is also leading in COD generation as 0.9 Mt, followed by Shandong, Guangdong, and Henan (Figure 15(B)).

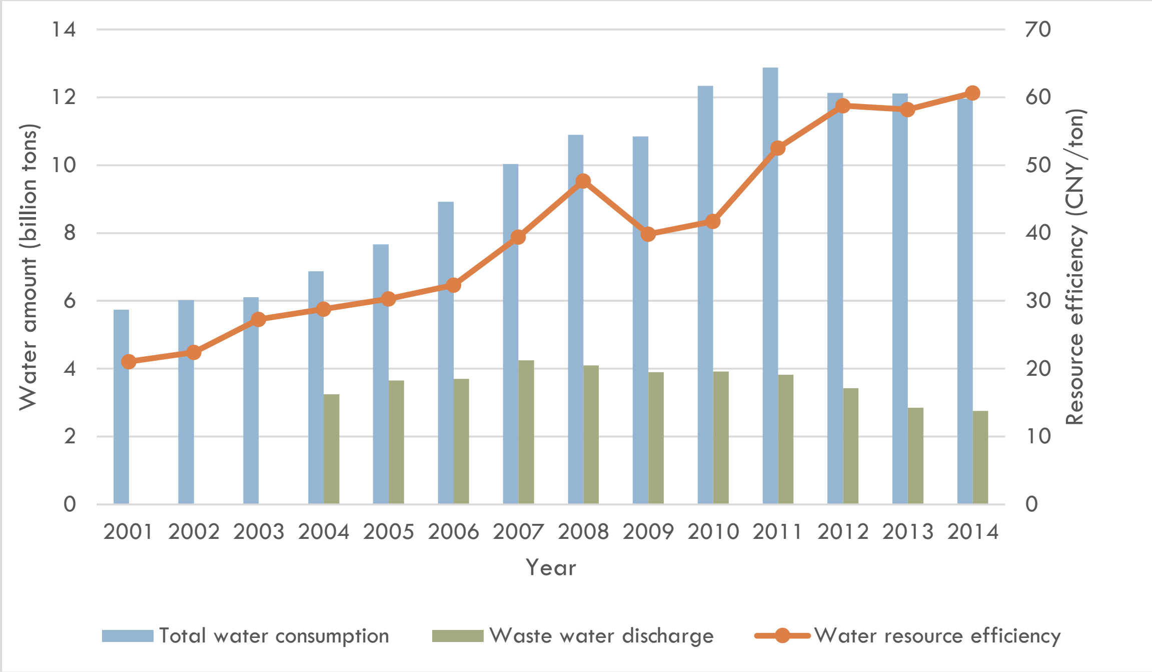
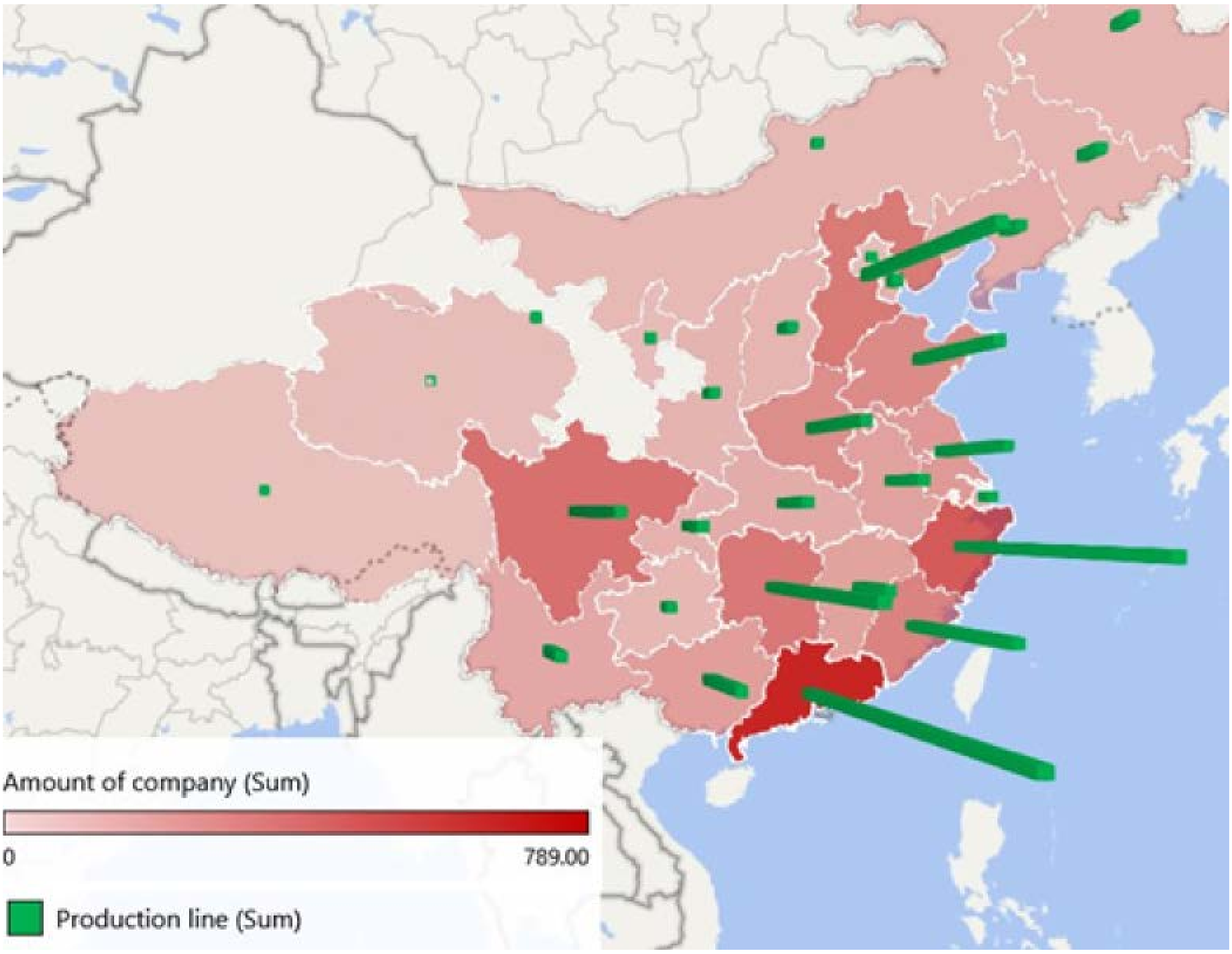
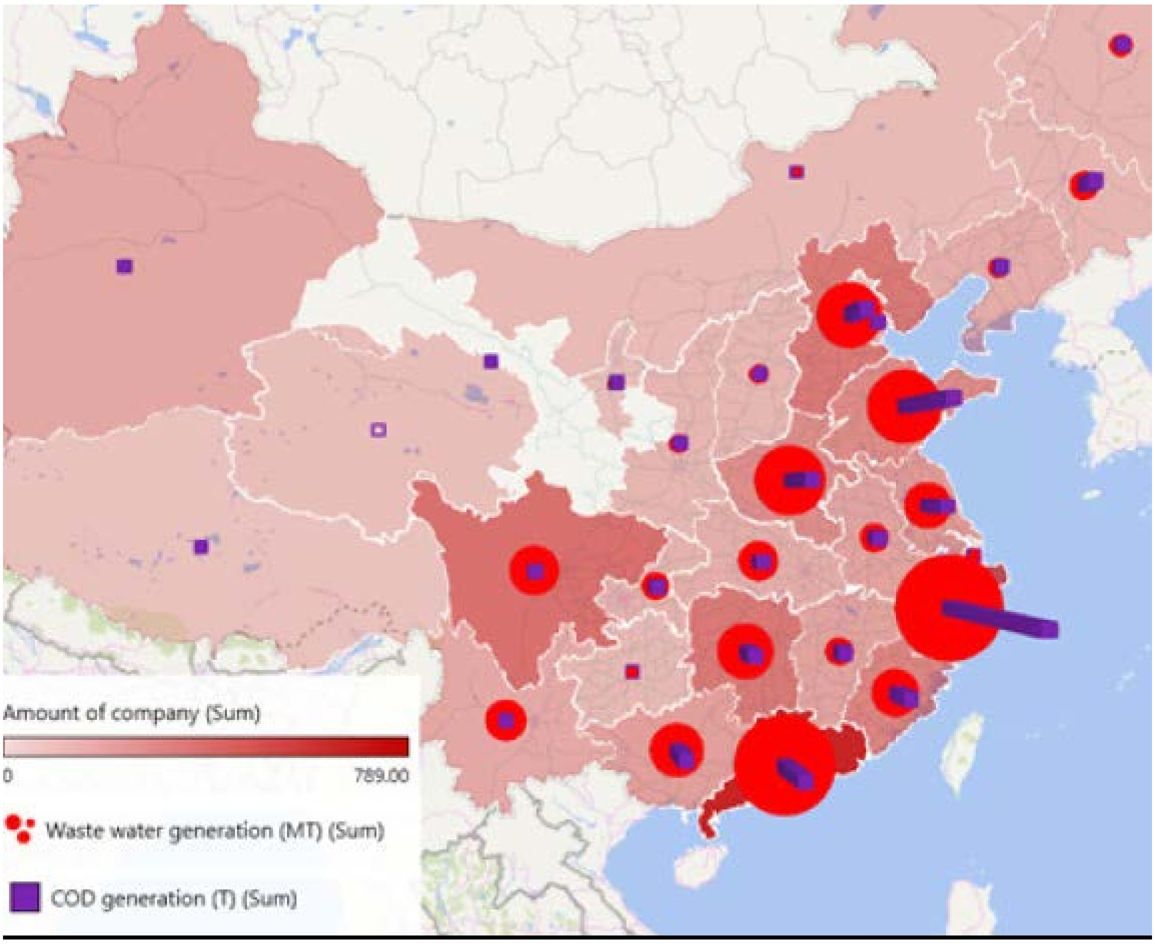


