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Assessment of the Municipal Solid Waste Management in China
Shanghai Case study

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EXECUTIVE SUMMARY

The present thesis aims to asses the Municipal Solid Waste (MSW) management in China, exploiting the case study of Shanghai that, on July 1st, 2019, has become the first Chinese city to incorporate into its legal framework the MSW classification at the source. The main findings will be the status quo of the MSW management of China and several proposals to remove certain barriers and improve different aspects related to it. In addition, to analyze the MSW management system of Shanghai, it will be discussed the effectiveness of the new MSW regulations and the current state of it, addressing numerous problems. It was chosen Shanghai as the case study because if the MSW classification will succeed, and the main barriers removed (especially the one related to the integration of the informal recycling system), it could be a great success case for the whole China, and Shanghai could be taken as an example model. Moreover, the study will show the main differences between MSW management in developed and developing countries (the comparison will be made with leading countries in MSW management practices). Since the beginning of industrialization, the industrial economy has never changed; its model is based on a linear model of resource consumption that follows a *"take-make-dispose"* pattern.

Manufacturing companies extract virgin materials, apply energy and labor to manufacture the product, and sell it to an end customer. Consequently, when the products will not be able to serve their purpose anymore, the end customers will discard them. The beating heart of the *"linear model"* is the consumerism, which inevitably brings to a huge generation of wastes. Kaza et al. (2018) have estimated the global waste generation of 2.01 billion tons in 2016, and the estimation is expected to increase to 3.40 billion tonnes by 2050. Currently, the East Asia and Pacific regions are generating most of the world's waste. In particular, China is considered an upper-middle-income level country, and it has become the first world waste generator in 2004, overcoming the US (Hoornweg & Bhada-Tata, 2012). The significant Chinese MSW growth is due to the high growth in GDP and the urban population that China is attending. Caused by considerable development both in the economy and society, China is struggling against an unprecedented increase in MSW. In 2017, it was generated over 215 million tons of MSW in China (National Bureau of Statistics of China, 2018). Therefore, although MSW management is a severe issue for each country worldwide, it seems to be more serious in China. It has been foreseen that in 2030 China likely will generate twice MSW as much as the US. Recently, China changed its long term strategy from one focused on rapid development to another based on environmental protection, and because of the *"Operation National Sword,"* China banned four categories of wastes. Moreover, in 2018, it was announced the Blue Sky policy, adding stricter restrictions and a plan to ban all-recyclable imports by 2020. The ban will have consequences on the overall global circular economy (stimulating developed countries to improve their recycling capacity), and it will force the Chinese recycling system to improve (because of the dependence from the recyclable materials of Chinese manufacturing industries). Therefore, studying Chinese MSW management in this historic moment has several advantages. Assessing the current state of Chinese MSW

management is fundamental to understand the effectiveness of the waste management practices of the first waste generator in the world. Being a developing country, China is struggling against several problems that could be the future problems of other countries like Thailand or some African countries. If China succeeds to manage MSW, it could be an example for other developing countries. Moreover, studying the status of MSW management help to estimate the future trend of the global circular economy, and in particular, China could become the next first waste exporter in the world, overcoming the US. Therefore, it is fundamental to comprehend if China and the Chinese Central Government have chosen the proper policies and regulations to deal with the home growing MSW generation because if it is not, it could have catastrophic consequences on the waste management on a global level (especially for the other developing countries). Moreover, the Chinese Government is aware of the great importance of recycling, but it is a developing country, and just taking the best practices of developed countries is not enough. One of the main objectives for the Chinese Government is to improve the formal recycling sector, but it is struggling against the presence of the informal sector (that is common in developing countries). It is helpful to assess the current situation of China in managing its recycling industry because useful recommendations for other developing countries will be made. In addition, if China will succeed, it could be considered as a benchmark. In the present thesis work, it was evaluated the MSW management system answering the previous questions. Moreover, the assessment was made adopting sustainable development, sustainable development goals, sustainable MSW management, and circular economy as reference concepts. The work was done through a detailed literature review on the MSW's best sustainable practices adopted by developed countries, on the MSW management in developing countries, and China. The thesis was done in the Sino-Italian Center For Sustainability (SICES) – Tongji University, Shanghai – with Professor Chen and Professor Liu. In addition, through several presentations of the work and the acquired data to Professor Liu and his PhD students, the thesis was validated, and in particular, the case study. The thesis work starts introducing the fundamental sustainability concepts and MSW key definitions, continuing to an analysis of the main policies and regulations that have influenced the Chinese MSW management system. Finally, the current MSW management status of China is assessed, along with the case study of Shanghai. Following there is a detailed explanation of the chapters, highlighting the logic behind this studying.

In the first chapter are introduced the main concepts that will drive the structure of the next chapters. In particular, there is an explanation of the main sustainable concepts, such as Sustainable Development, Sustainable Development Goals, and the topic of the Circular Economy applied to the MSW management field. Then, criticisms on the *"linear model"* and consumerisms are made, highlighting the Circular Economy as the only solution to the nowadays economic, environmental, and social problems. Finally, the main MSW definitions are explained, addressing each functional element of the MSW management system (considering differences between developed and developing countries). The main results of this chapter are the conceptual framework that will drive the entire work. In addition, through this chapter is possible to have a clear understanding of the global waste

problem, the importance of China in the current situation, and the catastrophic projection if countries do not commit to solving the problem.
In the second chapter is proposed an overview of the main policies and regulations that have influenced and influence the Chinese MSW management system. Particularly, all the policies that have contributed to reaching the current status of the management system are discussed. There is a focus on the regulations and policies that encouraged Circular Economies practices and favored the huge Chinese Waste-to-Energy (WTE) growth in the last decades (highlighting the national support of the WTE industry to decrease the open dumping). In addition, there is an explanation of the reasons that caused the *"Operation National Sword"* fundamental to comprehend the current situation of the global circular economy and the Chinese MSW management system. The main findings of this chapter are the clear comprehension of the policies and regulations framework, how the Central and local governments are chosen to address the Chinese waste problem. Given the recent history of the commitment of the Chinese Governments in the waste problem, it is fundamental to improve the current policies and regulations, and it should be ameliorated the people's awareness and knowledge about these topics.
In the third chapter, there is a detailed assessment of the MSW management system in China. The chapter starts with an introduction about China, the role of it in the global geopolitical situation, and the principal boundary conditions (such as the considerable economic development and urbanization growth that influence the waste problem). Then, there is an explanation of the MSW management problem in China compared to the USA situation. The chapter continues with a detailed analysis of each part of the Chinese MSW management system, placing much attention on the history and the current state of the recycling industry. There is a discussion about the beginning of the exploration by China about the MSW classification system, highlighting the experience of eight pilot cities. Moreover, it is explained the fundamental role of the informal sector in the management system of China, highlighting benefits and problems related to it. Then, there is an introduction of new internet-based tools such as the *"Intelligent Collection,"* that could help to ameliorate the relation between formal and informal sectors (and improved the status of the formal recycling system). Later, there is an overview of the landfills in China, considering that landfilling is still the most common treatment method, but the percentage of the Chinese MSW treated by landfilling is decreasing. The Chinese Governments in the last decades have posed increasing attention on the WTE industry, and in this chapter, there is a global overview of the current situation of incineration practices, followed by a focus on the Chinese WTE industry, highlighting weakness and strength points about it. This part is fundamental to understand the main barriers of MSW management in China. Having studied the fundamentals of the Chinese MSW management system, it is then proposed a comparison between China and other developed and developing countries. Moreover, near the end of the chapter, there is a short overview of food waste management in China, highlighting the lack of Chinese capacity to treat food waste. The last part of the chapter regards the conclusions about the MSW management system in China. The main findings are that the most common treatment in China is still landfilling, and the MSW incineration is encouraged by the Central Governments to

increase the percentage of harmless treatment (in the future, the primary goals are to replace the landfilling with MSW incineration, accordingly with the waste hierarchy). Moreover, China is still far from developed countries in the matter of recycling, but it has started to explore this field later than them. Then, there is a discussion about the main barrier to the formal recycling industry, mainly composed of the presence of the informal sector. In addition, there are some recommendations to remove this barrier and, mainly, how to incorporate the informal sector in the formal recycling industry exploiting the intelligent collection system.

The last chapter is represented by the Shanghai case study. It was chosen Shanghai as the case study because if the MSW classification will succeed, and the main barriers removed (especially the one related to the integration of the informal recycling system), it could be a great success case for the whole China, and Shanghai could be taken as an example model. This chapter was made studying and reviewing Chinese paper through the help of Professor Liu (Tongji University) and his PhD students. All the main results of this chapter were presented and validated by Professor Liu through several presentations in the department of Economics & Management of Tongji University. The chapter starts with a characterization of Shanghai, followed by an overview of its ranking in China and in the world, its GDP, and its huge urbanization growth. Then, it is showed the MSW problem in Shanghai, the current MSW generation rate, the future projection, the collection rate, and the coverage rate of the city. Moreover, it is presented an overview of Shanghai's MSW treatment, highlighting that the landfill is still the most common method to treat wastes, but by the end of 2020, the primary method will be MSW incineration (to support these declarations there is a detailed table of all the MSW facilities in Shanghai at the current state and the related projection). It is followed by a short discussion about some important advanced MSW facilities in Shanghai. Then there is an explanation of the formal recycling system of Shanghai and its development, followed by a discussion of the new MSW classification regulation enacted on July 1st, 2019. The main findings of this policy are following introduced. First, the leading role of the government in the initial stage of the system implementation and proper coordination among its departments is considered crucial, and it is encouraged to ensure proper MSW classification development. Second, waste collection fees system and private capital and private companies should be involved to promote a sustainable and marketized MSW-relevant industry in the future. Third, laws and regulations should be refined and optimized, and continue enforcement of them is needed. Fourth, more publicity and school education on the MSW classification system are helpful in making the MSW classification part of the habits and moral principles of Shanghai's citizens. In addition, there is an explanation of the informal recycling system in Shanghai, highlighting benefits and weaknesses. The main findings of this chapter are the current situation of the MSW treatment in Shanghai and the already discussed recommendations about the new MSW classification. Moreover, the formal recycling industry of Shanghai is characterized by most of the same barriers already discussed for the whole of China. Particularly, one of the most important achievements is to incorporate the informal recycling system in the formal one. Also, in this case, it is recommended an integrative approach using the new innovative mode exploiting *"intelligent collection"* instruments and companies. If the MSW classification will succeed, and the main barriers removed (especially the one related to the integration of the informal recycling system), it could be a great success case for the whole China, and Shanghai could be taken as an example model, as a benchmark.

The thesis ends with the overall conclusion about the MSW management of China and Shanghai, drawing out conclusions about the MSW management of China and Shanghai and the application of the possible successful case of shanghai to other cities and the whole of China. The MSW management system in China has made much progress in the last decades. It has been able to decrease the open dumping rate significantly, increasing the harmless treatment exploiting the WTE industries, encouraged by effective policies and regulations. However, it is still far from the MSW management of developed countries, and its rate of recycling is still too low. The principal findings of the current thesis are the importance of the informal recycling system in improving the formal sector status, one of the most achievement for the Chinese Central Governments (at a national and a local level) should be to incorporate, exploiting an integrative approach, the informal sector. Moreover, Shanghai is considered by China, the *"showpiece"* of the enormous Chinese economic growth, and if the MSW classification will succeed Shanghai will be an excellent example for all the Chinese cities and megacities. This could be a real and important great step for China to reach a sustainable MSW management system.

1 Sustainable Municipal Solid Waste Management

1.1 Sustainable developments and the SDGs

Sustainable development has been defined by the United Nations as "*Sustainable development is a development that meets the needs of the present without compromising the ability of future generations to meet their own needs" (1987).* In addition, it is possible to think about Sustainable Development utilizing a systemic approach: *"Sistemical approach is a managed process of continuous innovation and systemic change to maintain a sustainable planet and human needs together long into the future"* (APLP, 2019) (Figure 1.1).

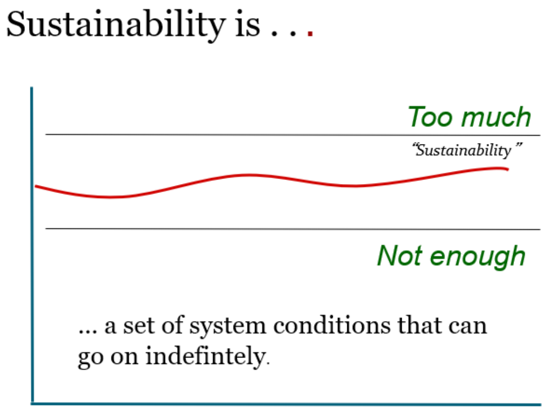

Figure 1.1: Sustainability systemic definition (APLP, 2019).

Sustainable development is not a fixed state of harmony, but rather a process of change in which the exploitation of resources, the direction of investment, the orientation of technological development and institutional change are made consistent with future as well as present needs (APLP, 2019). It is fundamental to recognize that there are three integrated dimensions in sustainable development: economic development, social progress, and environmental responsibility. Detailing the previous dimensions:

- *Economy:* Human societies, communities, and organizations need functioning economies to provide for their needs and to support their aspirations;
- *Nature:* The physical and biological limits of Earth's ecological systems must be respected;

- *Society:* Social systems should be organized in ways that promote equity, fairness, resilience, and opportunity for all.

In September 2015, more than 150 international leaders met at the United Nations to contribute to global sustainable development, promoting environmental protection and human well-being. The states community approved the 2030 Agenda to achieve sustainable development. The essential elements of the 2030 Agenda are the 17 Sustainable Development Goals (SDGs) and the 169 sub-objective, which aim to eliminate poverty and to struggle against social and economic inequality (Figure 1.2). In addition, in the 2030 Agenda, there are fundamental topics for the importance of global sustainable development, such as facing climate change and building peaceful societies by 2030. The SDGs are deployed in the three sustainable development dimensions, and Figure 1.2 shows how the 17 SDGs are organized.

Figure 1.2: SDGs and the three sustainability dimensions (APLP, 2019).

The SDGs have general validity; each country should give a contribution to reach these objectives, concerning their capacity. Obtaining such global improvements will be not an easy achievement, but the previous experience about the objectives settled in the 2000s showed that it works. The Millennium Development Goals (MDGs) fixed in 2000 have improved the lives of millions of people. Global poverty was decreased; more and more people gained access to water sources; a larger number of children attends elementary schools; and several investments aimed to struggle against malaria, AIDS, and tuberculosis saved millions of lives. The SDGs are strictly interdependent (Figure 1.3), and each of them has a list of targets (sub-objective), which are monitored by indicators.

Figure 1.3: SDGs interdependence (APLP, 2019).

In the following will be listed a series of design principles of the SDGs:

- *Universal:* The SDGs are global goals settled for the *"World We Want,"* and they are applicable to all countries (i.e., both developing and developed countries);
- *Indivisible:* There is not a hierarchical order among the SDGs. Not considering all the three areas of sustainable development (social, economic, environmental) or one of the SDGs impedes or hinders the achievements of the other goals;
- *Transformative:* Transforming the challenges int opportunities for the 5Ps (Peace, People, Planet, Prosperity, and Partnership);
- *Localized*: The SDGs should be implemented locally in cities and communities, urban and rural, and the goals should be supported by the central and local governments;
- *Measurable*: The goals have to be measurable by means of indicators to evaluate the achievement of them and draw lessons and recommendations;
- *Inclusive*: The SDGs have to guarantee *"leaving no one behind"* in implementation and in outcomes by means of participation and transparency;
- *Integrated*: The goals are all interconnected in all the dimensions and levels: between Goals, between countries, and between global, regional, and national levels.

The SDGs are not divisible and have to be considered and implemented together, because each of them represents sub-systems of the human planetary systems. It is fundamental to adopt a system perspective because considering just individual parts of the system it is not possible to understand the whole. The World is too complicated for linear and reductionist perspectives (Figure 1.4).

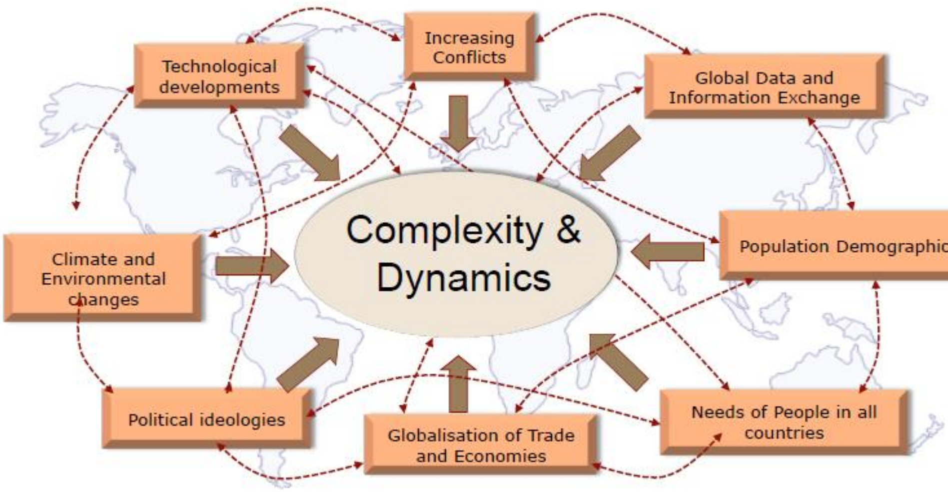

Figure 1.4: World complexity & Dynamics (APLP, 2019).