FIGURE 14 PERFORMANCE OF WATER CONSUMPTION IN 2004-2011. DATA SOURCE: CAO, 2016.



(A)



(B)

FIGURE 15 THE STATUS OF CHINA'S PPI FROM PRODUCTION (A) TO ENVIRONMENTAL PERFORMANCE (B)

Data source from Annexes A.3.

In the last two decades, the rapid growth of the PPI in China has run parallel to an increasingly strict and comprehensive control of discharged water pollutants. The adopted actions included large-scale closures of small and backward mills, as well as enforced construction of EoP treatment facilities. To meet long-term water quality objectives, however, China is believed to rely increasingly on the application of innovative technologies.

3.2.3 EXTRACTED EXPERIENCE OF GREENING MANUFACTURING PROCESS

Industry is a typical complex ecosystem from the perspective of social–economic–natural complex ecosystem. The sustainability of such industrial complex eco-systems is crucial for the overall sustainability of the economy and society. The PPI is the most important industrial sector for water pollution control in China. The key issue facing the paper industry with respect to pollution control is black liquor, which is expected to be solved by the continuous pursuit of cleaner production, combined with much reduced EoP treatment. The best available and most economically viable solution lies in alkali recovery for the caustic pulping process, which represents over 70% of the paper production of China. The major means of launching cleaner production have proven to be non/low cost options, which not only cut down pollution quickly and significantly, but also create a sound foundation for high cost changes and a competitive advantage on the market.

The current paper develops a technology-based model to assess alternative water pollution reduction policies in the pulp and paper industry up to 2020. Five policy scenarios are established to represent measures of raw material substitution, eliminating backward small-sized capacities, promoting cleaner technologies, advancing EoP treatment technologies and the integration of all these policies.

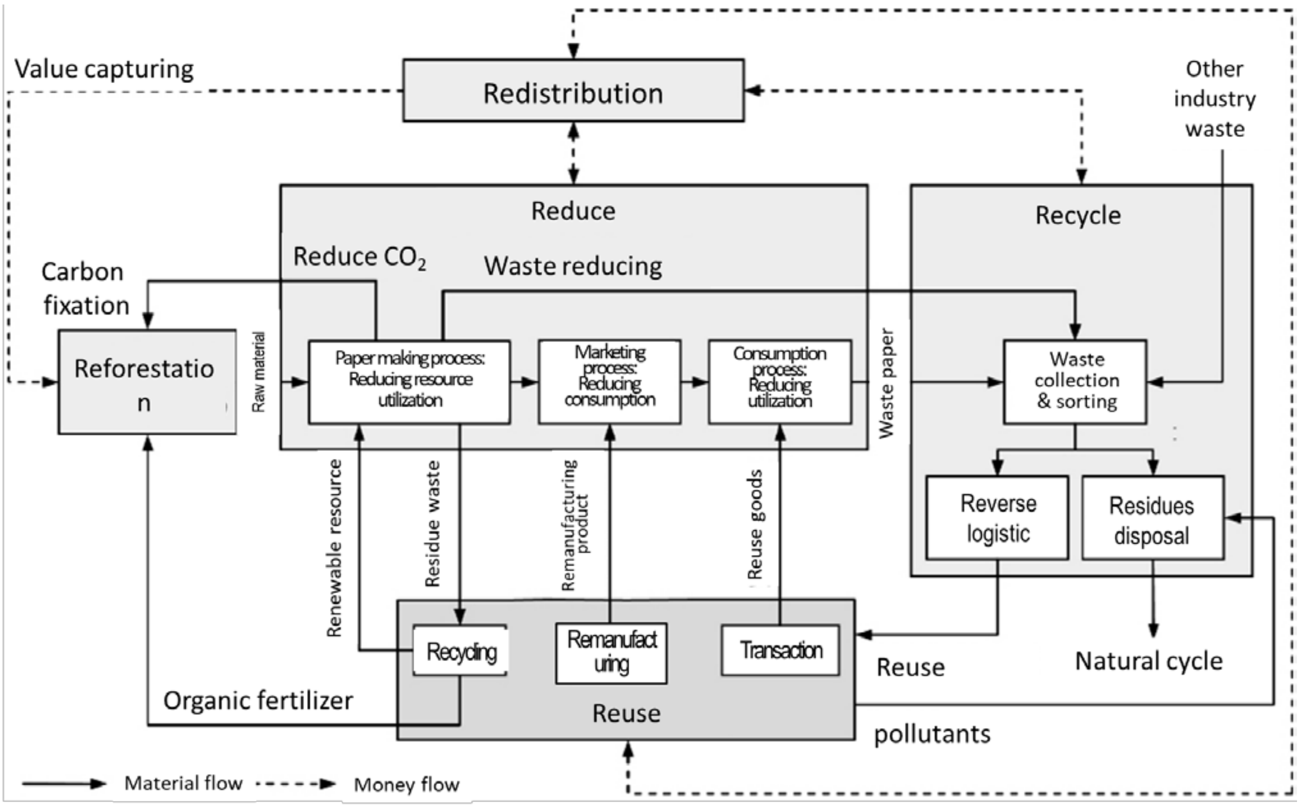


FIGURE 16 THE IDEAL CIRCULAR ECONOMY MODEL IN PPI (ZHANG AND YAO, 2012)

The successful green supply chain of PPI is characterized with green symbiosis of circular economy, the core of PPI enterprises, and the coalition of forestry industry and PPI. The circular economy system of PPI is consisted of resource flow, money flow, and ecological flow in supply chain (Figure 16). It can in essence relieve the negative impact of resource, environment, and ecology imposed by PPI, enhance the forest resource and ecological environment system, and then realize the sustainable development of green supply chain for forestry and paper.

3.3 Greening recycling performance: case study of e-waste management

3.3.1 WHY FOR E-WASTE CONCERN AS CASE STUDY?

Not only does e-waste contain amounts of toxic substances such as lead, cadmium, mercury, polychlorinated biphenyls (PCBs), and brominated flame retardants, but its informal disposal (e.g. open burning, improper acid leaching) in backyards and low-technology recycling enterprises generates additional toxic pollutants, such as polychlorinated dibenzo-p-dioxins and dibenzofurans (PCDD/Fs), Polybrominated dibenzo-p-dioxins and dibenzofurans (PBDD/Fs), and heavy metals. Therefore, e-waste is an emerging and critical environmental issue, and highlights the need for increased resource recycling in both developed and developing countries (Li et al., 2015).

China is not only the largest producer and consumer of EEE, but also the country ever most seriously polluted from illegal e-waste importation and informal recycling (Zeng et al., 2017). Among urban mining, China's adventure in e-waste recycling has attracted global concern since 2000 with the notorious environmental incidents such as Guiyu town as electronic graveyard of the world. China would generate 15.5 and 28.4 million tons of WEEE in 2020 and 2030, respectively, and has already overtaken the U.S. to become the world's leading producer of e-waste (Zeng et al., 2016). Informal recycling of e-waste hasled to a fragile ecological environment, especially in eastern China.

Driven by above-mentioned policies and regulations in China, new e-waste recycling enterprises greatly proliferated. By September 2015, 109 licensed and certified enterprises across the country had been authorized to receive the subsidies (Figure 17), creating a capacity to process 150 million units of WEEE annually. Almost all the enterprises only have about 50-100 employees and around 50-100 million RMB. Based on the definition of SMEs (Table 1), the 109 e-waste recycling enterprises belong to SMEs. China has employed the best available recycling technologies, including: manual dismantling, mechanical treatment, deep recovery, and ultimate disposal. As a result, the total confirmed dismantled volume was around 75 million units in 2016, and the recycling rate of 60% by unit reached the level of developed countries or regions like the U.S. and EU. Formal recycling facilities are now available throughout the country, and informal recycling is shrinking for five types of WEEE.

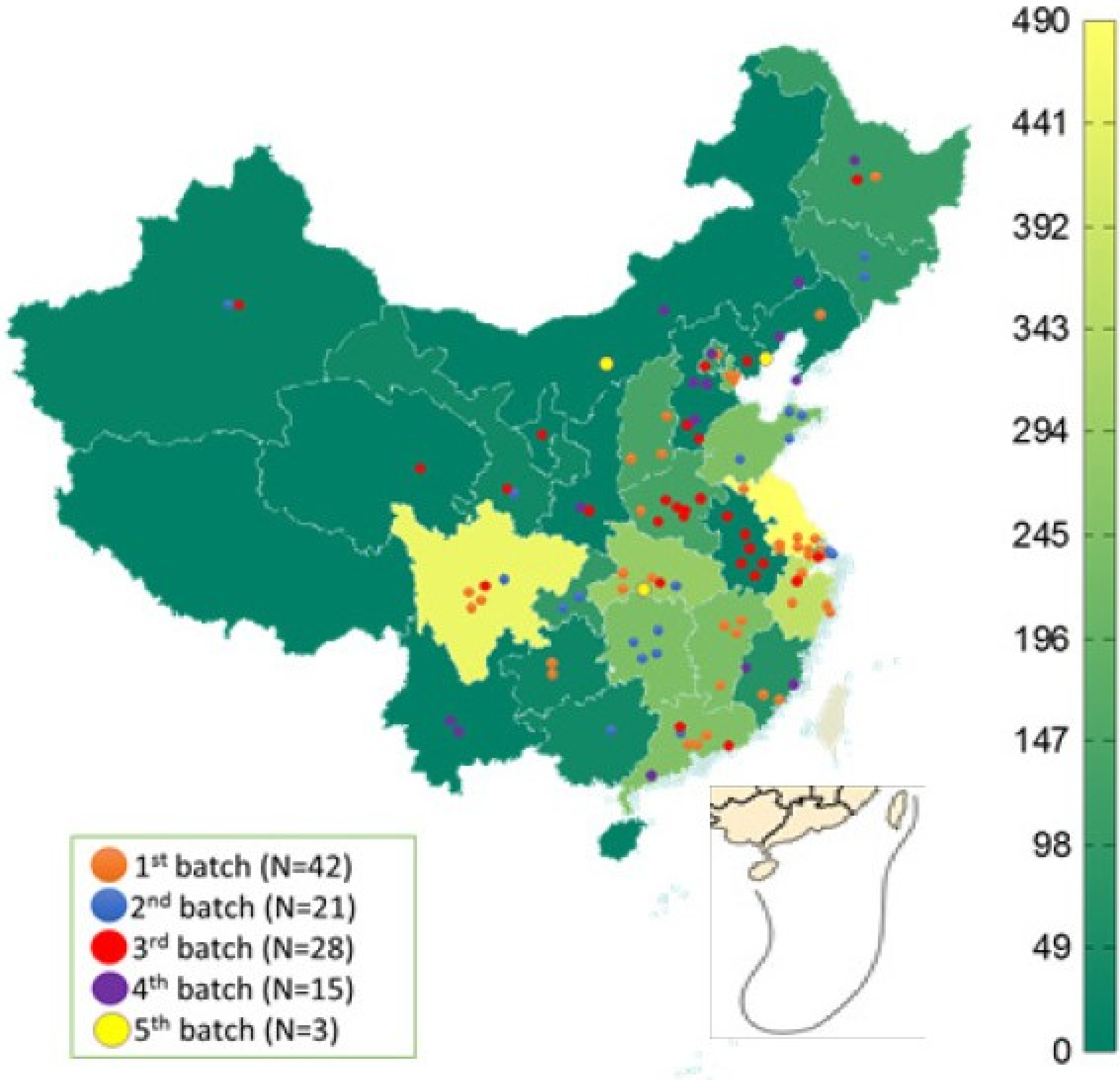


FIGURE 17 DISTRIBUTION MAP OF WEEE DISMANTLING AMOUNT (IN 2013) AND ENTERPRISES IN CHINA (IN 2015).