For Sustainable Development, it is necessary to consider the world as a whole system. The 12th SDG aims to reach *"Responsible consumption and production,"* and it is strictly related to the main topic of waste management. Currently, the global population is consuming more resources than what the eco-systems are able to generate, and it is needed a radical changing in the societies' methods of consumption and production. The 12th goals aim to the ecological management of chemical products and all wastes, reducing the production of wastes through several methods such as source reduction, reusing, and recycling (more, in general, the waste hierarchy). In addition, the goal aims to reduce food waste and encouraging enterprises to adopt sustainable practices.

1.2 The linear model

Since the beginning of industrialization, the industrial economy has never changed; its model is based on a linear model of resource consumption that follows a *"take-make-dispose"* pattern. Manufacturing companies extract virgin materials, apply energy and labor to manufacture the product, and sell it to an end customer. Consequently, when the products will not be able to serve its purpose anymore, the end customers will discard them. Even though many steps forward have been done in resource efficiency, each system based on resource consumption rather than on the restorative use of resources generates considerable losses all along the value chain. The question is not only about the depletion of earth resources, but many companies have also noticed that the linear model increases their exposure to risks concerning the higher prices of resources recovery. The Ellen MacArthur Foundation (2013) states that raw materials prices have touched a tipping point in 1999 (Figure 1.5), and the previous decreasing raw materials costs have started to increase with a volatile upward momentum.

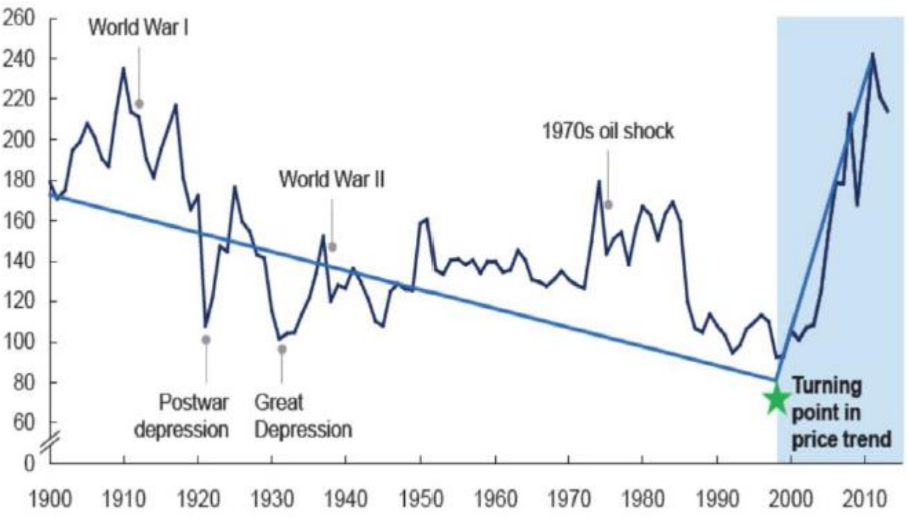

Figure 1.5: Raw material prices (The Ellen MacArthur Foundation, 2013).

Further, in the next 20 years, it is foreseen an increase in raw material consumers of 3 billion. Consequently, a significant number of businesses feel squeezed between rising and less predictable prices in resource markets and stagnating demand in many end-customer markets. Unfortunately, price and volatility likely will remain high as populations grow, the urbanization increase, resource extraction moves to harder-to-reach locations, and the environmental costs associated with the depletion of natural capital increase. In this scenario, the needing for an industrial model able to decouple the resource material input and the sales revenue has acquired more and more importance, along with Circular Economy concepts. The term *"Circular Economy"* consists of an industrial economy that has its bases on a restorative model by intention and design. In a Circular Economy, products are designed for easy reuse, disassembly, and refurbishment, or recycling. Moreover, the basis of the Circular Economy is the recognization that the foundation of economic growth is in the reuse of material reclaimed from end-products rather than the extraction of new resources. Through the adoption of this new model, unlimited resources like labor take a central role, whereas limited resources take a supporting role (McDonough and Braungart, 2002). The Circular Economy has considerable promises, already appreciated in several industries, being in grade to counter-act the squeezing feeling of several businesses between resource prices and stagnating end-customer demand. Therefore, leaping consuming and discharging products to using and reusing them, aligning with the patterns of living systems, is fundamental to ensure prosperity along with continuing growth. It can be possible stating that the Circular Economy is an attempt to mimic natural ecosystems. In natural ecosystems, waste materials generated by an organism are typically consumed by another organism, which means nutrients are cycled through an ecosystem. In literature, this process is defined as the biological metabolism of an ecosystem. Technical metabolism, as opposed to the biological metabolism, through innovation, planning, and design can be designed to use totally waste generated, thus mimicking natural processes observed in biological systems. During the 20th century, the decreasing in resource prices supported the economic growth in advanced economies. The low level of resource prices has generated the current wasteful system of resource use. The materials reusing has not had significant economic priority because of the easy way to obtain new resources and to dispose of them. Indeed, economic efficiency has been founded on the extensive use of resources, especially energy, to reduce labor costs. The system has had problems in correcting itself as long as accounting rules and the fiscal regimes that govern it allowed to remain unaccounted to a wide range of indirect costs, even called *"externalities."* The resulting system is defined as the *"take-make-dispose", "linear model," or also "the materials economy."* The phases through materials cross are extraction, production, distribution, consumption, and disposal (Figure 1.6). In other words, resources are acquired, processed, and sold as final products with the expectation that consumers will throw those goods and buy more of them (MacArthur et al., 2015). It could be said that the heart of the current linear model is the consumerism. In five steps, the systems convert raw materials into waste, and the more a country is developed, the faster this transformation takes place (Connect, 2007).

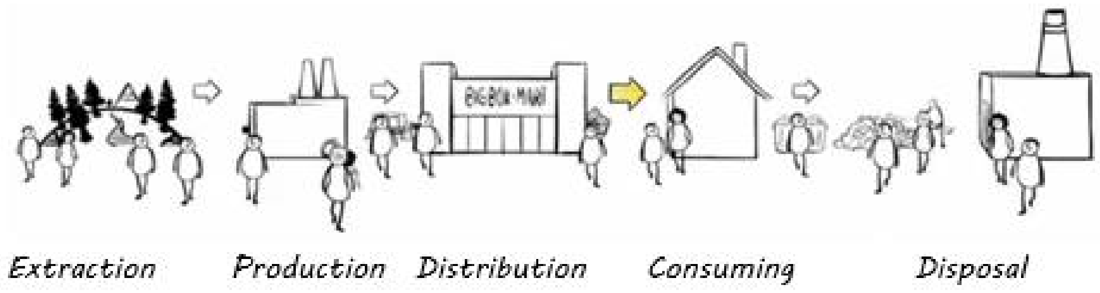

Figure 1.6: The linear model (The Story of Stuff Project, 2009).

Thus, human beings impose a linear society on a planet that works in circles. In each phase of the chain, there is depletion of resources, environmental, and social burden. During the extraction phase of virgin materials, much energy is required, producing vast quantities of solid waste, air pollution, water pollution, ecosystem damage massive quantities of carbon dioxide, which in turn leads to global warming (Connect, 2007). In the production phase, most of these impacts take place another time. During transport between every stage, there is a further energy requirement and the subsequent generation of carbon dioxide, causing more global warming. In addition, the consumption generates wastes that have to be disposed of, and without a proper waste management system, they are able to generate air and soil pollution, public health problems, and social difficulties. The report of the Sustainable Europe Research Institute has declared that 21 billion tons of raw material used as linear model input have not incorporated in the final product (i.e., they have been lost during the production process from virgin materials to final product) (MacArthur, 2013). In terms of volume, around 65 billion tonnes of virgin materials came into the global economic system in 2010. The European economy generated 2.7 billion tons of waste, but only around 40% of them were used again in any form, such as reusing, recycling or composting, or recovery. In addition, inside the linear system, waste disposal by landfill means the loss of all of the residual waste energy. The incineration and recycling are not enough because of recover just a small part of the residual energy. Whereas, the reuse of the end-of-life product can save most of the residual energy. The use of energy resources is typically the most intensive upstream of the value chain (i.e., those phases that include extracting materials from the earth and transforming them into a commercially usable form) (McDonough and Braungart, 2002). Now the focus will be on the *"golden arrow"* shown in Figure 1.6 (The Story of Stuff Project, 2009). The golden arrow is the engine of the industrial economy, and it can be considered as the beating heart of the current linear model. It is the "Consumerism," that mindset which pushes people to buy stuff, again and again. The consumerism is stimulated by advertising, using TV, social networks, and any forms of publicity. "*Over-advertising produces over-consumption [...] every seven minutes, we are told that we need something. We are told that we are hungry, thirsty, too fat, too sick, sexually frustrated, and need a new car! By the time a high school student leaves school in the US, he or she will have watched over 350,000 TV commercials. Our children are being programmed for life, for an over-consuming lifestyle*" (Connect, 2007). The high consumerism level, characterizing the current society, is mainly driven by that *"fashion changes,"* which require a manufacturing change of the product (i.e., the high hill changing). *"What is fashion? It is usually a form of ugliness so intolerable that we have to alter it every six months"* (Oscar Wilde, as quoted in The Dictionary of Humorous Quotations (1949) by Evan Esar). Linear model and this way of thinking find its roots in American consumerism, one of the most famous definitions of consumerism comes from Victor Lebow speech (1950): "*Our enormously productive economy demands that we make consumption our way of life, that we convert the buying and use of goods into rituals, that we seek our spiritual satisfactions, our ego satisfactions, in consumption. [...] We need things consumed, burned up, worn out, replaced, and discarded at an ever-increasing pace. We need to have people eat, drink, dress, ride, live, with ever more complicated and, therefore, constantly more expensive consumption. The home power tools and the whole "do-it-yourself" movement are excellent examples of "expensive" consumption."* Analytical research on this matter states that if everyone consumed at the European rates, humanity would need several planets to consume and several more if everyone consumed as much as the American average. *"There is enough in the world for everyone's need, but not enough for everyone's greed"* (Mahatma Gandhi, 1992).

1.3 Circular economy as a sustainable response

The Circular Economy is born to respond to the post industry revolution linear model. The limitations of the linear model explained precedently, are what the Circular Economy seeks to solve. The *"the Take-Make-Dispose"* model based its fundamentals on the easy access of a large number of resources and energy, but this is not suitable for the reality in which the industrial model operates. Unfortunately, working on resource efficiency alone will not solve the problem of the limited state of resources, and it is able only to delay the inevitable. A radical change in the industrial system seems to be necessary. One of the most important definitions of the Circular Economy was given from the Ellen Macarthur Foundation (2013): *"A circular economy is an industrial system that is restorative or regenerative by intention and design. It replaces the 'end-of-life' concept with restoration, shifts towards the use of renewable energy, eliminates the use of toxic chemicals, which impair reuse, and aims for the elimination of waste through the superior design of materials, products, systems, and, within this, business models".* The Circular Economy concepts come from the study of living systems considered as non-linear systems. The notion of optimizing system instead of the components is one of the most significant insights from studying the living systems, referring to components as *"design to fit."* Consequently, it is needed careful management of materials flow, which, in the Circular Economy, are considered to be of two types: biological nutrients, designed to re-enter the biosphere, and technical nutrients, which are designated to circulate without entering the biosphere (Figure 1.7)(McDonough and Braungart, 2002).

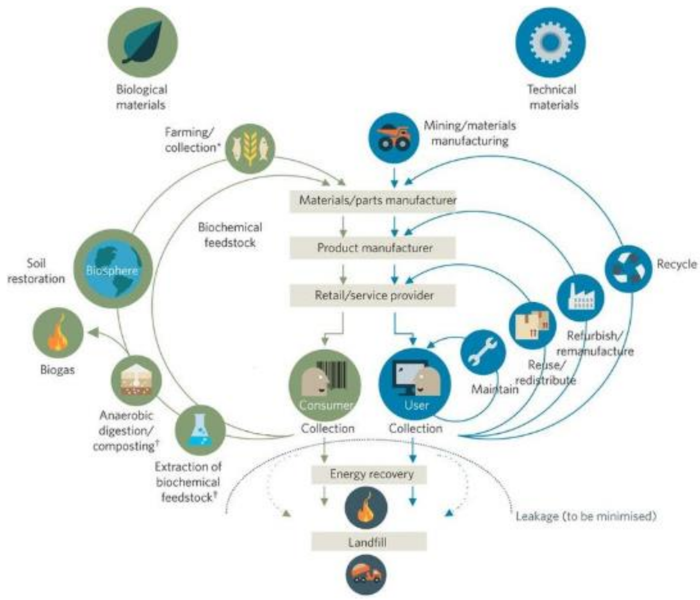

Figure 1.7: The Circular Economy & the biological and technical nutrients (McDonough and Braungart, 2002).

The Circular Economy provides a difference between the consumption and use of materials, and it means that manufacturers or retailers should act as service providers selling the use of a product rather than the one-way consumption of the product. This changing has direct implications on the development of product and business model design aid to create more durable products, facilitate disassembly and refurbishment. Nowadays, reuse and service-life extension are highlights of good resource husbandry and smart management. The Circular Economy has its fundamental pillars on a few simple principles (MacArthur, 2013). Firstly, the entire system should rely on renewable sources, and each circular changing should start by looking at the source of energy utilized in the production process. Moreover, waste does not exist if the biological and technical components of a product are designed with the purpose to be suitable with biological or technical materials cycle. Technical components should be designed to be utilized again with minimal energy and highest quality retention, whereas the biological nutrients (or components) should be designed to be non-toxic and simply composted. This basic principle can be shortly called as *"Design out waste."* On the biological side, the reintroduction of products or materials back into the biosphere is at the heart of the Circular Economy idea. On the technical side, also improvements in quality are possible (i.e., upcycling). The modularity, versatility, and adaptivity of a product are prized characteristics and should be prioritized, making the product (or the system) resilient to external changing and, therefore, more durable good. Finally, it is fundamental to adopt a systemic approach to understand how the different components of the system interact with each other. Components of a product should be considered in their relationship with the environment, its infrastructure, and the social context.

1.3.1 The Waste Hierarchy

Accordingly, with the already explained Circular Economy concepts, the "3 R's approach" is an internationally recognized framework to address them, also known as *"the Waste Hierarchy."* The three R stand for "reduce, reuse, and recycle," (Figure 1.8). Moreover, because of the current situation characterized by the waste generation increasing and the scarcity of the availability of landfill spaces, the 3 R's approach has become one of the Circular Economy fundamental pillars to establish a proper and sustainable MSW management (Tudor et al., 2011).

Figure 1.8: The Waste Hierarchy (Tudor et al., 2011).

Many waste management systems have evolved to incorporate the waste hierarchy concept. In the UK, North America, throughout Europe and parts of Asia, the waste hierarchy is included in the MSW management system. Therefore, the waste hierarchy is an order of management options for handling the amount of waste generated from a system, pursuing economic, environmental, and social sustainability. As per the Missouri Department of Natural Resources, *"The three R's – reduce, reuse, and recycle – all help to cut down on the amount of waste we throw away. They conserve natural resources, landfill space, and energy. Plus, the three R's save land and money communities must use to dispose of waste in landfills. Siting a new landfill has become difficult and more expensive due to environmental regulations and public opposition"*. The three R's approach has the purpose to address the MSW in relation to their characteristics. The most preferred is the reduction option, after that reuse and then recycling. In most frameworks adopted recently from developed countries, there is a fourth R, often called "Recovery," or more precisely, "Energy Recovery." In the following, the different management options will be detailed to understand better the waste hierarchy. The notion of waste reduction consists of reducing waste generation and minimize the toxicity of the generated waste by redesigning products and changing the consumption patterns of the end-costumers (USEPA, 1995). The most compelling moment to consider the source reduction option is in the product or process design phase. The most effective method to manage the wastes is not to create them, indeed, the reduction option is the most preferred one in the waste hierarchy. Source reduction also includes the utilizing of reusable goods and packagings. A typical example of waste reduction practice is choosing a coffee mug instead of a disposal one, eliminating the packaging waste, and with a durable good, the product can be repaired instead of replaced (Davidson, 2011). Moreover, the reduction is also achievable by decreasing the consumption of products, goods, and services. The waste reduction can be made by everyone; indeed, consumers can participate by buying less or reusable goods and use more efficiently the products. The public sector and the private sector can also be more efficient consumers. The public sector can reconsider the procedures which distribute the paper, purchasing longer life products and cut down the purchasing of disposable products (O'leary, 2002). The private sector can rethink its manufacturing process, reducing the waste generation in manufacturing phases. Reducing the amount of waste can imply the use of closed-loop manufacturing processes, different production processes, and different raw materials. Moreover, the private sector can redesign products, increasing the durability, ameliorating product effectiveness, and eliminating toxic materials. The source reduction can be encouraged by the full internalization of waste management costs (O'leary, 2002). The cost internalization consists of pricing the service, including all the costs. In the case of waste management, the costs to be internalized include pickup and transport, site and construction, administrative and salary, and environmental controls and monitoring. It is fundamental to consider that these costs have to be considered if the products are disposed of in a landfill, combustion, recycling, or composting facility. In addition, sometimes, it is possible to use a product more than once for the same purpose, and this is known as reuse (USEPA, 1995). For example, reusing disposable shopping bags, or utilizing boxes as storage containers (UC Davis, 2008). In other words, the reuse of products decreases the needing to buy other products, preventing a further generation of waste (O'leary, 2002). Decreasing waste generation by reduction and reuse offers many advantages, including decreasing the use of new resources to produce new products, decreasing the generation of waste during the manufacturing phase, and reducing the costs related to waste disposal (USEPA, 2010). Recycling is likely the most positively perceived option of all the waste management options. Recyclable materials are converted into new raw materials to market by separating reusable products from the general municipal waste flow. Recycling has several benefits, saving precious finite resources, decreasing the needing for mining virgin materials (which also decrease the environmental impact for mining and processing), and finally decrease the quantity of energy consumed. Moreover, recycling can alleviate the pressure of wastes on landfills, and ameliorating the efficiency and the ash quality of incinerators and composting facilities by diverting non-combustible materials (i.e., glass and metals). If recycling and composting are not executed in a responsible manner can be able to cause several environmental problems. To be effective, recycling should be supported by stable markets for recycled materials, and consequently, stable supplies. In addition, public education is another fundamental factor to improve the amount of recycling (O'leary, 2002). Recycling requires to go beyond a mere waste collection for recycling. It requires consumers to buying recyclable products, and companies to involve recycled materials in manufacturing processes and to design products for easy disassembly and separation of the recyclable components. Finally, the purpose of the recycled material can be different from the purpose of the original product (O'leary, 2002). Unfortunately, recycling requires energy and the input of new materials contrarily to reduction and reuse, and this is the reason that put recycling to the third level of the waste hierarchy. The least preferred option before landfilling is combustion (waste-to-energy). Incineration is attractive because it is able to reduce the waste volume by 90% (O'leary, 2002). Nowadays, incineration plants can also recover energy, either in the form of steam or in the form of electricity. Incineration plants can be useful in the case of unavailability of landfills or when the landfill is distant from the point of generation. The major constraints related to incinerator plants are their high costs, the high degree of technical sophistication needed to operate them safely and economically, and the fact that the public is skeptical about their safety. Mostly, the public is concerned about the emissions from incinerators and the toxicity of as produced by incinerator plants (O'leary, 2002).