Note: The unit is $\times 10^4$, and color circles indicate the batches that recycling facilities obtained the license of subsidy. © 2016 Published by Elsevier Ltd. Used after permission.

3.3.2 RECYCLING PERFORMANCE OF E-WASTE AFTER GREENING SMES

(1) Total national performance

As shown in Figure 18(A), the e-waste stream in China is dominated by CRTs from TV sets, which were accumulated by businesses and households but released to the recycling market only after 2011 when WEEE regulation was implemented, allowing recyclers to obtain a standard subsidy for treated e-waste. Yearly supplies of new forms of e-waste such as computers and IT products are growing rapidly in quantities, with 18.6% of computers being recycled by 2016. This exceeds by 4% the level of computers recycled in 2012. A similar landscape can be also found for weight of treated e-waste owing to the heavy weight of CRT TV.

Figure 18(A) demonstrates that in China the dominant form of e-waste comes from CRT TVs, both black & white and color, while the increased use of LCD and plasma TVs has yet to make a mark in the statistics. Meanwhile, other white goods (e.g., washing machine, refrigerator, and air conditioner) in China are starting to be recycled with growing levels of collection as shown in the chart. In 2011 a huge amount of electronics obsolete in past two decades was collected and treated only in one year, so the calculated recycling rate was rather high. Since 2012, both recycling and generation of e-waste have been growing, as shown in Figure 18(B). We also reveal the recycling rates of unit and weight and their rising impact over the years 2012 to 2016, while recognizing that there was a peak in 2011 as accumulated e-waste was surrendered by households after emergence of the economic policy.

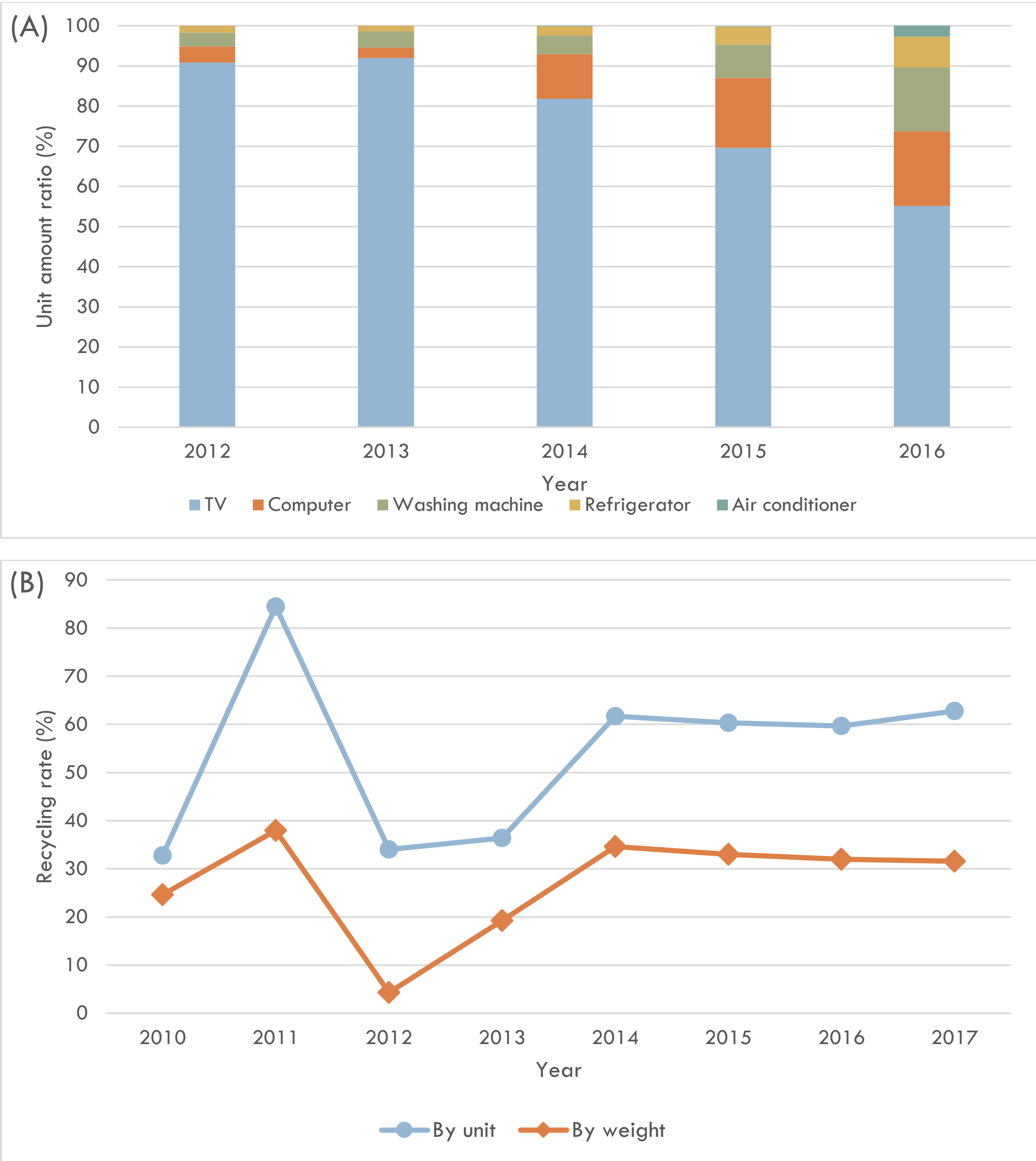


FIGURE 18 CHINA'S FORMAL E-WASTE RECYCLING. (A) AMOUNT SHARE OF TREATED E-WASTE IN 2012-2016; (B) RECYCLING RATE.

Note: recycling rate = actual recycling amount/theoretical generation amount ×100%. Data source from Zeng et al., 2017 & 2018; CHEARI, 2018.

Based on combination of physical separation technologies of e-waste recycling, here we roughly drew a material flow diagram of current e-waste recycling in a typical enterprise for WEEE recycling in China, which is clearly illustrated in Figure 19.

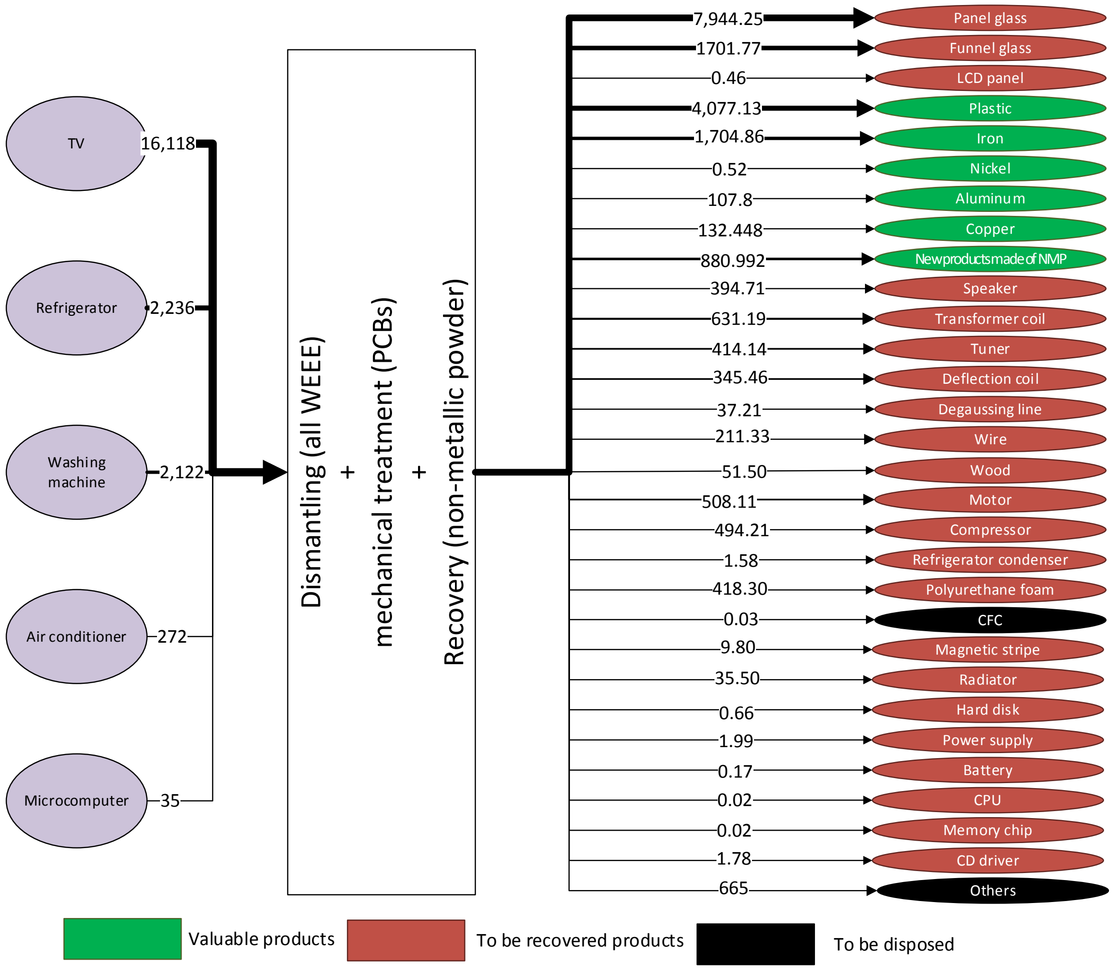


FIGURE 19 MFA OF E-WASTE RECYCLING IN A TYPICAL ENTERPRISE OF CHINA (TON)

Note: the thickness of line indicates quantity of material flow. Some data are from Song et al. (2013), and copper content is approximately 10% by w.t. in waste printed circuit boards (PCBs). © 2016 Published by Elsevier Ltd. Used after permission.

By informal process, valuable products including plastic, iron, aluminum, and copper could be recycled from e-waste. Regulated by WEEE regulation, some formal processes were employed to obtain plastic, iron, aluminum, copper, nickel, and new products, which can be recovered from non-metallic powder of waste PCBs.

Here the material recycling rate is defined as

$$r = \frac{R}{T} \times 100\% \qquad (1)$$

Where r is the material recycling rate, R is total weight of all the achieved valuable products, T is total weight of input WEEE. Therefore, the current material recycling rate with formal process is

$$r = \frac{4077.13 + 1704.86 + 0.52 + 107.8 + 132.448 + 880.992 + 1701.77 \times 5\%}{16118 + 2236 + 2122 + 272 + 35} \times 100\% = 33.4\% \qquad (2)$$

Where 5% is the estimated recycling rate of CRT funnel glass, because most CRT funnel glass currently went to landfill and only one licensed company could recycle a small proportion. And the material recycling rate with informal process is

$$r = \frac{4077.13 + 1704.86 + 107.8 + 132.448}{16118 + 2236 + 2122 + 272 + 35} \times 100\% = 29\% \quad (3)$$

In many industrial nations, pyro-metallurgical process of e-waste recycling is the most popular, for instance, in Umicore, Kaldo, and Noranda smelting plant in the EU. In this situation, only plastics and metals could be recovered, so that recycling rate in the EU was just around 29%. Thus, the added recycling rate driven by WEEE regulation is only 4.4%.

Consequently, the large quantity of resource is recycled, compared with China's traditional informal recycling and developed countries' process (crushing, screening, & smelting), additional 5% material recovery has achieved [e.g. recovered from non-metallic materials of waste PCBs. More resources than some developed countries with smelter process (e.g. Umicore) were substantial recovered from waste PCBs and CRTs for new products.

Comparing with informal recycling process, the emission of heavy metal such as Lead can be declined when CRT funnel glass of color TV is appropriately recycled. However, very few substance is recovered in hydrometallurgical process in China. Therefore, assuming 5% of recycling rate and 25% composition of Lead in CRT funnel glass, in 2013 the Lead emission reduction was about 1,800 tons. Approximately 2.1 tons' chlorofluorocarbons (CFC) refrigerant could be collected for safe disposal, which means the equivalent CFC has been declined to discharge.

Song et al (2013) firstly carried out the life cycle assessment of an e-waste treatment enterprise in China When 1 ton of e-waste was recycled in the recycling enterprise, the recycling of metals could bring the most important environmental benefits, accounting for 52.42% of the total benefits, followed by plastics recycling, PCB treatment, and funnel glass reuse. The environmental benefits were, first, in human health, accounting for 48.52%, and then in resources (41.61%) and ecosystem quality (9.87%). E-waste recycling could bring large environmental benefits through avoiding the energy use and emissions to air or water, etc. Here, the highest benefits were from emissions avoided from arsenic and cadmium (ion) to water, accounting for about 49 % of the benefit, attributable to the avoidance of extraction and processing of these metals. Because of the high energy requirements in the extraction and processing of the materials, avoiding consumption of fossil resources appears to be more important than the other three environmental impacts (e.g., metal resources, emissions to air, and emissions to water). The e-waste treatment could reduce the potential impacts on the environment and human health, e.g. for abiotic depletion and marine aquatic eco-toxicity 1.16× 10-2 kg Sb eq and 2320 kg 1,4-DB eq could be avoided through the treatment processes, and the other impact categories were also similar.