1.4 Municipal Solid Waste definitions

According to directive 2008/98/EC of the European Parliament, waste is defined as *"an object the holder discards, intends to discard or is required to discard."* In other literary works, the waste definition can be different, but all the meanings are similar. Wastes are generated from human and animal activities and are discarded as useless or unwanted by the generator entity (Open Wash, 2016). The recycled or reused materials at the place of generation are not considered as waste (Glossary of environment statistics, 1997). In addition, a more international definition is from the United Nations Statistics Division (1997), describing waste as *"materials that are not prime products (that is, products produced for the market) for which the generator has no further use in terms of his/her own purposes of production, transformation or consumption, and of which he/she wants to dispose. Wastes may be generated during the extraction of raw materials, the processing of raw materials into intermediate and final products, the consumption of final products, and other human activities. Residuals recycled or reused at the place of generation are excluded."* Solid Waste, according to the Glossary of environment statistics (1997), is defined as *"Useless and sometimes hazardous material with low liquid content. Solid wastes include municipal garbage, industrial and commercial waste, sewage sludge, wastes resulting from agricultural and animal husbandry operations and other connected activities, demolition wastes, and mining residues."* There are several definitions of Municipal Solid Waste, but the most recognized one is from the World Bank. World Bank (2018) stated that "*Municipal solid waste"* (MSW) is a waste type that includes residential, commercial, and institutional waste. Industrial, agricultural, medical, hazardous, electronic, and construction and demolition waste are out of MSW scope. Similarly, O'leary (2002) individuated the followings source waste categories: (1) residential, (2) commercial, (3) institutional, (4) construction, and demolition, (5) municipal services, (6) treatment plant sites, (7) industrial, and (8) agricultural. Typical facilities, activities, or locations associated with each of these sources' waste categories are reported in table 1.1. The MSW is typically assumed to include all community wastes, except wastes generated by municipal services, water, and wastewater generated by treatment plants, industrial processes, and agricultural operations.

Source	Typical facilities, activities, or locations where wastes are generated	Types of solid wastes
Residential	Single-family and multifamily dwellings; low-, medium-, and high-density apartments; etc.	Food wastes, paper, cardboard, plastics, textiles, leather, yard wastes, wood, glass, tin cans, aluminum, other metal, ashes, street leaves, special wastes (including bulky items, consumer electronics, white goods, yard wastes collected separately, batteries, oil, and tires), and household hazardous wastes
Commercial	Stores, restaurants, markets, office buildings, hotels, motels, print shops, service stations, auto repair shops, etc.	Paper, cardboard, plastics, wood, food wastes, glass, metal wastes, ashes, special wastes (see preceding), hazardous wastes, etc.
Institutional	Schools, hospitals, prisons, governmental centers, etc.	Same as for commercial
Industrial (nonprocess wastes)	Construction, fabrication, light and heavy manufacturing, refineries, chemical plants, power plants, demolition, etc.	Paper, cardboard, plastics, wood, food wastes, glass, metal wastes, ashes, special wastes (see preceding), hazardous wastes, etc.
Municipal solid waste*	All of the preceding	All of the preceding
Construction and demolition	New construction sites, road repair, renovation sites, razing of buildings, broken pavement, etc.	Wood, steel, concrete, dirt, etc.
Municipal services (excluding treatment facilities)	Street cleaning, landscaping, catch-basin cleaning, parks and beaches, other recreational areas, etc.	Special wastes, rubbish, street sweepings, landscape and tree trimmings, catch-basin debris; general wastes from parks, beaches, and recreational areas
Treatment facilities	Water, wastewater, industrial treatment processes, etc.	Treatment plant wastes, principally composed of residual sludges and other residual materials
Industrial	Construction, fabrication, light and heavy manufacturing, refineries, chemical plants, power plants, demolition, etc.	Industrial process wastes, scrap materials, etc.; nonindustrial waste including food wastes, rubbish, ashes, demolition and construction wastes, special wastes, and hazardous waste
Agricultural	Field and row crops, orchards, vineyards, dairies, feedlots, farms, etc.	Spoiled food wastes, agricultural wastes, rubbish, and hazardous wastes

Table 1.1: Municipal Solid Waste scope (O'leary et al., 2002).

1.5 Municipal solid waste management

Historically, MSW management has ever been a fundamental function, and it is related to the technological evolution of modern society. Along with the benefits of mass production, there are also several problems associated with the disposal of MSW. Further, waste is one of the most global environmental issues (O'leary, 2002), representing an inefficiency symbol of any modern society and a misallocation of resources. When the lifestyle of people improves, looking for a better life and a higher standard of living, they tend to consume more goods and generate more waste. As a consequence, the society aims to ameliorate the MSW management methods and to reduce the amount of waste that needs to be disposed of. MSW management, according to O'leary (2002) definition, is a complex process, involving several technologies, disciplines, and stakeholders. MSW management is related to the control of generation, storage, collection, transfer and transport, processing, and disposal of MSW. In other words, a MSW management includes the control and the management of all the activities required to manage MSW from its generation site to its final disposal. These processes have to be performed within legal and social guidelines, protecting the public health and in a sustainable manner from an economic, environmental, and social perspective. The purpose of a MSW management is to reduce the adverse effects of MSW on human health, the environment, or the aesthetics of a city. The disposal process needs to consider administrative, financial, legal, architectural, planning, and engineering functions to be compliant with public attitudes. These disciplines have to communicate with each other effectiveness, making the MSW management process soundness and effectively. Moreover, MSW management practices vary considerably between developed and developing nations, urban and rural areas, and residential and industrial sectors (Davidson, 2011). In addition, O'leary (2002) has defined integrated MSW management as the selection and application of suitable methods, technologies, and management programs to reach MSW management objectives and goals. The U.S. Environmental Protection Agency (EPA) has identified a fundamental strategy based on four basic management options for an IMSW management process (precedently defined as the *"waste hierarchy"*): source reduction and reuse, recycling and composting, combustion (waste-to-energy facilities), and landfills. These management options should be considered with hierarchical order. For example, recycling has to be considered after having considered source reduction. Correspondingly, the waste-to-energy transformation has to be considered after all the recyclable materials are recovered. The least preferred option is landfilling because of the high environmental burden related to it (Figure 1.8) (O'leary, 2002). Further, the needing for IMSW management is due to the recognition that the MSW management is included in a wider system (i.e., the MSW management system), consisting of several stakeholders. Concluding, IMSW management tends to be environmentally sound, economically viable, and socially desirable (Medina, 2004). The following sector will analyze each phase of the described MSW management process, highlighting the relationships among them. The MSW management is considered as a process, and it can be defined as follow: *"A process* *is a collection of related, structured activities or tasks by people or equipment which is a specific sequence produce a service or product (serving a particular goal) for a particular customer or customers. Processes occur at all organizational levels and may or may not be visible to the customers. Moreover, each process has one or more input, transforming them to one or more output, through the process activities"* (Weske, 2012; Kirchmer, 2017; Von Scheel et al., 2014). Notably, in the case of the MSW management process, it is possible to think about the generation of waste as the trigger event of the entire process, whereas the activities to be performed are waste storage, collection, transfer, and transport, treatment and disposal by landfilling (often treatment and disposal by landfilling are considered as only one phase called treatment). Figure 1.9 shows a general overview of how the different phases interact with each other, but the detail of the interaction depends on how the MSW management process is implemented.

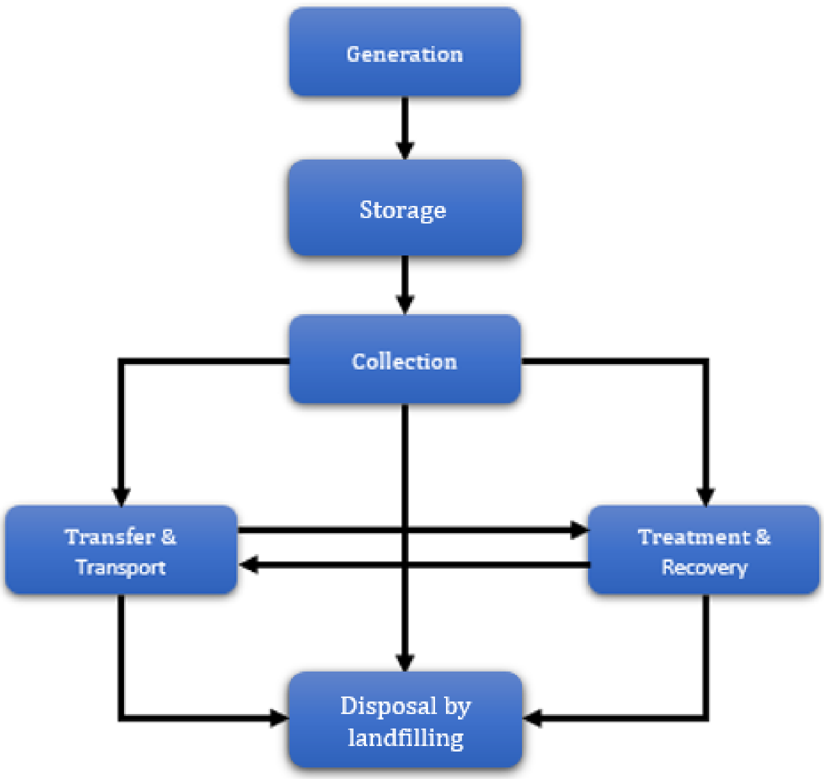

Figure 1.9: The possible relation among the MSW functional element.

1.6 Waste generation

Waste generation is the first phase of all the process (it is possible to consider it the event trigger of the entire process) and, further, the only one directly uncontrollable. Generation phase includes all those activities in which generators identify some products as without value. After the identification step, citizens throw them away, introducing them as the input of the MSW management process. Waste generation is a consequence of urbanization, economic development, and population growth. When a country, or a city, grow up, increase its population and prosperity, offering more product and services to its citizens. Consequently, the waste generation rate is destinated to increase when a city, or a country, improve its prosperity (World Bank, 2012). Particularly, MSW generated from an urban settlement is related to the human development index, depending on the following variables: life expectancy, gross domestic products, and education indices. In literature can be found different studies among countries and over time that reveal a positive relationship between GDP per capita and urbanization rate with waste generation per capita (World Bank, 2018). The negative impacts of MSW include land occupation, environmental pollution, and the spread of disease. Kaza et al. (2018) have estimated the global waste generation of 2.01 billion tons in 2016, and the estimation is expected to increase to 3.40 billion tonnes by 2050. Currently, the East Asia and Pacific regions are generating most of the world's waste (Figure 1.10). Even though the high-income countries represent only the 16% of the world's population; they generate the 34% of the world's waste (Figure 1.10)(Kaza et al., 2018), and the North America region has the highest amount of waste generation per capita of 2.21 kg/day.

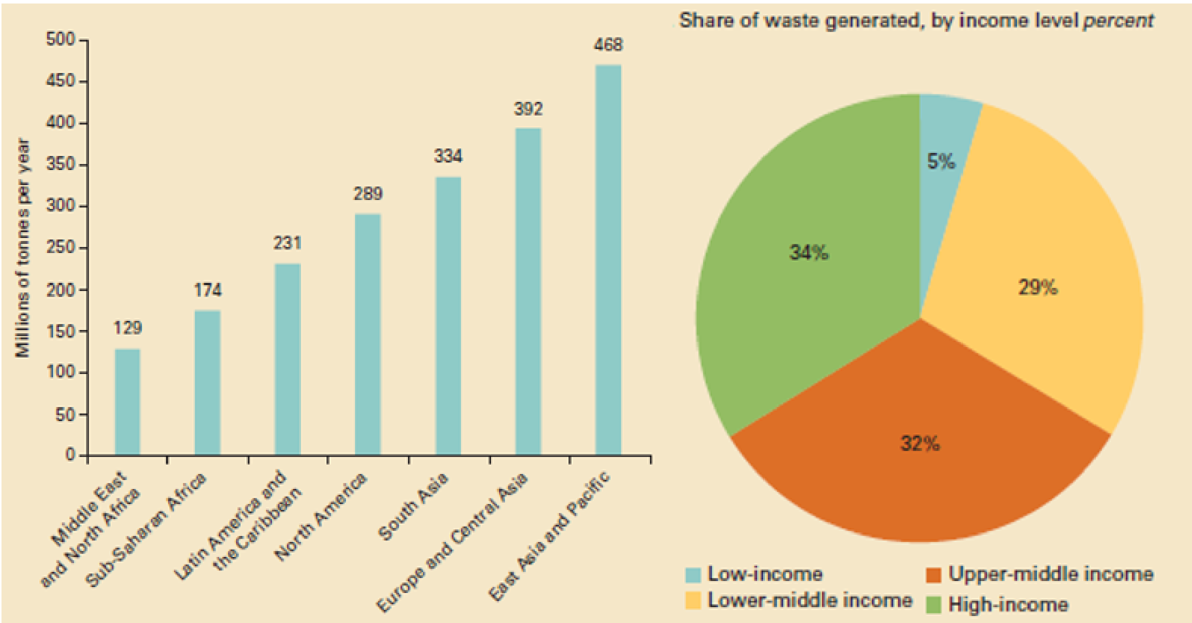

Figure 1.10: Waste generated by regions and the share of waste by income level (Kaza et al., 2018).

1.7 Waste composition

The waste composition consists of the classification of MSW in different categories. There exist several methods to determine the MSW composition in a country or a city. The most practical one is through a waste audit, in which a sample is taken from the disposal sites, sorted in predefined categories, and finally weighted. Within the same category, MSW have similar physical properties. The most used categorization was stated by Kaza et al., (2018):

- Food and green;
- Glass;
- Metal;
- Other;
- Paper and cardboard;
- Plastic material;
- Rubber and leather;
- Wood.

The number of categories can be refined, but in most cases, the previous amount of categories is able to offer a proper analysis degree. MSW composition can be influenced by several factors, such as economic development, cultural norms, energy sources, geographical location, and climate. If the urbanization increase and the population become wealthier in a country, the consumption of inorganic materials (i.e., plastics, paper, and aluminum) will increase, while the organic fraction will decrease. Indeed, low and middle-income countries tend to have a high percentage of the MSW organic fraction, ranging from 40% to 85% of the total. Consequently, paper, plastic, glass, and metal fractions increase in the composition of middle and high-income countries. Figure 1.11 shows a comparison of the different MSW compositions among different levels of income (Kaza et al., 2018). Moreover, geography ubication influences MSW composition through the availability of different resources, determining building materials (e.g., wood versus steel), ash content (often from household heating), the quantity of street sweeping (can be as much as 10% of a city's MSW in dry locations), and horticultural MSW. The type of energy source also can have a significant impact on the MSW composition generated. It is particularly true in low-income countries where energy for cooking, heating, and lighting, is not from district heating systems or the electricity grid. Another MSW composition influencing factor is the climate, and it can influence the MSW composition in a city, country, or region. Precipitation is also an important driver in waste composition, particularly when measured by mass, as un-containerized waste can absorb significant amounts of water from rain and snow. Humidity also influences waste composition by influencing moisture content (Hoornweg et al., 2012).

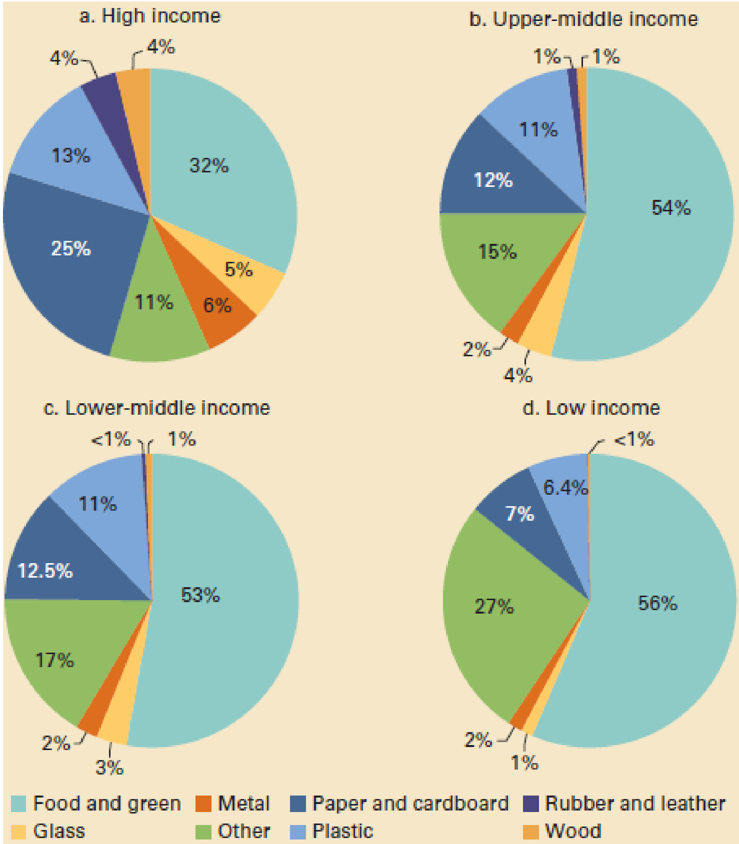

Figure 1.11: Different MSW compositions among different levels of income (Kaza et al., 2018).