In 2016, China's current processing technologies could also achieve some environmental benefits by removing from direct disposal 1800 tons of lead, 2685 tons of refrigerant, and over 11.55 million tons of CO_2-equivalent emissions. Pollution control requirements have also been put into practice in recycling activities, so that the health of recycling-operation workers is appropriately protected. And all of this additional activity has stimulated the economy by creating more than 5000 new jobs in the e-waste recycling industry.

(2) Case of Guiyu model

Here, we take greening 'Guiyu' as an instance. Guiyu was once the largest e-waste dumpling site on earth, Regions like Guiyu rely on primitive electronics recycling in 1990-2000s as an economic staple despite the adverse effects e-waste has on human health and the environment. The burning off of plastics in the town has resulted in 80% of its children having dangerous levels of lead in their blood. A recent study of the area evaluated the extent of heavy metal contamination from the site. Using dust samples, scientists analyzed mean heavy metal concentrations in a Guiyu workshop and found that lead and copper were 371 and 115 times higher, respectively, compared to areas located 30 kilometres away. The same study revealed that sediment from the nearby Lianjiang River was found to be contaminated by polychlorinated biphenyls at a level three times greater than the guideline amount.

Since 2013, local authorities moved most e-waste workshops into an experimental industrial ecology park called the National Circular Economy Pilot Industry Park (Figure 20). There, toxic waste by products can be better treated and recycled. Today, the air and water in Guiyu is much cleaner. However, many areas are still contaminated from the remnants of E-waste processing and have not been cleaned up.

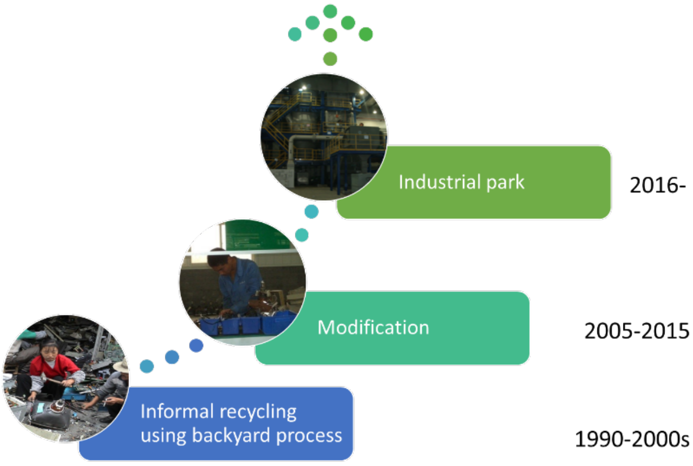


FIGURE 20 EVOLUTION OF GAIYU IN GREENING PROCESS

3.3.3 EXTRACTED EXPERIENCE OF WASTE RECYCLING

The overall effects of this new approach could be drew as follows.

First, the most effective regulatory core in China, in contrast to the regulations in developed countries, is the ‘old-for-new’ policy and the WEEE ‘producer-pays’ funding. The economic incentives are crucial to the success of the new WEEE regulations; the subsidies—totaling 725 million USD in 2016—are responsible for diverting a huge amount of e-waste from the informal recycling sector into formal recycling channels.

Second, environmental maintenance and management costs have been internalized to significantly change the e-waste flow and destroy the economic incentives that historically drove the informal recycling sector, which profited by avoiding the costs of environmental conservation and sound process management. The new subsidies for recyclers now cover these costs.

Third, China needed to develop its own approach to recycling WEEE; it would not have been feasible to try to duplicate other countries’ experiences or processes. The best available technology (BAT) and best environmental practices (BEPs) of e-waste management are predominantly based on locally available technology. China is still a developing country where the pursuit of individual economic interests remains the primary incentive for dismantling workers and companies. Manual dismantling operations generally employ more workers, an approach that is more workable in practice in China.

Finally, an effective and practical management system has been well established, including permitting, reporting, auditing, inspection, information systems, and funding systems. A new recycling enterprise initially obtains the license and permits from the local Environmental Protection Bureau (EPB), and reports its recycling volume, once it is up and running. The local EPB or the Ministry of Ecology and Environment could audit and inspect the operation and recycling volume through the information system and onsite inspection. Once it is formally approved, the recycling enterprise could start receiving its subsidies, based on its recycling volume.

Chapter 4: Critical lessons and opportunities learned from Chinese experience

in terms of social, political, technological, institutional barriers (or) constraints in integrating circular economic development in industrial sector of China. According to Chinese statistics, 68% of SMEs would close down in their first five years, only 19% can survive 6–10 years, and only 13% of SMEs' lifespan can exceed 10 years. This problem is not unique to China. The reason is that SMEs are more sensitive to response for the regulation and policy from government, especially on some stringent environmental laws in recent years.

4.1 Main lessons from regulation and policy

Since 1980s, the principle of "polluter pays and handles" was carried out. It was implemented well in many large-sized enterprises. Lots of troubles have been found for the SMEs to take this principle. First, this principle is the scale diseconomy for many SMEs. It does not consider the distinct difference of marginal cost tracking pollution among the various enterprises. Also, SMEs have a short average lifespan, and prone to transfer their operation so that they have to afford to high equipment amortization. Second, it is much difficult for SMEs to raise fund for pollution controlling. Owing to a highly hard supervision, some raising fund cannot be used for only pollution controlling. Last, over 50% devices in the half national SMEs still took the old equipment. Thus the production efficiency and recycling rate remain very low.

For instance, in order to green the SMEs in e-waste recycling, the Chinese government had already implemented over ten regulations related to e-waste management during the period 2001–2008, including a prohibition on the importation of e-waste and Administrative Measure on Pollution of E-waste. But they generally failed to support effectively e-waste recycling industry until the 'old-for-new' policy in 2009 and China WEEE regulation in 2011. Therefore, the most effective regulatory core in China, in contrast to the regulations in developed countries, is the 'old-for-new' policy and the WEEE 'producer-pays' funding. The economic incentives are crucial to the success of the new WEEE regulations.

Therefore, the stringent legislation system with the hard controlling is of very necessity to green the SMEs' process. On the other hand, the economic incentive in the soft supporting is indispensable to maintain the enthusiasm and motivation of SMEs.

4.2 Main lessons from technical process

The technical process of circular economy mainly involves cleaner production and waste recycling. Regarding the latter, the recycling industry in China has grown so rapidly that neither domestic nor foreign processing technologies have been fully transferred or utilized. China's e-waste recycling industry has rapidly increased from only a handful to over 100 formal enterprises in 3 to 5 years. However, the experience and technology from developed countries have not been transferred or well adapted to fit China's situation. To successfully combat the informal treasure hunting for e-waste, recycling enterprises grew quickly without proper technological application. BAT and BEP are the fundamental approaches for e-waste management, but these are always evolving. Currently, because the deep recovery industry for e-waste in China is still in its infancy, the government subsidies include grants for e-waste pre-processing involving dismantling and mechanical treatment. To maximize the utilization of e-waste, updated technology and facilities expansion are urgent, for responding to emerging challenges.

4.3 Main lessons from institutional barriers

Despite significant development, SMEs in China continue to experience institution-based barriers, especially in the area of innovation. The top five barriers focus on (1) competition fairness, (2) access to financing, (3) laws and regulations, (4) tax burden, and (5) public support systems. Table 6 shows that nearly all of the factors hampering innovation activities of SMEs are relevant for regulatory environment, which provides policymakers with some guidance to crafting effective innovation policy by examining specific policies that constitute the core of national innovation strategies (Zhu et al., 2012).

TABLE 6 INSTITUTION-BASED BARRIERS HAMPERING SMES' INNOVATION ACTIVITIES

	Cost of innovation	Risk of innovation	Opportunity of innovation
Competition fairness			
No priority for government procurement	+		–
Difficulty of starting a business	+		–
Poor enforcement of the Unfair Competition Law	+	+	–
Regional protectionism	+		–
Access to financing			
Difficult to get bank credit	+		–
High doorsill for capital market	+		–
Lack of venture capital, especially angle capital		+	–
Hard to access to public sources of funding	+		
Laws and regulations			
Extra entry barriers	+		–
Unclear to assess intangible collateral	+	+	–
Weakness of property rights			–
Lack of regulations and/or concrete regulations at operational level	+	+	–
Ambiguity of property rights and creditors' rights in the event of bankruptcy	+	+	–
Inconsistent policies		+	
Lack of regulations to protect non-technological innovation	+	+	–
Tax burden			
Current value-added tax (VAT) system	+		–
Pro-innovation tax system	–	–	+
R&D tax credit policy	–	–	+
Public supporting systems			
Lack of infrastructure	+		–
Lack of linkage with public research institute	+	+	–
Deficiencies in the availability of external services	+	+	–
Lack of information on markets	+	+	–
Lack of information on technology	+	+	–
Short of training and education	+		–
Lack of intermediary to provide services for SMEs	+	+	–

"+" means positive correlation; "–" means negative correlation.

4.4 Extracted opportunities for circular economy along the adventure

The main target of circular economy is to improve the profit along the supply chain in SMEs. Main phases are summarized here.

(1) Eco-design

During the nearly 30-year development of eco-design, legislation, consumer demand, and internal motivation have been frequently mentioned as incentives for SMEs to take up eco-design methods. The historical ventures have shown that the beginning of the life cycle—materials choice and technological innovation in products—and its end—final EoL product disposal—are often regarded as the most critical aspects of the eco-design. And the three key aspects of eco-design—new materials, emerging technology, and legislation—have developed together through the years. In the long run, eco-design for SMEs can make the profit from economy to environment.

(2) Green manufacturing/Cleaner production

By analyzing the flow of materials and energy in a company, one tries to identify options to minimize waste and emissions out of industrial processes through source reduction strategies. Improvements of organization and technology help to reduce or suggest better choices in use of materials and energy, and to avoid waste, waste water generation, and gaseous emissions, and also waste heat and noise. Regarding the SMEs, cleaner production is the most important approach to green themselves and realize circular economy.

(3) Remanufacturing

Remanufacturing is "the rebuilding of a product to specifications of the original manufactured product using a combination of reused, repaired and new parts". It requires the repair or replacement of worn out or obsolete components and modules. Remanufacturing is one simple process to upgrade the product function using the repair operation. Previous practices indicate lots of SMEs can make a high economic profit. Greening the process of remanufacturing with the regulation and market is much substantial to achieve for some recycling companies.

(4) Recycling

Recycling is the most often approach to finalize the closed-loop supply chain. In many developing countries, high recycling rate can be easily reached, but losing the environmental quality and human health. The stringent legislation system with the hard controlling is of very necessity to green the SMEs' recycling process. On the other hand, the economic incentive in the soft supporting is indispensable to maintain the enthusiasm and motivation of SMEs.

Chapter 5: The Way Forward

To promote and implement sustainable development and achieve Millennium Development Goals, the 2030 Agenda for Sustainable Development had been adopted by world leaders at the UN Sustainable Development Summit in September 2015 and had established 17 sustainable development goals (SDGs) as the core. At least four SDGs about environment, consumption, and city are very related to SMEs in the world.
Providing practical examples of the circular economy in action, and at various scales and in different sectors, is vital to gain traction amongst SMEs of the benefits that the circular economy can provide. However, we also need to provide sufficient resources and networking opportunities so that SMEs can explore the benefits of circular economy opportunities themselves and with their supply chains. And for that to work effectively we need a strong government agenda, supported by programmes designed to engage, enlighten and encourage SMEs to think and act differently.

There is no polluting industry, but polluting technology and polluting management. The future of global manufacturing and recycling in SMEs can and must learn from new supply-chain management systems to improve environmental and social sustainability. Solving environmental problem is not only depended on the progress of science and technology but also relied upon an integrity of regulation and policy. Previous adventure of SMEs in China has resulted in an emerging model of circular economy technology, characterizing with the identification of key process, integration of combined process, marketization of recycled product, and maintenance of regulation and policy.

Firstly, using some methods such as material flow analysis and life cycle assessment, we can identify the key process or procedures declined resource/information flow, and systematically design the whole city 's circular economy and optimize the adjustment of resource flow. Secondly, the identified process will be focused to develop the key technology or policy driver for high-efficiency resource/information flow. Then it will be integrated with the existing upstream or downstream technology to form the combined and integrated process. Thirdly, the integrated process is operated from pilot to field practice. The products obtained from processing should be well linked to market demand, which also determines, in most extent, which the combined process is chosen and which products are generated. Lastly, rigid-constraint regulations should be carried out to fully cover the entire life cycle of material. Policies of economic incentive should be adopted to finalize the development of environmental industry from disorder to order and from informal to formal.

The harsh situation also drives that circular economy should play an increasing role in supply-side structural reform and ecological civilization construction, which can provide the huge room of the Chinese experience of greening the SMEs. The experience needs to be urgently deepened and intensified in near future. Additionally, its leading in the theory and practice will enable that this integrated model is to be duplicated for other regions or countries.