1.8 Municipal Solid Waste classification & collection

Storage regards the activities aimed to contain MSW, in an approved manner. Dumpsters or other containers are typically designed to storage MSW. Waste storage can be separated or mixed, depending on the local regulations. Waste sorting can be done by the household or automatically in material recovery facilities, but hand sorting by users is still the most common method. Separating waste at source enables differentiated collection in the collection phase and subsequent recovery of raw materials and energy in the treatment and recovery phase. Source separation has provided the fundamentals for reuse, recycling, and recovery by addressing different types of MSW to the proper treatments. Source separation is one of the best practices to reduce the environmental burdens of disposing MSW. Hence, it is essential to create high public participation in source separation by the adoption of a mix of policies and education approaches. The MSW management system has to own the proper recovery and post recycling facilities; otherwise, the source separation system does not have any sense. Adopting a source-separated collection is one of the enabling steps to achieve sustainable MSW management. The source-separated collection begins in the storage phase (with source separation) and influences the entire process of collection, transportation, disposal, and treatment. It is done dividing into different storage units, with a distinctive color, the diverse MSW categories. It could be asked to users to separate garbage at source, and one of the most common source-separations can be "wet" (food waste, organic matter) and "dry" (paper, glass metal, and plastic), and possibly a third stream "waste" or "residue." It is done in order to address every MSW category to the best disposal or treatment, allowing a more accessible collection phase, increasing recycling and reuse rate, and the energy recovery. The degree of source separation influences the amount of material recycled and the quality of secondary materials that can be supplied. Recyclables recovered from mixed waste tend to be contaminated, reducing the attractiveness of them. Unfortunately, the source-separated collection can also have negative aspects; first of all, it adds complexity to the storage and collection phases. Further, an increase of the MSW differentiated categories number means higher collection costs, and it can become too complicated for citizens separating MSW, and the probability of a wrong separation can increase. It is crucial to find an equilibrium between the previous aspects. Talking about the collection of MSW, it is considered a crucial phase in the matter of public health in cities and countries around the world, and the amount of MSW collected varies widely by region and income level. The waste collection concerns the transfer of MSW from the generation site or the temporary storage to the facility treatment or landfill. The collection services are typically performed at a municipal level, and several collection models are used across the world. The most utilized one is the door-to-door collection, and trucks or small vehicles, or handcarts or donkey in low-income countries, are used to collect waste outside of the household's home at a predetermined time and frequency. Whereas in certain areas, communities dispose of waste in public containers or collection point where the waste is picked up by the municipalities and transported to the treatment facilities. In areas where there is not a regular collection, and communities can be notified by a bell or other signal that a collection vehicle has arrived in the neighborhood. Following, it will be summarised the more diffused models to collect the MSW (Hoornweg, 2012):

- Door-to-door: also known as home-to-home service, it is the case in which MSW collectors collect garbage from every house directly. Typically, the users pay a fee for this service.
- Community Bins: also known as the drop-off system, in this case, there are community bins situated at fixed places in a neighborhood or locality in which users bring their garbage. MSW is picked up by the municipality, according to a set schedule.
- Curbside pick-up: Users leave their garbage directly outside their houses. There is an accorded pick up schedule settled from local authorities.

Moreover, the frequency of collection is another significant variable; unfortunately, there is not a fixed range for collection frequency. It depends on the size of the containers, the kinds of MSW, and the average waste amount per capita per day. From a health point of view, it is enough a weekly waste collection, but, in some cities, mostly because of culture and habituation, it is offered a three-times per day residential waste collection. In high-income countries, the collection rates are near to 100%. Unfortunately, because of several constraints factor, it is not valid in other income levels, indeed in low-middle-income countries, the collection rates are around 51%, and in low-income countries, about 39% (Figure 1.12) (Kaza et al.,2018). Often, in low-income countries, the wastes are managed by households directly, and they can be openly dumped, burned, or composted. The waste collection is fundamental, and improve it allow to reduce pollution and improve human health. Moreover, the collection rates tend to be higher in urban areas than in rural areas (i.e., more than twice), mainly because the collection services are provided by municipalities (Figure 1.12) (Kaza et al., 2018).

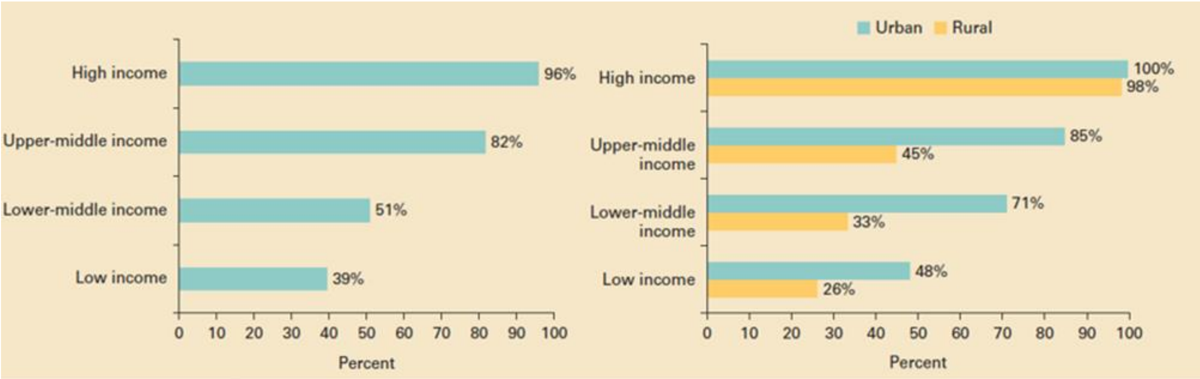

Figure 1.12: Collection rates by income level and the differences between Urban and Rural (Kaza et al., 2018).

1.8.1 Recycling activities in developing countries

Informal waste recycling activities are usually executed by disadvantaged and marginalized social groups. Moreover, it is mainly labor-intensive, unregulated, and unregistered, low-technology manufacturing or provision of services (Wilson, Whiteman, and Tormin, 2001). The informal recycling occurs in developing countries due to the low level of economic development. Indeed, paltry salary and low prices for products or services can make possible to gain profit margin collecting and selling recyclable materials. If there were working alternatives, scavenging would be less attracted by informal recycling (Porter, 2002). The informal sector is crucial in developing countries, and in developed countries, a strong presence of the informal recycling sector is unusual. The informal waste sector includes individuals, groups, and micro-enterprises executing informal waste services but, in contrast to the formal recycling sector, "*are not sponsored, financed, recognized or allowed by the formal solid waste authorities, or who operate in violation of or competition with formal authorities*" (Wilson et al., 2006). The primary purpose of informal recycling workers is to gain a profit through service fees or by selling valuable recyclables picked from mixed waste. These actors are called in different ways in relation to their own country, but they are usually known as recyclers, scavengers, waste-pickers, or rag-pickers (Medina, 2000; Wilson et al., 2006). In cities with a formal MSW collection and disposal system, at least four informal waste recycling categories can be identified (Wilson et al., 2006):

- *Itinerant waste buyers:* Waste collectors who usually provides a door to door service, collecting valuable recyclable materials from households. They buy or barter the waste and then transport it to a recycling shop. They invest labor and capital to acquire and run a vehicle. The "*3-wheelers*" is one of the most common vehicles used by itinerant waste buyers, such as in China or Bangkok (Li, 2002).
- *Street waste picking:* Informal pickers who collect recyclables, recovering them from mixed waste thrown on the streets or from public bins.
- *Municipal waste collection crew:* In this case, households should bring their wastes in determined collection points(e.g., public bins). Recyclables materials are recovered from vehicles transporting mixed MSW to the dumping site by informal pickers. This practice is largely diffused in different countries such as Mexico, Colombia, Thailand, and the Philippines.
- *Waste picking from dumps:* Waste actors, such as pickers or scavengers, recover recyclables directly from the open dump, as shown in Figure 1.13 (Wilson et al., 2006). These activities are often associated with communities that live in shacks built with waste construction materials close to the dump. Waste picking open dumps actors are prevalent in different cities belonging to developing countries such as Manila, Mexico City, Cape Town, Bangalore, Guadalajara, Rio de Janeiro, Dar es Salaam, Guatemala City and many others (Bernache, 2003).

These are the basic informal categories involved in the informal recycling system, but variations can occur. For example, if between the collection and disposal site, there are other intermediate points, this can provide another opportunity to recover recyclables for informal pickers.

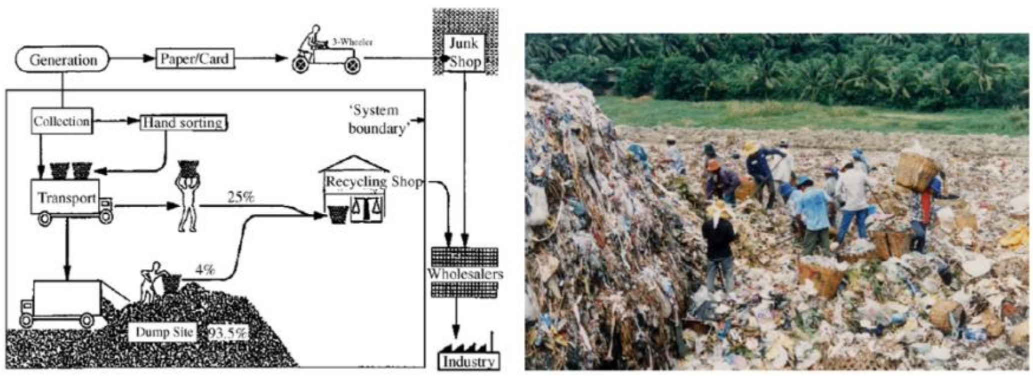

Figure 1.13: Informal recycling system and waste workers in an open dump (Wilson et al., 2006).

The informal organizational structure has consequences on working conditions, social status, and income generation of informal recycling workers. It is possible to declare that the less organized is the informal sector, the less informal waste workers are able to add value to the raw materials collected (Wilson et al., 2006). Therefore, when the informal sector is not structured, the people involved are more vulnerable to be exploited by intermediate dealers, and this is particularly valid when only one buyer exists. After picking and sorting, people involved in the informal sector sell the recyclable materials to gain a livelihood (Wilson et al., 2006). Recyclables picked by informal workers are traded locally. The usual end-users are industries, including artisans and craftsmen. Several intermediate dealers often exist between scavengers and end-users. The chain can be composed of primary and secondary dealers, micro and small recycling enterprises, junk shops, intermediate processors, brokers, and wholesalers, and can include both formal and informal sector activities. Table 1.2 shows a possible secondary materials trade hierarchy (Wilson et al., 2006).

Highest value	Manufacturing industries
↑	Brokers, wholesalers and other processors
↑	Craftsmen, middlemen
↑	Recycling MSEs and scavenger co-operatives
↑	Family type units involved in waste collection or scavenging/picking
Lowest value	Individual waste scavengers/pickers

Table 1.2: Informal recycling trade hierarchy (Wilson et al., 2006).

Individual informal pickers are restricted to the lowest stage of the hierarchy, and this reduces their potential income. Individual waste scavengers/pickers are the most vulnerable actors in the informal sector chain because they do not have any organized supportive network. Family-organized activities usually include vulnerable individuals such as children, women, and the elderly, increasing their exposition to health risks. Further, this kind of organization does not allow children to have a formal education (Wilson et al., 2006). Nevertheless, the family organization reduces individual vulnerability, providing a certain level of social and economic support. Through the organization and the training of the informal recycling workers into micro and small recycling, enterprises can be an effective method to upgrade their capacity to add value to recyclable materials (Haan et al., 1998). Moreover, being structured in an organization, informal workers can be able to avoid intermediate dealers, and their income can be considerably increased and their activity can become more socially acceptable and legitimized. Forming a scavenger/waste picker cooperatives and associations, they can be able to enhance their position, negotiating as an entity with local authorities and/or private sector (Medina, 2000). The informal recycling sector can be highly skilled in identifying waste with potential value. Informal workers collect recyclables materials from mixed waste and add value to them by sorting, cleaning, altering the physical shape to facilitate transport, or by aggregating materials into a commercially available quantity (Scheinberg, 2001a). Table 1.3 offers an overview of the different methods to add value to the collected recyclable materials by the formal sector (Wilson et al., 2006). The informal recycling system can be highly efficient, and often it is more efficient than the formal recycling system. The typical collected recyclable materials are plastics, paper, cardboard, aluminum, steel, other metals, glass, and textiles (Haan et al., 1998). The recyclable activities related to certain recyclable materials are influenced by several factors, such as potential profit margin, the existence of local and national markets, the related demands, and international commodity prices. In many countries (e.g., China), industries have a heavy dependency on recycled materials, either local or imported.

Extracting and adding value processes	Explanation and comments
Collection	Identification and picking of items or collecting mixed waste allows the sector to acquire the waste and turn it into a resource. Most primary materials recovered from refuse, such as paper, plastics, rags, metal, glass, and food leftovers, constitute a commodity as they all have a market price
Sorting	Main process that increases the value of the waste recovered. The deeper the sorting differentiation, the higher the value of waste. For instance, if plastic is grouped into one major category, its value is lower than when it is further separated into sub-categories of hard and soft, then HDPE, PET, LDPE, etc. Sorting according to colour, size, shape and potential use or re-use of the materials so as to meet the end-users quality specifications
Accumulation of volume	Additional volume adds value: larger volumes command higher per-unit prices. The greater the quantity, the better bargaining power the trader has. For small quantities, transactions costs, such as checking quality, arranging transport and paying the seller, reduce the profit margin. Industrial feedstocks are massive in volume. It follows that storage space is required
Pre-processing	For instance: washing, changing in shape-cutting, granulating, compacting, baling
Small manufacturing craftsmanship	Creation of micro-enterprises that use the special skills of informal recyclers to transform recyclates into articles traded directly to the community and being affordable by the poor
Market intelligence	Proximity to markets where informal recyclers and traders conduct business allows for the flow of information which allows decisions to be made on accurate market prices, competitors, trading partners, etc
Trading	In informal or formal markets. Links to the secondary materials network are crucial. Traders should be financially capable to add and conserve value of recyclates. Difference between buying and selling should also provide buffer against risk

Table 1.3: Different methods to add value to the collected recyclables by informal workers (Wilson et al., 2006).