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Annexes

A.1 Main economic performance of above-designated-size SMEs in China in 2016

Province	Amount	Employee		Operation income		Operation cost	
	unit	(10^4)	YoY(%)	(10^8 CNY)	YoY(%)	(10^8 CNY)	YoY(%)
Totally	369676	6140.6	-1.6	721679.6	6.0	623485.9	6.1
Beijing	3310	58.2	-5.2	7062.9	5.5	5638.0	5.4
Tianjin	5251	82.8	-3.4	14708.5	7.8	12883.5	8.4
Hebei	14478	228.9	-0.2	29839.0	6.6	26228.8	7.3
Shanxi	3355	84.5	-3.5	6258.3	2.8	5329.0	1.0
Inner Mongolia	4204	71.8	-0.8	14215.5	8.0	12054.2	8.6
Liaoning	10106	141.7	-18.0	13169.8	-38.7	11525.8	-39.3
Jilin	5596	83.2	-5.6	14259.1	5.2	12297.8	5.2
Heilongjiang	3941	55.3	-6.3	6848.7	0.4	6002.8	0.5
Shanghai	8441	135.5	-6.9	15746.7	2.9	12688.7	1.8
Jiangsu	46367	742.1	-0.4	99929.2	9.7	85642.2	10.0
Zhejiang	39622	551.0	-1.5	48676.0	3.1	41766.5	2.5
Anhui	19110	219.4	0.3	27883.9	9.9	24601.3	10.6
Fujian	16801	296.8	-2.3	30617.3	8.4	26757.3	8.6
Jiangxi	9901	195.3	2.6	26032.2	8.6	22919.2	8.7
Shandong	39699	585.1	-3.1	95694.5	2.7	84460.5	3.1
Henan	22642	466.9	1.9	53053.2	10.7	46252.9	11.3
Hubei	16128	230.3	1.3	29335.4	9.3	25544.1	10.0
Hunan	14148	258.9	0.9	28124.8	8.4	24045.1	8.4

Guangdong	39996	869.7	-3.3	69410.9	6.9	59873.7	6.7
Guangxi	5331	117.7	1.2	14356.9	9.0	12299.5	9.6
Hainan	348	8.0	-4.8	1332.5	1.4	1021.4	-0.8
Chongqing	6616	127.4	6.2	13680.7	16.2	11616.7	17.0
Sichuan	13290	223.7	-2.3	28010.7	11.5	23911.2	12.0
Guizhou	4953	65.1	3.8	7773.6	18.2	6657.7	18.8
Yunnan	4054	63.7	-1.4	5771.1	8.7	4901.4	9.1
Tibet	109	1.4	-6.7	135.7	24.6	84.7	19.1
Shaanxi	5325	85.2	1.4	10518.1	11.8	8661.4	12.1
Gansu	2049	25.7	-3.4	2274.7	2.3	2000.1	3.3
Qinghai	567	10.6	7.1	1232.1	6.6	1078.2	4.9
Ningxi	1202	15.1	-2.6	1849.9	6.6	1609.1	7.2
Xinjiang	2736	39.3	3.1	3877.8	13.7	3133.0	12.1

Note: Above-designated-size SMEs are the SMEs of operation income over 20 million CNY.

Data source from National Bureau of Statistics, http://www.lwzb.gov.cn/pub/gjtjlwzb/sjyfx/201705/t20170524_3750.html

A.2 Main economic profit of above-designated-size SMEs in China in 2016

Province	Total Profit		Product storing		Accounts receivable	
	(10^8 CNY)	YoY(%)	(10^8 CNY)	YoY(%)	(10^8 CNY)	YoY(%)
Totally	43184.4	6.2	24252.7	2.4	74208.9	8.6
Beijing	518.7	0.6	480.5	9.1	2373.0	9.2
Tianjin	799.4	0.7	488.0	4.6	1835.2	11.2
Hebei	1896.2	2.5	936.9	3.8	2332.3	6.9
Shanxi	67.4	1371.7	370.7	-5.2	1131.9	3.4
Inner Mongolia	907.3	7.1	339.9	-7.3	1034.8	5.1
Liaoning	507.2	-44.9	690.6	1.9	2026.8	2.7
Jilin	674.2	9.5	354.0	-2.9	851.6	7.2
Heilongjiang	320.6	-0.7	263.2	-5.9	700.0	2.8
Shanghai	1054.5	10.1	962.4	3.9	4101.8	9.8
Jiangsu	6906.4	10.9	2993.7	4.4	11801.9	8.1
Zhejiang	2756.5	14.0	2505.3	2.0	8400.1	6.4
Anhui	1444.5	1.0	896.1	5.3	2772.1	13.2
Fujian	1769.6	13.3	997.9	-0.6	2815.9	7.5
Jiangxi	1925.2	9.4	624.5	9.8	1385.7	16.0
Shandong	5720.5	0.4	2628.6	-0.5	4774.2	5.5
Henan	4044.4	6.2	928.8	0.9	2636.9	6.5
Hubei	1430.2	2.7	988.7	1.8	2589.6	13.3
Hunan	1306.3	4.1	558.2	8.0	1552.3	13.4

Guangdong	3940.9	11.9	2546.6	2.8	9331.2	8.9
Guangxi	845.9	3.9	519.1	8.9	1048.8	10.1
Hainan	92.0	27.6	54.6	1.5	142.4	11.3
Chongqing	1000.8	15.6	421.1	4.2	1599.4	20.6
Sichuan	1656.4	11.9	856.7	2.9	2556.6	10.1
Guizhou	326.8	17.4	200.6	-7.1	691.2	14.7
Yunnan	67.7	-69.7	366.9	-0.6	720.3	6.9
Tibet	28.7	50.3	9.7	31.1	20.4	18.6
Shaanxi	809.7	15.4	479.4	6.9	1199.4	7.4
Gansu	23.2	-28.6	224.5	-5.8	520.2	12.8
Qinghai	34.6	78.4	76.0	4.0	219.7	14.5
Ningxi	74.6	14.2	169.1	5.9	373.3	12.3
Xinjiang	234.0	26.4	320.4	-1.0	669.7	6.3

A.3 Production and environmental performance of PPI in 2014

Province	Amount of company	Production line	Waste water generation (MT)	COD generation (T)
Beijing	15	4	0.258	156.5
Tianjin	64	17	17.137	31563.9
Hebei	348	288	267.998	221078.3
Shanxi	49	34	24.78	14678.5
Inner Mongolia	30	8	5.369	4758
Liaoning	89	37	26.468	39469.5
Jilin	46	39	51.749	106244.5
Heilongjiang	47	34	31.619	25899
Shanghai	57	21	7.828	4454.9
Jiangsu	189	146	136.093	226311.7
Zhejiang	511	372	717.584	900652.1
Anhui	146	81	53.862	82255.9
Fujian	300	225	141.344	185089.2
Jiangxi	144	83	49.112	95106.7
Shandong	261	177	341.733	534590.3
Henan	251	144	311.78	340058.6
Hubei	90	74	99.816	93094.1
Hunan	355	286	195.577	193062.8
Guangdong	789	474	631.265	325006.8
Guangxi	164	115	180.92	225086.8
Hainan	5	4	28.901	48362.5
Chongqing	71	59	48.956	74801.8
Sichuan	396	206	154.899	116416.3
Guizhou	38	25	8.081	4728.8
Yunnan	110	71	106.24	31202.2
Tibet	1	1	0.079	282
Shaanxi	52	27	24.129	48348.5
Gansu	13	11	8.901	15071.1
Qinghai	0	0	0	0
Ningxia	17	9	15.499	79704.5
Xinjiang	116	63	10.322	11832

Source: Cao, C. 2016. Almanac of China Paper Industry. Beijing: China Press of Light Industry. ISBN: 978-7-5184-1082-8.