Informal recycling systems are able to bring significant economic benefits to developing countries. The informal recycling sectors largely contribute to improving the recycling rates in low and middle-income countries. From a macroeconomic point of view, they are well adapted to the boundary conditions; indeed, the informal sectors are characterized by an abundant supply of working force, but limited capital. In other words, they minimize capital expenditures, relying upon hand (and animal) power in places where the labor costs are low (Haan et al., 1998; Scheinberg, 2001b; Wilson et al., 2006). The informal recycling systems generate between ten and forty times more jobs than MSW management systems in a high-income country (Steuer et al., 2018). Through a steady supply of recyclable materials to the local manufacturing industry, it is possible to replace the use of more expensive imported raw materials. Moreover, this stimulates the low-cost manufacturing of affordable products made by recycled materials. In addition, they have positive effects on formal sectors, especially from a financial point of view. Informal recycling systems existing in many developing countries help to reduce the cost of the formal MSW management systems, reducing the amount of waste to be collected (resulting in less expenditure of collection and transport for the formal management system), and diverting recyclable materials from landfill sites, leaving more space for mixed waste (Wilson et al., 2006). Most of the benefits coming from informal recycling sectors are achieved with no direct costs to the households who pay taxes. In addition, there are even social benefits from informal sectors, providing employment and a livelihood for impoverished, marginalized, and vulnerable individuals or social groups (Medina, 2000). Despite the not favorable working conditions of informal workers, it should be considered that it allows surviving and be employed to individuals in regions where the unemployment rates are high. Some studies about the economic benefits from the informal sectors are following reported. An assessment of six cities made from by Simpson et al. (2011b), informal recycling system contributes avoiding costs related to MSW collection amounting to 14 million EUR/year in Lima (Peru), 12 million EUR/year in Cairo (Egypt) and 3.4 million EUR/year in Quezon City (Philippines). In Lusaka (Zambia), the cost of informal MSW collection is 10.4 USD/ton less than in the formal sector. UNEP (2010) studies the cases of Jakarta, Delhi, and Bangalore, where MSW informal recycling system avoiding around 30% (in Jakarta) and 15% of MSW going to landfill (Delhi and Bangalore). Moreover, the informal sector represents a reduction in waste collection and disposal costs of around 13,700 USD/day for the Delhi and Bangalore formal sector. Despite the positive aspects of informal waste, several studies have shown serious social problems about informal recycling system workers, such as poor working and living conditions, child labor and school absences, and incomplete school education for adults (Medina, 2000; Wilson et al., 2006). Family informal waste activities often include their children, who can be found picking wastes in the street or dumps (Wilson et al., 2006). The main reasons for child labor are their economic contribution to the family with unpaid work, family poverty, the lack of educational skills, and the relatively high costs of schooling, (ILO, 2004). Another issue about the informal sector is health. Informal pickers do not have any protection clothes, being more likely to be hurt by sharp objects and animals (UNEP, 2005). Further, several studies have reported the increasing risk in medical diseases related to informal waste work (Cointreau, 2006; UNEP, 2005; Aparcana, 2016). Moreover, citizens and authorities have hostile behavior versus informal waste-workers (Medina, 2000). They are socially marginalized and work in poor conditions. Informal pickers and workers of the last levels of the informal hierarchy suffer from being associated with waste. Citizens rarely appreciate the informal pickers' job (Simpson et al., 2011). Consequently, informal waste workers tend to assume self-hatred behavior and suffer from a lack of self-confidence. In some cases, they tend to consider themselves to be associated with "*sub-human characteristics*." Some studies about the social conditions about the informal sector workers are following reported. Scheinberg and Savain (2015) study the condition of informal waste-workers in Tunisia, Morocco, and Palestine, where they perceived themselves as abandoned and rejected. This self-perception was different when they were active in higher stages of the materials hierarchy (Table 1.2), such as professional recyclers. This kind of waste workers tends to have access to better equipment, allowing them to collect more MSW and trade directly with recycling companies or the public sector. They appear to have a better self-perception of their social condition, considering themselves as business or service providers (Scheinberg and Savain, 2015). In addition, public policy in MSW management has been typically driven by the needing to ensure the public health and control the environmental burdens related to poor MSW management. Therefore, in many developing countries, informal sector public policies have been mostly negative (Wilson et al., 2006). During the last 30 years, there has been an increasing acknowledgment about the economic, social, and environmental benefits of the informal recycling system in MSW management, leading towards a developing of more supportive policies to improve the informal workers working conditions. Often, the leading role in developing supportive policies has been taken by local or national non-governmental organizations. The municipal authorities and politicians should be convinced to move from their traditional policies of repression and neglect of, or collusion with, the informal recycling system to one of constructive engagement. Indeed, the primary challenge is to support and to integrate the formal MSW management with the informal recycling system. The first step should be the recognization of the economic, social, and environmental benefits of the informal sector by the authorities (Wilson et al., 2006). Moreover, it should be recognized that merely copying the developed countries' MSW management approaches is not appropriate given the boundary conditions. Likely, the most difficult challenge is to shift the officials and public perception towards those who work in the informal sector. One step to the integration of informal waste recycling is to work with it, to help them to organize themselves (i.e., in micro and small enterprises) and how to add value to their recycled materials before selling them. In other words, helping them to move up the hierarchy (Table 1.2) and to extract more value from their recycled materials, as shown in Table 1.3 (Wilson et al., 2006). Nevertheless, there are some potential conflict points between informal recycling system and formal MSW management services that should be known and addressed to allow integration. When both MSW collection crew and scavengers are collecting wastes, this can increase the loading time and reduces the MSW collection crew efficiency. Moreover, the presence of informal pickers at transfer stations and landfill sites could cause interference with vehicle movements, which could be dangerous and reduce efficiency (ISWA, 2002). It is not possible to solve the problem by ignoring the informal sector workers. To address these problems many MSW management investment projects have been proposed, seeking to improve transfer stations or engineered landfill sites to replace open dumps. The proposed solutions were to provide different areas of the sites where pickers could collect recyclables safely, without butting in with MSW crew vehicle movements or with MSW placement at the landfill site. These proposed engineering solutions should be combined with social development programs (Wilson et al., 2006). For example, working with non-governmental organizations to provide schools and health care facilities, making it possible to ban children under a certain age from informal recycling activities and require pickers to have regular medical certificates. However, all these interventions should be carefully planned and integrated to reach maximum impacts. Planning improvements without considering the huge informal sector can mean the failure of the plans (Wilson et al., 2006).

1.9 Transport & Transfer

Transport can be defined, from a theoretical point of view, as the moving of collected waste from one point to another one. The previous definition has a large scope intentionally because there may be several instances, such as moving a full load of waste from the collection area to the first transfer point, transport to or between treatment facilities, or transport from the waste management system to the industries using recovered materials. The most diffused ways to transport waste are the following (Eisted et al., 2009):

- Road: trucks, flatbeds, compaction trucks, tractors and trailers, and containers;
- Rail: trains, heavy locomotives, and open and closed freight coaches;
- Inland water navigation: barges;
- Ocean: oceanic ships and coasters.

The different transport choices are related to local conditions, such as available options, costs, and how far are transfer points and/or treatment facilities. The variation of the density and the compaction of the waste are significant variables in transport issues. Plastic, paper, and cardboard have a low density but are more compactable than metals and rubble, which have a higher density. Following, there are explained the major differences among transport methods. Transport by road is the most commonly utilized (Eisted et al., 2009). The trucks can have several sizes and dimensions. Their capacity can vary from approximately 2 tonnes for small collection vehicles to more than 40 tonnes for heavy goods vehicles with trailers. Generally, collection trucks transport garbage from the collection points to facilities where wastes are discharged. The first facility could be a transfer station or material recovery facility, where the wastes are moved to other facilities for recycling, incineration or landfilling. Sometimes, the waste can be transported by train, and it can mean one or several locomotives pulling a long chain of coaches transporting a considerable amount of MSW over very long distances, such as between transfer stations or waste treatment facilities (Eisted et al., 2009). Every coach can have a capacity from 20 to 40 tonnes; therefore, it can vary with coach size, number of axles, and the condition of the track. A hypothetical train can have more than 50 coaches, and it means it could be a load of more than 1000 tonnes. Moreover, barges can be used to transport garbage by inland navigation. Inland navigation can be the best transport option when road transport is complicated, limited, or too expensive. The waste can be loaded directly into the barge's bulk, and the barge capacity is about hundreds of tonnes, but it intensely depends on the size of the barge, the width, and the depth of waters of navigation. Also, wastes can be transported through the ocean (Eisted et al., 2009). Ocean navigation to transport wastes is not a standard solution, and in these cases, ships are utilized to move wastes from one part of the world to another. In other words, ship transportation is a global method for carriage waste. Typically, ships are loaded with containers that contain different types of waste fractions. The total load depends on the size of the ship. Finally, the transfer consists of the reloading of garbage from one means of transport to another, but in some transfer facilities are done even other activities like compaction and/or segregation of the waste (Eisted et al., 2009). Frequently, transfer facilities are the conjunction point between one or more means of transport (e.g., road transport with rail transport). Dividing carriage, from the collection point to the final destination, in different transportation types is called *"transport rationalization."* It is done in order to increase the efficiency and lower the costs. Further, transfer points are a way to decrease the cost of handling recyclables and subsequently increase the net value of recyclables fractions such as paper, glass, electronics, plastic, cardboard, metals, or organic waste (Eisted et al., 2009).

1.10 Treatment & Recovery

The MSW treatments are fundamental to decrease the potential waste emission, to recover recyclables, to recover energy from MSW, and to reduce the landfilled MSW volume. When garbage gets treatment facilities, through one or more ways of transport, there starts the *Treatment & Recovery* phase. Treatments can be divided into four categories: material recovery and recycling, thermal conversion, biological treatment, and mechanical treatment (Figure 1.14). In the next paragraphs, there will be made an overview of the major types of MSW treatments.

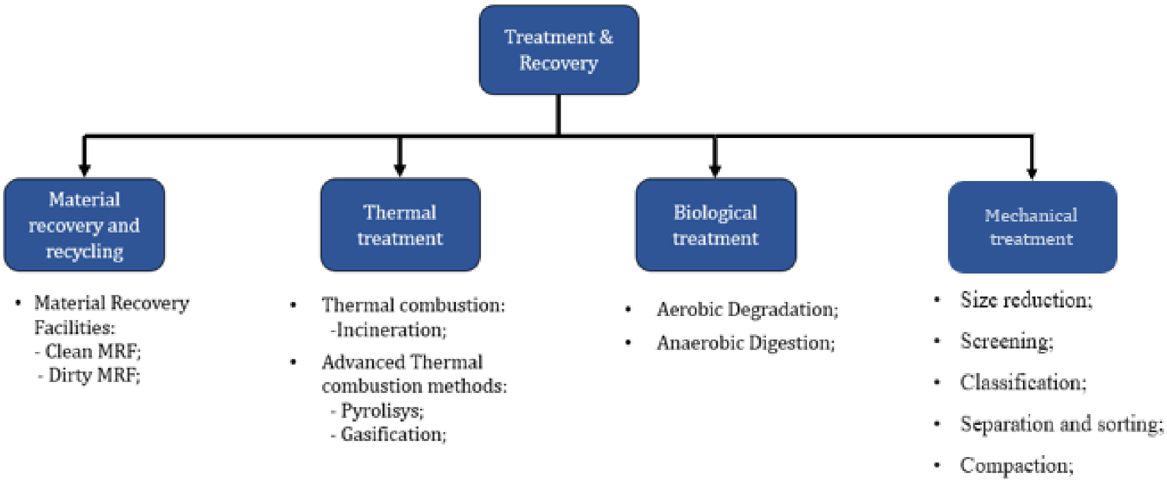

Figure 1.14: Treatments & Recovery methods.

The main objective of mechanical treatments is to make more accessible the handling, transporting, and increasing the efficiency of biological and thermal treatments. It is possible to divide the overall mechanical treatments into the following five categories:

- *Size reduction*: The primary purposes of size reduction are to facilitate the separation and further treatment, facilitate the transport, improve the reaction surface (for combustion process) and increase the density;
- *Screening*: It is the method to take granulated material and separate it in several degrees by particle size, and the utilized machines can be the following: the drum screen, disc screen, and vibrating screen;
- *Classification*: Similar to the previous mechanical treatment, but here are adopted different machines, such as air classifier, ballistic separator, and swim-sink separator;
- *Separation and sorting*: The purpose of separation and sorting treatment is to divide into different categories the coming waste;

- *Compaction*: The most helpful compaction machines are the Brikette press, the Pellet press, and the Bale press. Again, the objective is to make easier handling and transporting.

Material recovery facilities (MRFs) are facilities where recyclable materials are received, sorted, and stored. Consequently, recyclable materials are shipped and marketed to manufacturer users. MRFs accept, as input, both mixed and sorted waste. The MRFs are an intermediate step between the collection of recyclable materials from waste generators and the sale of recycled materials. The primary goal of the MRFs is to maximize the number of recyclables processed. Typically, it can be possible to find two types of MRF:

- *Clean MRFs*: These facilities can accept materials already separated at the source. The most common MRFs have a single stream where all recyclable materials are mixed, or dual-stream MRFs, where the source-separated recyclables are brought in a mixed container stream (typically glass, ferrous metal, aluminum, and other non-ferrous metals, PET and HDPE plastics) and a mixed paper stream including newspapers , cardboard boxes, magazines, office paper, and junk mail. Then, materials are sorted by specification and consequently baled, shredded, crushed, compacted, or otherwise prepared for shipment to market
- *Dirty MRFs*: They are a mixed-waste processing system that accepts mixed MSW stream. Here, whit a mix of manual and mechanical sorting, the MSWs mixed stream is separated, picking the designated recyclable materials. Recyclable materials may undergo to further processes because of meeting other requirements established by end-markets. The remaining mixed stream is sent to an incinerator and/or to a landfill. The operational costs of dirty MRFs are higher than clear MRFs because they are labor-intensive facilities.

Biological treatments are used to recycling organic matter fractions of the MSWs. The major biological treatments are the following: aerobic degradation (also known as composting) and anaerobic digestion. The main difference between the two methods is the absence of oxygen in the second one. In addition, often, to execute biological treatment, there is the needing for pretreating the MSWs through mechanical treatment. Therefore, mechanical-biological treatment facilities are born to integrate mechanical and biological processes.

- *Aerobic Degradation/Composting*: it consists of a bio-oxygenation and humification process in which it is possible obtaining an important substance: the compost. Compost is used as fertilizer, and it can improve ground structure. Nowadays, compost is a fundamental component of several sustainable techniques utilized in agriculture.
- *Anaerobic Digestion*: the anaerobic degradation is carried out by microorganisms that break down biodegradable material in the absence of oxygen. Anaerobic

digestion is widely used as a source of renewable energy. The process produces biogas essentially. The major application of resulting biogas is as fuel or to provide heat to residences of households.

- *Mechanical-Biological Treatments*: These facilities allow the integration of several processes commonly executed in different MSWs facilities such as MRFs, composting plants, or anaerobic digestion plants. Therefore, within a mechanical-biological facility, different processes are performed in a variety of combinations. Figure 1.15 shows how the process takes place inside the MBTs, from the delivery of MSW to the plant to the final destination (i.e., recycling, waste-to-energy, and landfilling) (Covanti, 2015). To allow proper execution of the activities performed inside the mechanical-biological treatments facility is needed a MSW preparation. It can be supposed to be a preliminary phase of the overall treatment. The MSW amount is prepared through removing not proper objects such as mattresses, carpets, or other bulky wastes, which could cause problems with processing equipment down-stream

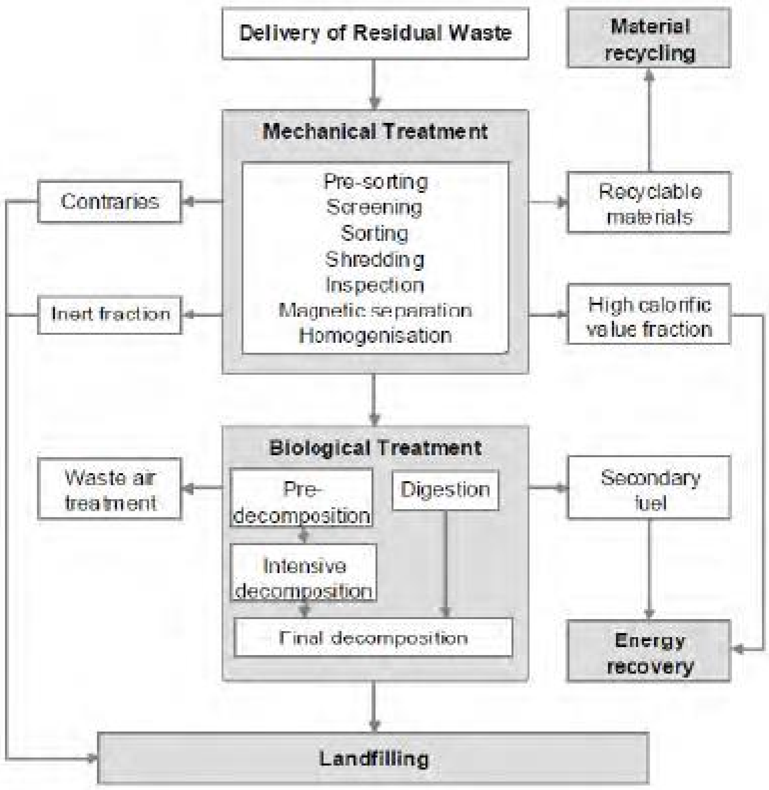

Figure 1.15: Mechanical Biological treatments (Covanti, 2015).

MSW thermal treatments include processes carried out through high-temperature processing of the waste feedstock. They are typically divided into two categories:

incineration and advanced thermal treatment. The primary purposes of thermal treatment are to reduce MSW volume and recover energy. Nowadays, most of the incinerator plants allow recovering energy from waste, but it has not always been the same. In history, the firsts thermal treatment plants did not allow energy recovery from MSW, and the only purpose was the MSW size reduction. Moreover, the old incineration plants were not environmental friendly. In the next paragraphs, MSW incinerator plants with energy recovery will be the object of further detailing.

1.10.1 Incineration process

MSW incineration is recognized to be a fundamental step for sustainable waste management when recycling is not possible. Energy recovery by incineration is the fourth preferred option of the MSW management hierarchy. Through MSW incineration technique can be achieved several goals:

- Reduction of the MSW mass and volume. It is possible to get a mass reduction of up to 70% and a volume minimization of up to 90%;
- Destroy harmful substances that may be released during the combustion process;
- Inerting of MSW by producing steady and non-volatile matter (i.e., the bottom ashes and dust;)
- Energy recovery from MSW, both electrical and thermal, exploiting the gasses' high temperature. The thermal energy generated through the combustion process can be used directly without any other treating. Otherwise, electric energy can be generated diverting fumes flow into a boiler, which allows the heating of water, producing hot steam utilized from gas turbines.

In a typical incinerator plant (Figure 1.16) (Covanti, 2015), the incoming MSW is stored in a bunker. Then, the MSW is gradually introduced in the furnace, where happens the combustion process under controlled conditions. In particular, the combustion should come above 800°C, to avoid organic residues, and under 1000°C to prevent bottom ash melting. Typically, the MSW incinerated are heterogeneous, including also recyclable materials (i.e., paper, plastic, glass, metals) not intercepted by the MSW source-separated collection that are able to increase or decrease the calorific value of MSW. Unfortunately, not all the wastes are suitable for combustion; indeed, if the MSW is characterized by a large part of organic matter, the calorific value will be low. Moreover, the resulting ash from combustion is extracted and cooled in a quenching bath, while the fumes generated, both gas and particulate can go to a boiler, generating water steam necessary for electrical energy production. Then, there are the most important components in an incinerator plant, the air pollution control devices, even known as APCDs (Vergnano, 2018). They are fundamental in terms of pollutant abatement and also in economic terms because they account for almost 70% of the entire cost of the plant. Notably, most of the incineration by-products are pollutants such as the dust, the sulfur oxides, the dioxins, and the nitrogen, and before discharging the gas into the atmosphere, it has to be cleaned to avoid environmental burdens. Therefore, it is crucial that where waste is burnt, gas cleaning systems are required to ensure adequate environmental protection from toxic materials. Finally, the cleaned gases are discharged into the atmosphere through a chimney, and the gas outgoing is facilitated by an ID fan (Covanti, 2015).

Figure 1.16: Incineration plant typical configuration (Covanti, 2015).

There are several processes to convert waste into energy (i.e., waste-to-energy processes). One of the most effective processes is to burn MSW and use the generated heating to produce steam and drive it to a steam turbine for electrical energy (in the present work, will be used the expression *"waste-to-energy"* to refer to incineration). Incineration plants are able to carry out this process, including techniques such as movable grate and fluidized bed. The movable grate (Figure 1.17) is the most diffused technology for the MSW combustion (World Bank, 1999), and it is fittable for the mass burning of as-received and inhomogeneous waste. Inside the combustion ovens, there is a cast iron or steel grate. The latter is formed by movable elements that rotating push the MSWs to the exit of the oven. The drosses go under the grate and after they collected by hoppers. Generally speaking, MSW remains in the oven from 30 minutes to 60 minutes to allow the effectiveness of the entire combustion process. With movable grate technology, there is no need for pretreatment (Lu et al., 2017). Whereas the fluidized bed technology (Figure 1.17) is adaptable to a wide variety of waste types, but it is suitable for the burning of pretreated homogeneous wastes (World Bank, 1999). The burning wastes are put on the top of a bed of mineral grains, which is continuously agitated by an upward flowing airstream. Fluidized bed incinerators can burn and ignite the MSW uniformly (Lu et al., 2017). The three most used fluidized beds are the traditional bubbling, rotating, and circulating fluidized bed (Lu et al., 2016). Unfortunately, a fluidized bed incinerator needs a periodic manutention because of the corrosion of the plant parts.

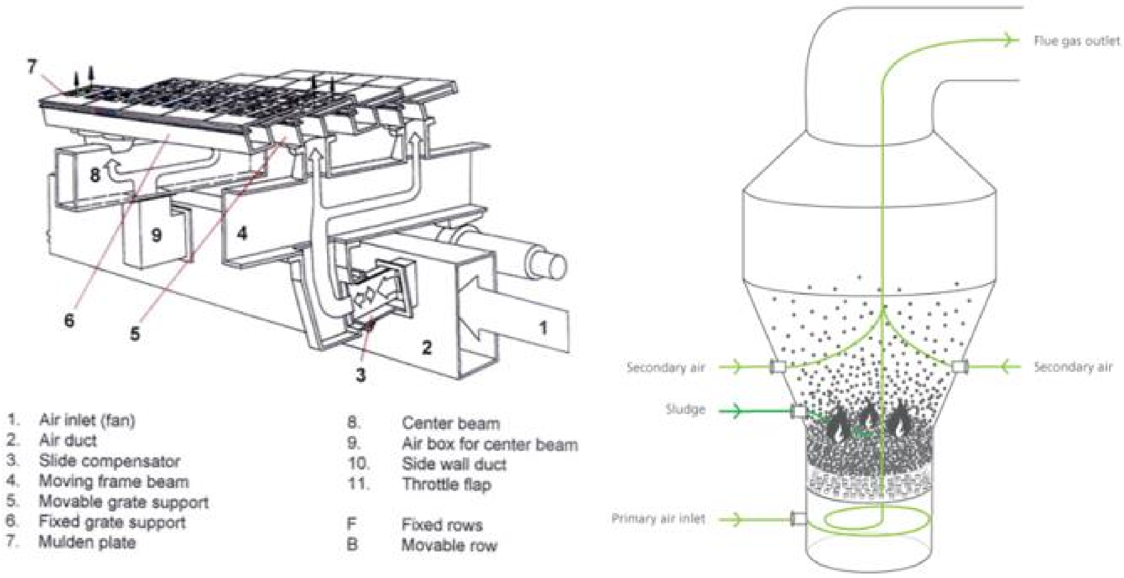

Figure 1.17: Movable grate and fluidized bed (Lu et al., 2017).

Not all the MSW materials are fittable with the incineration process; in particular, it is actual difficult using organic matter as incineration material. An important variable to take into consideration to understand the compatibility of the material with the combustion process is the Low Heating Value (LHW). The heating value (HV) is the quantity of heat generated by the combustion of fuel. It is measured as the unit of energy per unit mass or volume of the substance (e.g., kcal/kg, kJ/kg, J/mol, and Btu/m^3). There exist two significant indicators to express the heat of combustion of fuels, namely the higher and lower heating values (HHV and LHV). The first one is also known as the gross calorific value. The HHV is measured using a bomb calorimeter and defined as the amount of heat released when fuel is combusted, and the products have returned to a temperature of 25°C. The LHV is defined as the net calorific value, and it is calculated by subtracting the heat of vaporization of water vapor from the HHV (Lu et al., 2017). In Table 1.4 is shown the HV for different MSW fractions, more the HV is high, and more the waste fractions are suitable for energy recovery by incineration. The energy recovery is a fundamental pillar of MSW incineration. The potential energy recovery from a fraction of MSW is expressed by LHV. Energy recovery includes heating generation and electrical generation (Lu et al., 2017). The large scale new incinerators plants are involved in generating electricity, whereas plants in some cold regions can prefer to generate heat. The temperature and pressure of the superheater of a heat recovery boiler are important variables to the efficiency of the plant. Theoretically, higher temperature and pressure of the superheater result in higher efficiency of energy recovery. MSW incineration plants usually involve boilers with medium pressure (3.8-5.3 MPa) and medium temperature (e.g., 400 °C) (Mian et al., 2017).

	water content %	volatile components %	fixed carbon %	ash content %	heating value [kJ/kg]
paper	5	73	9	13	14200
waxed milk carton	3,5	91	4,5	1	26300
vegetable matters	78	17	4	1	4100
fat	0	98	2	0	38300
parc waste (branches)	69	25	5	1	6300
foliage	10	67	19	4	18500
grass	75	19	4	2	4800
leather shoes	8	57	14	21	16900

Table 1.4: HVs for different MSW fractions (Covanti, 2015).

Figure 1.18 shows the incinerator mass balance. Supposing to have 1000 kg of MSW as input. It will have a generation of about 20-30% of ashes that have to be treated (Vergnano, 2018). In addition, there will be other by-products such as carbon dioxide, macro-pollutants, micro-pollutants, and powders. The combustion process executes a MSW transformation, and the outcomes are the ashes, the energy recovery, the emissions into the atmosphere, and the release of pollutant materials in the wastewater. The critical aspects of managing an incinerator plant are the emissions and the pollution of wastewater. In the nowadays incinerator, there are several filters able to hold the most of the pollutant particles, releasing emissions under the allowed threshold by law. Unfortunately, there are some pollutant substances with a microscopic size (nanoparticles) that the filters cannot hold, and they are released into the atmosphere. The generation of emissions and pollutant substances depends on several boundary conditions (Vergnano, 2018):

- The composition of the MSW input to the incinerator;
- Combustion condition such as the temperature and the pressure of the furnace;
- Functioning condition of pollution controlling and abating system;

The recent incinerator plants have to adopt all the anti-pollution measures available in the market and the most advanced technologies.

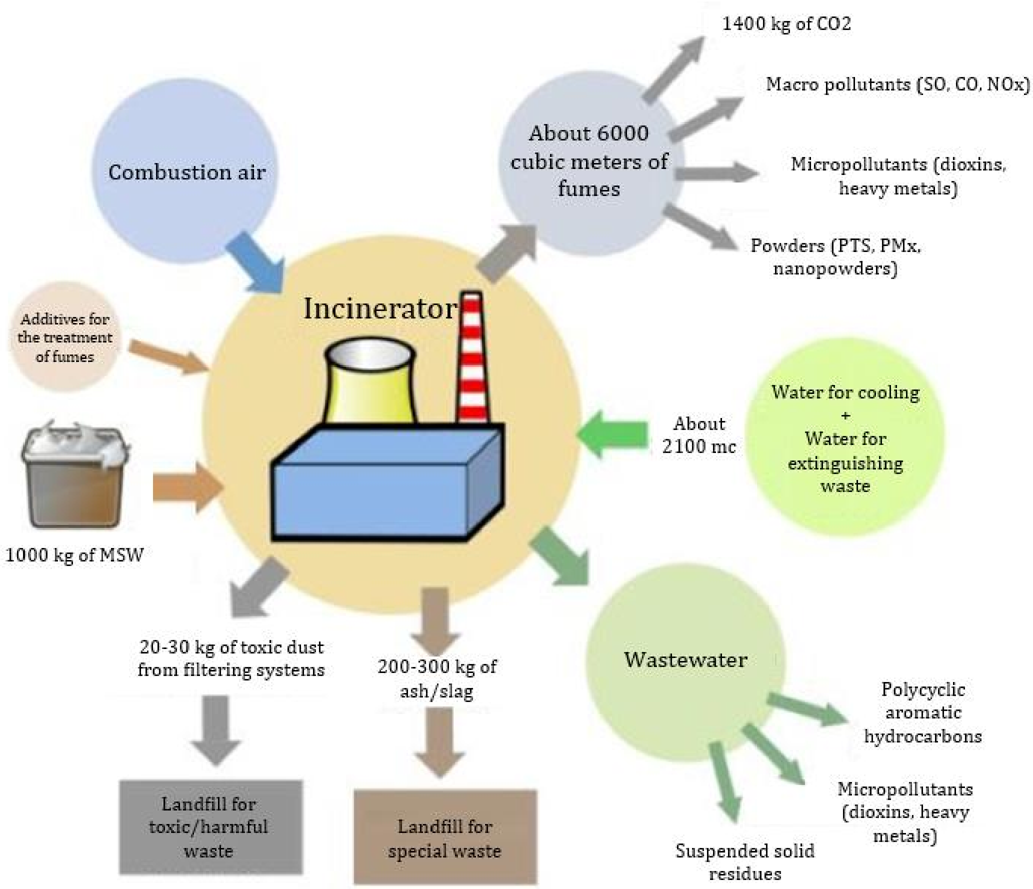

Figure 1.18: MSW incineration plant mass balance (Vergano, 2018).

Incineration has two important by-products that have to be treated, such as bottom ash (BA), and fly ash (FA). They are generated in MSW incineration plants (Quina et al., 2018). Unfortunately, these by-products can contain pollutant heavy metals. Metal concentration in BA and FA depends on metal volatilization. BA is characterized by heavy metals with low volatilization, whereas FA contains more volatile metals, such as Zn, Ni, Cu, As, Hg, Cr, and Cd (Quina et al., 2018). Consequently, BA residues are considered by-products already able to be used, for example, during the substitution of quartz sand in cement production (Li et al., 2018). Nevertheless, FA has to be managed as hazardous waste in a proper landfill. The stabilization of MSW incineration FA is proposed by involving several processes, such as melting, calcination, cement solidification, using chelating reagents, and chemical agent extraction, promoting its reuse (Zacco et al., 2014). Unfortunately, these processes are not often realizable because of high operational costs (Zhu et al., 2018). Further, some MSW incineration FA treatment need pretreatments, which are not suitable for the architecture of the current incineration plants. Figure 1.19 purposes an overall overview of the main identified method in the recent literature to manage FA.

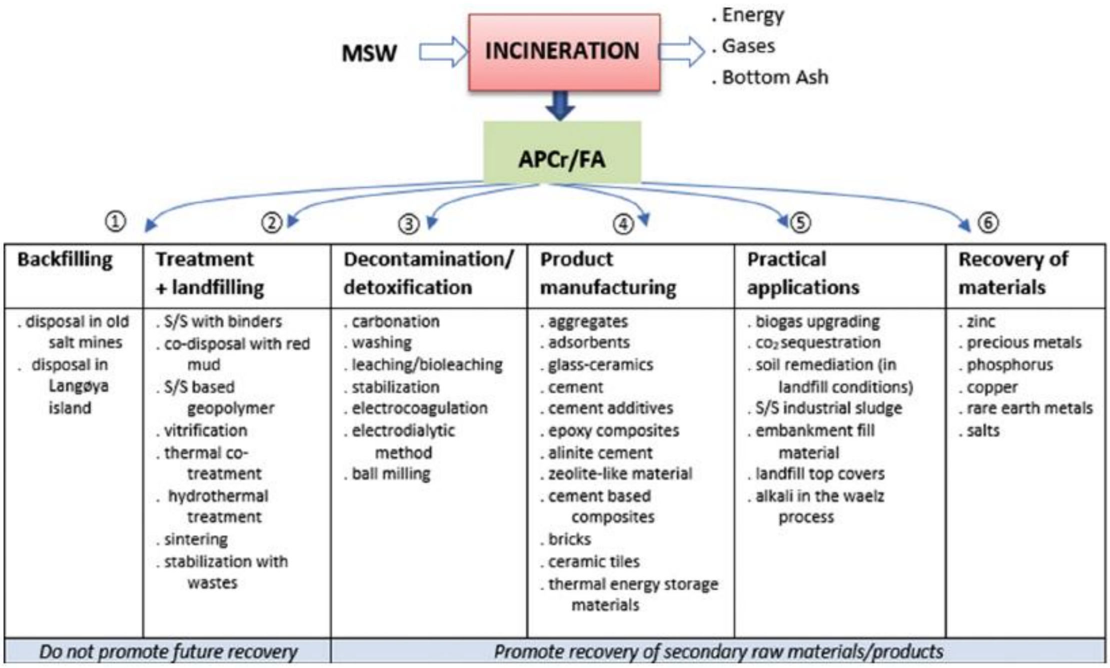

Figure 1.19: The main methods to treat fly ashes (Zhu et al., 2018).

1.10.2 Advanced Thermal Treatments

Advanced Thermal Treatments (ATTs) are those processes that involved pyrolysis and/or gasification to treat MSW. The MSW incineration is excluded from ATT because it is already a mature technology. The ATTs have been used extensively to produce. In Pyrolysis and gasification plants, the process takes place in a high-temperature thermo-chemical cleavage. Unfortunately, they are characterized by great operational costs and a low capacity to receive mixed waste. Figure 1.20 shows a hypothetical ATT generic process flow.

- *Pyrolisis*: The treatment consists of thermal degradation of MSW without oxygen. The process needs a steady external heat source to hold the temperature. Typically the temperatures involved to burn MSWs are quite low, between 300°C to 850°C. The output will be a non-combustible solid residue (i.e., ash) and synthetic gas, also known as syngas (Li et al., 2018). The first can be helpful for industry needs, whereas the second one can be condensed to produce oils, waxes, and tars. The Syngas has a net calorific value (NCV) of between 10 and 20 MJ/Nm^2, and the syngas can be potentially used as a liquid fuel.
- *Gasification*: In contrast to pyrolysis, gasification uses oxygen partially; it means that oxygen is added, but the quantity is not enough to allow the full combustion. The ordinary temperature is close o 650 °C (Li et al., 2018). The main output

product is the syngas, and the typical net calorific value (NCV) of gasification syngas is between 4 to 10 MJ/Nm³. The other output is a non-combustible solid residue.

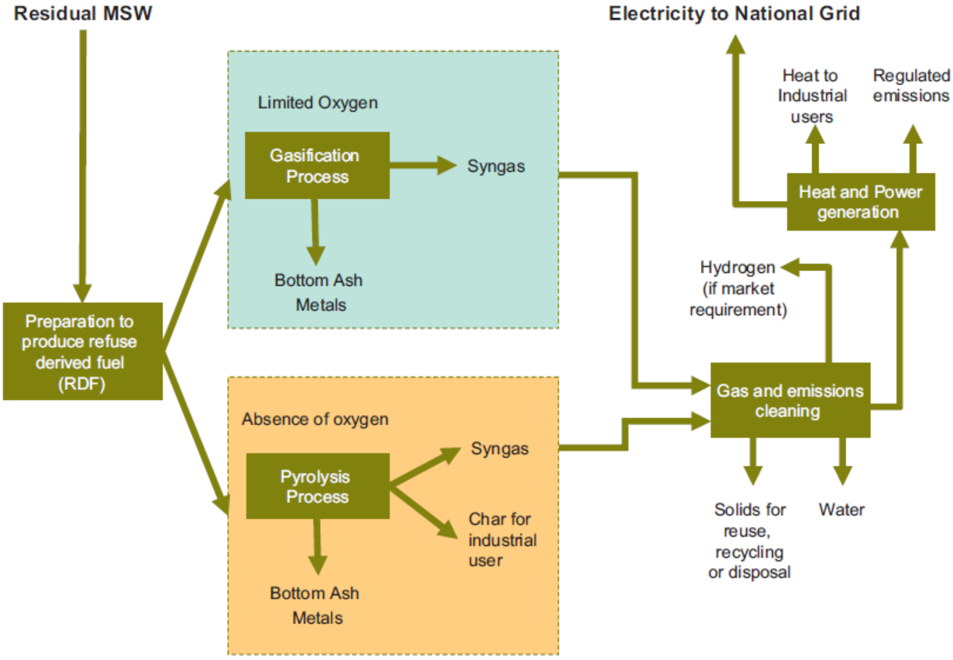

Figure 1.20: Advanced Thermal Treatments process flow (Li et al., 2018).

1.11 Disposal by landfilling

The landfills are places where it is possible to dispose MSW by burial, and it is one of the oldest MSW disposal methods. The landfilling of MSW is still the most common disposal solution in a significant number of countries all around the world, particularly in developing countries. Landfill sites can be utilized in several modes, and for example, they can be used also for temporary storage and transfer, or MSW processing. It can be possible to individuating three main different landfill structures (UNEP, 2010): open dump, non-engineered landfill, and sanitary landfill. Following, there will be discussed the last two. The non-engineered disposal system consists of a simple burying of the waste under the ground without having any control. Generally, non-engineered landfills remain for a longer time and have high environmental and health costs. Environmental degradation phenomena can be many, such as mosquito, rodent and water pollution, and degradation of the land. Non engineered dumpsites are still utilized in developing countries, nevertheless also in developed countries, it is possible to find them as remnants from the twentieth century. The effort of IMSW management should be in the elimination of these uncontrolled dumpsites. Whereas the sanitary landfill is a technological plant designed, realized, and managed to obtain a minimization of adverse effects (Figure 1.21). The land has to be carefully engineered before use. This landfill type avoids the harmful effects of uncontrolled dumping by spreading, compacting, and covering the wasteland. For considering a landfill as a sanitary landfill, four basic requirements have been identified: full or partial hydrological isolation, formal engineering preparation, permanent control, and planned the waste placement and covering. Moreover, there are some basic principles to follow to reduce the number of emissions. The first important concept is the proper quality of the waste; in particular, to prevent pollutant emissions the content of biodegradable waste should be low. Further, the presence of barriers at the top and the bottom of the landfill site is crucial to avoid the pollutant of the environment. Finally, the continuous control and extraction of leachate and biogas have to be done in a sanitary landfill. Landfills are one of the easiest methods to store MSW because of their initial investment is lower than other disposal treatment, and managing a landfill is quite easy. Nevertheless, they can have a negatively substantial environmental impact. Most of the landfilling environmental burdens are generated by landfill gas and leachate. Further, they need much proper space, and often it is not easy to find it. Nowadays, the overall ideally trend is to eliminate landfilling as a disposal method. Finally, the leading MSW management countries are trying to separate biological MSW from landfilling. The European Union Directive gave the goal to reduce the biodegradable municipal waste landfilled to 35% by 2016, but most of the European countries reached the goal before 2016, and many EU countries now have zero biodegradable waste landfilled.

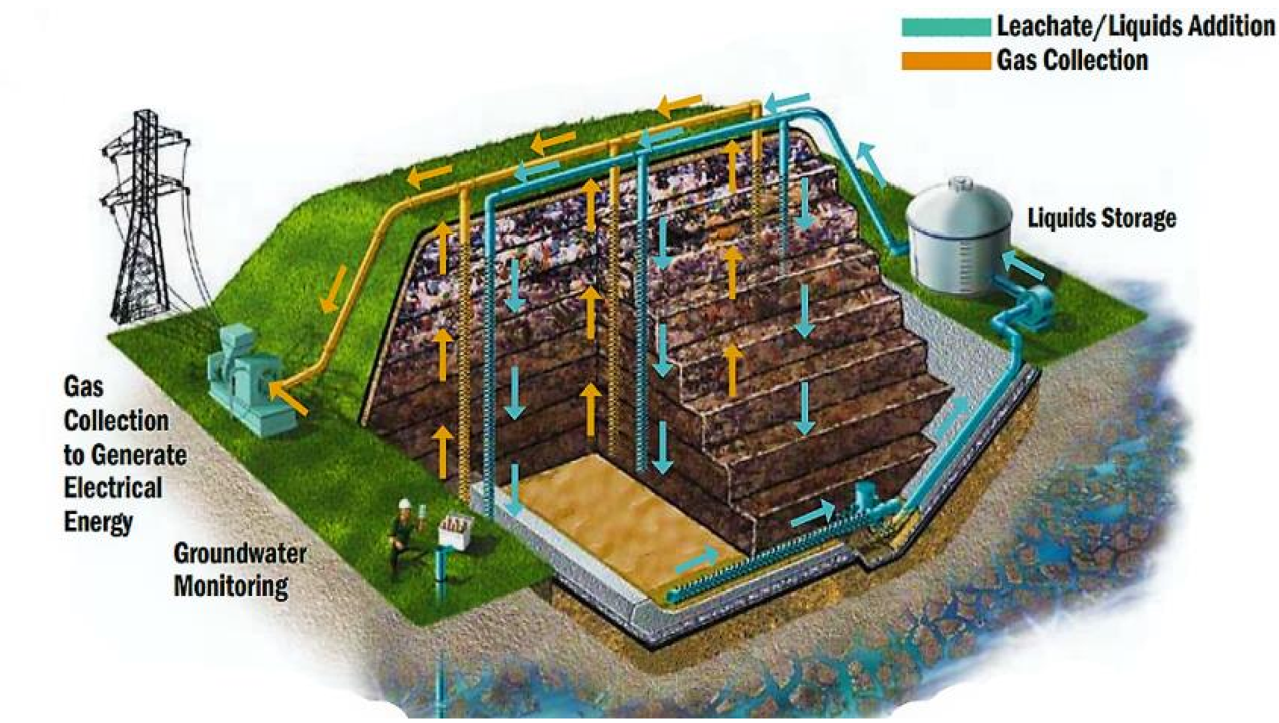

Figure 1.21: Sanitary landfills adopting a LFG facility (Stegmann R., 2013).

When MSW are deposited in a landfill site, they are subjected to an aerobic (with oxygen) decomposition. In one year, anaerobic conditions are established, and methane-producing bacteria begin to decompose the waste and generate methane. Table 1.5 shows the typical composition of landfill gas. The most quantity of gasses is composed of CH_4 and CO_2 because they are the result of the anaerobic degradation process. The composition is related to the type of biodegradable waste. The landfill gas (LFG) is a natural by-product of the decomposition of organic material. As shown in the Table 1.5, the composition of LFG is about 50% carbon dioxide, 50% of methane, and another small part of non-methane organic components (Covanti, 2015). Instead of releasing the biogas into the atmosphere, it can be taken, converted, and used as a renewable energy resource. The landfill gasses formed in a landfill site can be extracted and can be applied in direct combustion systems (boilers, turbines, or fuel cells) to generate heating or electrical power. Another opportunity to exploit the biogas could be to sell it through injection into a natural gas pipeline. Moreover, using landfill gas helps to reduce odors and other hazards associated with landfill gas emissions.

GAS	CONCENTRATION
Methane	45-65 % vol
Carbon dioxide	35-55 % vol
Cabon monoxide	<< 1 % vol
Hydrogen	<< 1 % vol
Hydrogen sulfide	< 50 ppm
R-SH	< 50 ppm
Trichloroethylene	< 50 ppm
Tetrachlomethylene	< 50 ppm
Carbon tetrachloride	< 5 ppm
Vynilchloride	< 20 ppm
Steam	2-4 % vol
Oxygen	<< 1 % vol
Nitrogen	<< 1 % vol
Argon	< 1 % vol
Traces	< 1 % vol

Table 1.5: The composition of landfill gasses (Covanti, 2015).

The word leachate means the wastewater produced by the infiltration of the water (often by rain) through the landfill body. In other words, the water, percolating through the MSW mass, incorporates organic components, metal, and salts. The composition of the leachate is related to the pH, the age and the type of the MSW, and the quantity of oxygen. Whereas, the quantity generated depends on the intensity of the rain, the landfill barrier system, the characteristics of the waste and site. Therefore, the overall quantity of leachate generation is related to the location and season of the year. The average precipitation in a particular region can be helpful to foresee the amount of leachate that should be extracted from the landfill. Consequently, the prevision can be used to dimension the leachate extraction system. As it is told precedently, another influencing factor about leachate composition and quantity is the MSW composition; in particular, the presence of biodegradable matter negatively influences the leachate composition and quantity. The leachate pollutions can be treated in different ways, such as activated sludge plants, aerated lagoons, in a sequential batch reactor, and they can be treated with urban wastewater in some particular cases. Moreover, the leachate can be recirculated in the landfill body to decrease its pollutant level (Stegmann R., 2013).

1.12 Waste treatments and disposal method - a global snapshot

Currently, almost 40% of global waste is still disposed of by landfills. Only 19% is recovered through recycling and composting, and 11% is treated by modern MSW incineration plants. Nevertheless, 33% of global waste is disposed of by open dumping. Fortunately, the awareness of governments about the related environmental and health risks of open dumping is increasing, pursuing sustainable waste treatment methods. Figure 1.22 shows the current treatment and disposal global scenario, offering an overview of the waste management structure all over the world. However, waste practices vary deeply by income level and region (Kaza et al., 2018). In lower-income countries, the open dumping is widely diffused mainly because landfills are not yet available. Around 93% of waste in low-income countries is dumped or burned in open lands, roads, or waterways, whereas only 2% is in high-income countries. About two-thirds of waste is dumped in the Sub-Saharan Africa regions and South Asia. Generally speaking, more a country prospers economically, more the waste will be managed sustainably, and building and utilize landfills is usually the first step toward sustainable waste management. Indeed, only 3% of waste is disposed of by landfills in low-income countries, whereas about 54% of waste is sent to landfills in upper-middle-income countries. However, accordingly, with the explained main principles of the Circular Economy and the waste hierarchy, most developed countries tend to put a higher focus on materials recovery through recycling and composting. In high-income countries, around 29% of waste is recycled and 6% composted (Kaza et al., 2018). The waste-to-energy treatment, especially incineration, is also more common, and in high-income countries, about 22% of waste is incinerated. Incineration practices are largely developed and diffused particularly in within high-capacity and land-constrained countries, such as Japan and the British Virgin Islands. Figure 1.22 shows an overview of the waste management system adopted all around the world by income level and region (Kaza et al., 2018).

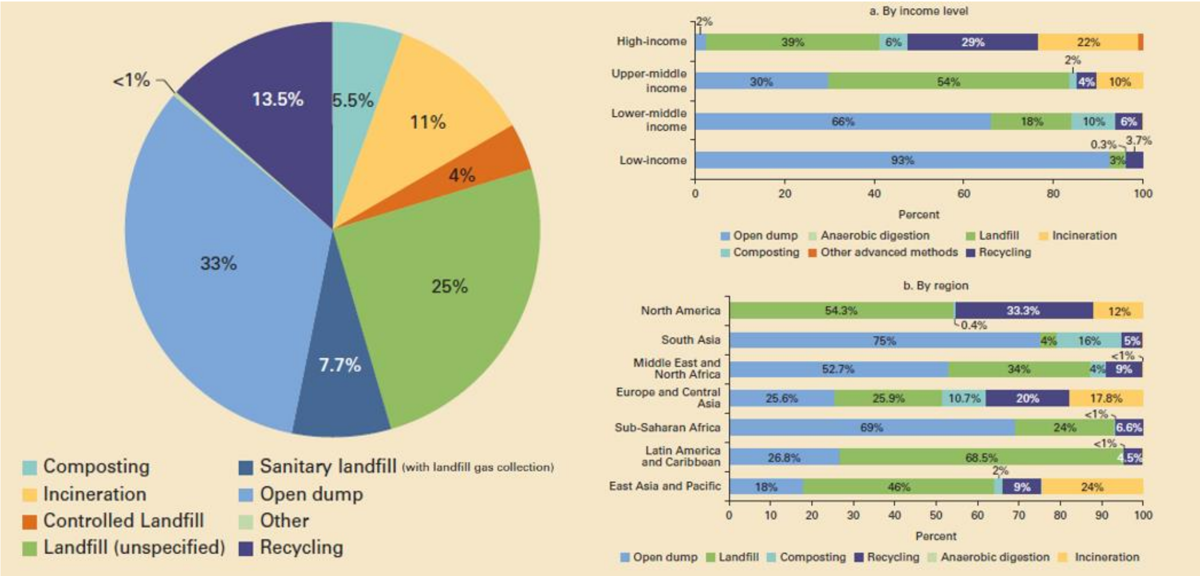

Figure 1.22: Waste management structure in the world and by income level and region (Kaza et al., 2018).

2 Policies & Regulations

2.1 Fundamentals

Regulations and policies are essential tools to support the government to face the problem of increasing waste, helping to implement a proper MSW management system. In China, the *“Law of the People's Republic of China on the prevention of Environmental Pollution Caused by Solid Waste”* (i.e., the *“Law on Solid Waste”*) is the most critical law in MSW and pollution control issue (Chen et al., 2010). The Law on Solid Waste was enacted in 1996, and it defined fundamentals to implement a MSW management, such as responsibilities for waste supervision and administration, pollution control measures, and associated legal responsibilities (Chen et al., 2010). All the ministerial and administrative regulations on MSW management have to comply with the primary Law on Solid Waste. In December 2004, the Law on Solid Waste was edited for the first time, and one of the most important amendments was the Extended Producer Responsibility as a fundamental pillar of MSW management (Chen et al., 2010). The previous version specified only the producer’s responsibility in the manufacturing process, whereas the amendment includes the entire life cycle by extending the producer’s responsibility to the consumption and disposal of goods. Under the Law on Solid Waste, significant administrative and ministerial regulations have been released by different governmental agencies. In particular, two major ministries are involved in MSW management. The first one is the Ministry of Construction (MOC), which supervises and administers each phase of the MSW management, such as the cleaning, collection, storage, transportation, and final disposal of MSW. Whereas, the second one is the Ministry of Environmental Protection (MOEP), which supervises and administers the collection, treatment, and disposal of hazardous MSW, MSW trade, and secondary pollution generated by the construction and operation of MSW treatment and disposal facilities. The following policy and regulations should be considered as significant regulations: *“The Notice on Charging Urban Waste Treatment Fee and Promoting Industrialization of the Waste Treatment Industry”* (2002) and *“The Opinion on Accelerating Marketization in the Municipal Public Utility Industry”* (2002). These two regulations represented attempts to promote the privatization of waste treatment and related services and to transfer responsibilities from the government to the private sector to improve the effectiveness and efficiencies of the MSW management system. Whereas, *“The Management Measure on Franchise of the Municipal Public Utility Industry issued”* (2004) defined the municipal government as the authority to designate franchised companies and the guidelines for franchised services. In 2007, the MOC issued the “*National 11th Five-Year*” Plan on Urban Environment and Sanitation and requested all the provincial governments to elaborate their MSW management plans (MOC, 2006). The national plan fixed a target rate of safe MSW disposal of 60% to be reached by 2010. In addition, the plan encouraged waste minimization and source separation, promoted commercialization and franchised operation, and aimed to establish relevant regulatory and planning systems (Chen et al., 2010). Moreover, the central Chinese government instituted policies for promoting waste reduction. For instance, plastic bags that were provided free in supermarkets after June 1, 2008, have to be purchased by consumers (The State Council, 2007). Further laws and regulations, there are several technical standards concerning MSW management. The *"Pollution Control Standard for Municipal Solid Waste incineration (GB 18485-2001)"* settled air emission standards and declared that bottom ash could be treated as general MSW, whereas fly ash must be treated as hazardous waste. In 2016, the previous standard on MSW emission standards was replaced by the new *"GB 18485-2014"*, settling more stricter standards (Chen et al., 2010). In addition, *"The Pollution Control Standard for MSW Landfills (GB 16889-1997),"* was amended by the Ministry of Environmental Protection in July 2008. The new standard (*"GB 16889-2008"*) fixed stricter regulations on landfill construction, establishing more rigorous pollution controls. For instance, the new landfills had to be equipped with landfill gas collection and treatment systems (if the total capacity was higher than 2.5 million tons and landfilling depth higher than 20 m), be surrounded by a green belt at least 10 m in width as a buffer zone. Moreover, it was settled stricter leachate discharge standards in landfill sites. Since the late 1990s, it has been done substantial progress in legislation and policies regarding MSW management, but practices vary across the country. Recently released regulations and policies have devoted effort to waste reduction and recycling (i.e., Circular Economy practices), and favoring the WTE treatments as a positive method. The above environmental laws are severely enforced by the Chinese government. The authorized environmental supervision institutions can conduct on-site inspections in companies emitting pollution, but cannot enforce administrative penalties. Only the environment authorities and ecology at the county level or above can enforce administrative penalties. They can take different enforcement measures, such as on-site inspections, seizing and impounding the polluting facilities and equipment, and so on. Public security departments at the county level or above have the possibility to detain an individual who violates environmental laws. Moreover, after the *"Environmental Protection Law"* implemented on 1 January 2015, Chinese environmental NGOs are gradually becoming active. They participate in several activities, mostly including taking part in public environmental interests, promoting the formulation of environmental policies and legislation. Moreover, they carry out proper education on environmental matters. Environmental NGOs are playing a more critical role in environmental public interest discussion than ever. There were 252 environmental public interest cases brought by Chinese environmental NGOs from 2013 to 2017, and they became a remarkable participant in public supervision. There were 59 environmental public interest cases in 2016 (raised by 14 environmental protection NGOs) and 30 in 2017. Environmental NGOs play even an essential role in promoting environmental legislation.

2.2 Circular economy policies

In China, the discussion about sustainable economics started around 1973, when the first National Environmental Protection Conference (NEPC) took place to discuss new environmental policies and guidelines (Mcdowall et al., 2019). In 1979, the comprehensive law on environmental protection was issued, and it was called the *"Environmental Protection Law of the People's Republic of China."* Under the law, basic policies were introduced to address conflicts between environmental sustainability and industrial growth. The environmental protection issue was considered as a more serious problem in 1983, after the second NEPC, where it made environmental protection an important national policy. The main concepts of the circular economy were accepted in 2002 by the central government. In particular, the fundamentals basis for the implementation of three R's approach and the waste hierarchy approach were settled by the *"Law of the People's Republic of China on the Promotion of Clean Production"* enacted in 2002. In addition, the Chinese Government issued the "*Law of the People's Republic of China on Environmental Impact Assessment"* to ameliorate the control of environmental pollution and the economical damaging. In 2004, the amendment of "*the Law of the People's Republic of China on the Prevention and Control of Environmental Pollution by Solid Wastes"* (the Law in Solid Waste) identified the Three R's approach as the main principle in sustainable MSW management (Mcdowall et al., 2019). The amendment also introduced the new Extending Producer Responsibility in MSW management. Moreover, the amendment defined clearly the responsibility and policies of the Chinese government in fostering the developing of the resource recycling industry. Several regulations and laws have been released since 2004 to improve the saving and efficiency of energy and resource, such as the*"Mid and Long-Term Plan on Energy Saving,"* and the *"Law of the People's Republic of China on Renewable Energy."* In the 2005 autumn, the Chinese Academy of Social Sciences wrote a crucial report on the Chinese Strategies for Promoting Circular Economy. In 4 paragraphs, the document explained measures and control mechanisms to implement a Circular Economy in China (Mcdowall et al., 2019). The definition of the Circular Economy in the report was the following "*an economic development system that is focused on environmental protection, avoidance of emissions, and on sustainable development in order to prevent waste and emissions at source, and reduce the formation of such at each production unit*". The report envisaged using resources efficiently, eliminating dysfunctions of the market that were endangering the environment. Finally, "*the Law on Promoting the Development of Circular Economy"* was passed in 2008 and became into action in 2009, clarifying the requirements of Reduce, Reuse, and Recycle (Mcdowall et al., 2019). The previous law served as the main national-level framework for pursuing the Circular Economy (National People's Congress, 2008). Indeed, the law was defined as a vital strategy in sustainable national economic and social development. Under the new, any new industrial policies created by the Government have to meet the criteria for promoting a Circular Economy. The industries have to implement a management model that reduces the needing for resource and waste generation, and at the same time, improving resource recovery and recycling. Through the *"Law for the Promotion of the Circular Economy,"* the Chinese Government address promotion, development, research, and international cooperation of science (Mcdowall et al., 2019). Moreover, the Government has been supported the education, publicity, and popularization of Circular Economy scientific knowledge, aiming to give citizens awareness about resource saving and environmental protection practices. Since the releasement of the Law on Circular Economy, several action plans have followed (e.g., State Council, 2013; NDRC, 2016), offering details for specific sectors. The *"12th Five-Year Plan"* regarded the period from 2011 to 2015, where the primary focus was toward recycling of heavy industrial resources. The most significant goals to meet were to increase the re-using of industrial waste to 72% by 2015 while raising resource output efficiency by 15% (Mcdowall et al., 2019). Moreover, the *"Circular Economy Development Action Plan"* was implemented in 2013, and it was further embedded in the concept of a Circular Economy into Chinese legislation. The scheme plan was built on three levels (corporate (micro), inter-firm (meso), and societal level (macro)), being within a company, industrial park, and city, or region. The plan has settled several targets for 2015 and 2020 to address both industrial and social sectors. The main goals to meet by 2015 were having and utilizing a proper advanced resource recycling technology, re-using 72% of industrial solid waste, a modern system for recovering at least 70% of waste products and ameliorating the recovery of relevant resources. Other significant goals included raising energy productivity by 18.5%, increasing water productivity by 43%, and helping the recycling industry to reach US $276 billion of output, and re-using 70% of certain minerals that are heavy pollutants (Mcdowall et al., 2019). Whereas the goals for 2020 fixed in the plan consists of having an innovative industrial-technological system that can efficiently re-use and recycle material, and the implementation of new industry related to the manufacturing of innovative technical equipment that promotes competitive advantages. The advanced technological system should be able to solve the waste management problems of rural and urban areas by 2020 (Mcdowall et al., 2019). The *"13th Five-Year plan"* was issued in 2016, addressing the growth plan for the period 2016-2020. All the plan is built above three core ideas, such as improving waste management solutions, ameliorating the environmental quality, and accelerating the environmental damage repairing. The plan emphasizes solving the problems of water and soil pollution. Other significant goals are to promote circular production to implement a circular economy at all society levels, establishing a circular development system with new resource strategies, decreasing waste and consumption, increasing resource efficiency, and promoting and supporting green initiatives. In addition, the plan also expects resource productivity to increase by 15% from the 2015 level, whereas the solid waste utilization rate should reach 73%. Moreover, around 75% of national industrial parks and 50 provincial industrial parks should be practicing complete circular strategies by 2020. The recycling industry output value is foreseen to reach US $450 billion (Mcdowall et al., 2019). Summarizing, the current Chinese approach to Circular Economy themes, China is steadily introducing new legislation to ameliorate the efficacy of its sustainability and circular economy initiatives. Every five years, the Chinese Government releases a five-year plan with numerous sustainability and economic growth targets for the country. The current plan is the *"13th Five-Year plan"*, and other important legislation that have been significant for Circular Economy development are the *"Law for the Promotion of the Circular Economy,"* "*Circular Economy Development Strategies and Action Plan,"* and the "*12th Five-Year plan"* (Mcdowall et al., 2019). The most important policies implemented to estabilish an effective MSW management and to encourage the Chinese Circular economy are summarized in table 2.1.

Release time	Name	Publishing unit
1979	The Environmental Protection Law Of The People's Republic Of China.	State Council of China
1982	Regulations On The Administration Of Urban Appearance And Environmental Sanitation (For Trial Implementation)	Ministry of urban-rural development and environmental protection
1993	Measures For The Management Of Municipal Solid Waste	Ministry of construction
1995	Law Of The People's Republic Of China On The Prevention And Control Of Environmental Pollution By Solid Waste	Standing Committee of the National People's Congress
1997	The Pollution Control Standard For MSW Landfills (GB 16889-1997)	National Development and Reform Commission, Ministry of environmental protection, Ministry of construction
2000	Technical Policy For Urban Domestic Waste Treatment And Pollution Control (GB 18485-2001)	Ministry of science and technology, Ministry of construction, Ministry of environmental protection
2002	Notice On Charging Urban Waste Treatment Fee And Promoting Industrialization Of The Waste	Ministry of construction, Ministry of environmental protection, National Development and Reform Commission
2002	Law Of The People's Republic Of China On Environmental Impact Assessment	National Development and Reform Commission, Ministry of environmental protection, Ministry of construction
2002	Opinion On Accelerating Marketization In The Municipal Public Utility Industry	Ministry of construction

2002	Clean Production Promotion Law	National People's Congress
2004	Management Measure On Franchise Of The Municipal Public Utility Industry	Ministry of construction
2004	Law Of The People's Republic Of China On The Prevention And Control Of Environmental Pollution By Solid Waste [Amendament]	Standing Committee of the National People's Congress
2005	The Mid and Long-Term Plan on Energy Saving	Ministry of science and technology, Ministry of construction, Ministry of environmental protection
2005	Law of the People's Republic of China on Renewable Energy	Ministry of science and technology, Ministry of construction, Ministry of environmental protection
2007	Management Measures For The Administration Of Municipal Solid Waste	Ministry of construction
2007	The 11th Five Year Plan For The Construction Of Harmless Treatment Facilities For Urban Domestic Waste	National Development and Reform Commission, Ministry of environmental protection, Ministry of construction
2008	The Pollution Control Standard For MSW Landfills (GB 16889-1997) Amendment	National Development and Reform Commission, Ministry of environmental protection, Ministry of construction
2009	Circular Economy Promotion Law Of The People's Republic Of China	Standing Committee of the National People's Congress
2011	Opinions On Further Strengthening The Treatment Of Municipal Solid Waste	The State Council
2011	Guidance On Comprehensive Utilization Of Resources During The 12th Five Year Plan	National Development and Reform Commission
2014	12th Five Year Plan For Energy Conservation And Emission Reduction	The State Council

2014	Notice On Carrying Out The Work Of Domestic Waste Classification Demonstration City (District)	National Development and Reform Commission, Ministry of environmental protection
2015	2015 Circular Economy Promotion Plan	National Development and Reform Commission
2016	Technical Policy For Urban Domestic Waste Treatment And Pollution Control (GB 18485-2014)	National Development and Reform Commission, Ministry of environmental protection, Ministry of construction
2016	13th Five Years Plan National Construction Plan For Harmless Treatment Facilities Of Urban Domestic Waste	National Development and Reform Commission, Ministry of environmental protection
2017	Notice On Accelerating The Classification Of Domestic Waste In Some Key Cities	Ministry of urban-rural development

Table 2.1: MSW management policies and regulations overview.

2.2.1 Recycling system policies

With the rapid urbanization and industrialization, China is facing several challenges, such as resource depletion, environmental pollution, and climate change (Chan and Yao, 2008; Gu et al., 2011; Shen et al., 2005; Zhou et al., 2004). Moreover, the increasing amount of MSW is a serious issue because of the lack of new landfill sites availability (Zhang et al., 2010). It is crucial to promote the utilization of recyclable wastes because it can solve the issue of limited landfill space, resource depletion, and environmental pollution (Xiao et al., 2018). The Chinese Central Government considers recycling recyclable wastes as the most effective measure to promote the Circular Economy (SCC, 2013). Several regulations and documents have been issued, especially in recent years, to promote MSW recycling and MSW source separation (MOC, 2006; MOC et al., 2016; MOC et al., 2007). Moreover, it was settled an ambitious target to reach a MSW recycling rate of 35% and a MSW source separation coverage rate of 90% for 46 pilot cities by 2020 (NDRC and MOHURD, 2017). The developed country began MSW management earlier than China, reaching significant goals in implementing a MSW recycling system, such as Germany and Japan (Fujii et al., 2012; Geng et al., 2010). The Central Governments issued different regulations and policies at the national level to promote recycling. Table 2.2 shows a brief overview of the most important regulations and policies to promote the formal recycling system that have been issued in recent years (Xiao et al., 2018). The most important laws in promoting Recyclable Waste Recycling are the *"Law of the People's Republic of China on the Promotion of Clean Production"* (2002) and the *"Law for the Promotion of the Circular Economy"*

(2009). Further, many other regional or local policies and regulations have been released to manage specific recycling activities. In addition, the "*Provisional Management Mesures on Packaging Resources"* was issued in 1999. It reported the descriptions of recovery channels, the principle for sorting, and the requirements for the treatment of different types of packaging materials, such as paper, plastic, metal, wood, and glass (Xiao et al., 2018). Unfortunately, there are no specific national regulations to manage low valuable recyclables, such as waste textiles, waste rubbers, and waste glasses. "*The Measures for the Administration of Recyclable Resources Recycling"* released in 2007 is the only national general regulation (NDRC et al., 2007). Many local governments released their local regulations to ameliorate the supervision and managing of the home recycling markets. The local regulations are able to be more effective because they can better promote the enforcement of national regulations at a local level. For example, on the 2nd May 2013, Shanghai issued *"the City of Shanghai Guidance Catalogue of Recyclable Resources Recycling"* (SMCC, 2013). Again, the city of Kunming, in southwest China, released "*the City of Kunming Administration Regulations on Recycling of Recycled Resources"* on January 1st, 2014 (SCKMPC,2014).

Release Time	Name	Publishing Unit	A brief introduction
1991	Notice On Strengthening Administration Of Recyclable Resource Recycling	State council of China	Specifying categories of recyclable resources; Preventing illegal business in recyclable metals; Requiring enterprises positively collect the low value recyclable resources.
2002	Clean Production Promotion Law	National People's Congress	Setting rules to require enterprises employ clean energy, advanced technology, and integrated management to decrease pollution and increase the utilization efficiency of resources all the way.
2007	Measures For The Administration Of Recyclable Resource Recycling	National development and reform commission, Ministry of public security, State Administration for Industry & commerce, Ministry of Environmental Protection	Providing crucial provisions to collect, trade and administrate recyclable resources; Identifying government departments' responsibilities.

2009	Law On Promoting The Development Of Circular Economy	National People's Congress	Clarifying requirements of Reduce, Reuse, and Recycle (3R); Emphasizing the process of recycling should meet national required standards.
2010	Guideline Of Further Advance In Development Of Recyclable Resources Recycling Industry	Ministry of Commerce	Making policies to develop the industry of recyclable resources recycling and establish administration schemes. Suggesting governments to foster leading enterprises and set up a modern information system
2011	Opinion On Construction Of Complete And Advanced Waste Recycling System	State council of China	Forming basic principles and main targets to construct a modern and advanced RWR system; Listing significant tasks, including improving sorting level, strengthening technological support, and completing the recycling system.
2013	Development Strategy Of Circular Economy And Recent Action Plan	State council of China	Concluding achievements and obstacles of circular economy in 2005–2010; Making action plans to promote the development of the circular economy at the social level
2014	Implementation Plan Of Important Resources Recycling Engineering	National development and reform commission, Ministry of Science and Technology, Ministry of Industry and Information Technology, Ministry of Finance,	production in the aspects of urban mineral (recyclable resources), remanufacturing, industrial waste recovery, and construction of waste goods recycling system.
2015	Construction Of Recyclable Resources Recycling System In	Ministry of Construction, National Development and Reform Commission, Ministry of Land and	Introducing current characteristics and problems of recyclable

	Mid-Long Term Planning (2015-2020)	Resources, Ministry of Housing and Urban-Rural Development, and All-China Federation of Supply and Marketing Cooperatives	resources recycling; Planning major tasks and programs to construct a complete and advanced RWR system in 2020.
2016	Opinion On Promoting Transformation And Upgrading In The Recyclable Resources Industry	Ministry of Construction, National Development and Reform Commission, Ministry of Industry and Information Technology, Ministry of Environmental Protection, Ministry of Housing and Urban-Rural Development, and All-China Federation of Supply and Marketing Cooperatives	Encouraging innovating RWR system, such as Internet+; Transforming extensive management modes to intensive management modes.

Table 2.2: Formal recycling system policies and regulations overview.

2.3 National Support and Policies of Waste-to-Energy in China

The term *"Renewable Energy"* refers to the energy that is replaceable or inexhaustible, such as water, wind, solar, and bio-organic materials. MSW mainly consists of paper, food, wood, cotton, leather waste, and plastic (Zhang et al., 2015). The transformation of MSW in energy has great potential also to reduce greenhouse gasses. In 2005, in China, it was approved the "*Renewable Energy Law,"* recognizing MSW as a renewable resource. Since then, MSW incineration plants have been considered as a renewable energy source, receiving benefits such as renewable tax credits, loans, and subsidies. The increasing MSW growth has generated several environmental damages because of the pressure on landfills (Cheng, 2017). The latter has been one of the most reasons that led to the adoption of the hierarchy of waste management to reach sustainable MSW management. The hierarchical system prioritizes reducing and reusing waste as the first option; after that, there is recycling/composting, WTE incineration, and finally, landfilling. WTE is a better choice than landfilling because it can reduce MSW volume by 90% and the MSW mass by 70%, recovering energy from the combustion process (Cheng et al., 2010). The MSW reduction has been the most significant reason for the construction of WTE plants across China (Dong, 2011). However, if WTE is compered to landfilling, the first has higher capital investment and higher operating expenses. For example, the Shanghai Pudong Waste Incineration Power Plant required an investment of $110 million, and the Shanghai Jiangqiao Waste Incineration Power Plant required an investment of $144 million (Zhang et al. 2015). The associated high costs with WTE facilities are the reason because most of the WTE plants are located in economically developed Eastern Regions, and the majority of the sites are principally funded by local governments (Zhang et al., 2015). Nevertheless, the Chinese WTE incineration sector has experienced huge growth in the past three decades. The rapid expansion experimented by the Chinese WTE industry is because of the several policies implemented by the Central government. Nowadays, the WTE industry has the special support status of renewable energy to better allow the developing of the potential of Chinese WTE. The potential of WTE technologies comes from the high growth of the Chinese population and the shortage of landfill sites (Cheng, 2017). Therefore, the extreme difficulties to find available landfill sites have driven local municipality authorities to look for other MSW management solutions. MSW incineration has positive aspects of reducing the MSW volume by 90% (Cheng, 2010). Further, MSW incinerators can burn over 1000 tons/day of MSW. WTE has become one of the best solutions for MSW treatment, replacing landfills gradually. The Chinese WTE incineration has already experienced great growth thanks to reliable and efficient policies, but the full WTE potential can be reached only through improving the existing policies and incentives. During the *"12th Five-Year plan"* (2011-2015), the Central government planned investment of 12.3 billion dollars into WTE development (Zhang et al., 2015), expecting to introduce MSW incineration solutions in more Chinese regions. Moreover, regarding funding policy for large environmental protection projects, the government proposed that private investors provided 30% of the initial capital, and the remaining is provided by local, provincial, or Central governments (Cheng, 2017). Central governments often can provide revenue policies (subsidies), making the WTE sector an attractive field for private investors. The government has tried to make the WTE sector a safer investment, reducing as much risk as possible for investors, by establishing favorable tax incentives, higher energy purchase price, and tax exemption on 5% of earned revenue (Zhang et al. 2015). Many policies have been released to address the MSW problem, utilizing MSW as a source of renewable energy. Table 2.3 shows a list of the most important policies that have encouraged Chinese WTE development, along with a short introduction (Cheng, 2017).

Release Time	Name	Brief introduction
1997	Temporary Regulations on the Basic Construction Projects of New Energy	Specific provisions on construction projects of new energy
1998	Notification of approval of new energy construction projects	Includes waste to energy in new energy, and provides a lot of preferential policies to support waste to energy
1999	Notification from the Planning Commission and the Ministry of Science and technology on further	Gives clear norms on the aspects of project setting up, financial support, grid combination preferential and pricing method, to accelerate the development of renewable energy;

	supporting the development of renewable energy	The priority of basic construction loans; 2% financial discount for renewable energy project loans; Acquisition of all power; The power grid would share the part that is higher than the average price;
2000	Municipal solid waste disposal and pollution control technology policy	Specified garbage disposal technology and pollution treatment technology in detail.
2002	Opinions on promoting the industrialization of urban sewage and garbage treatment	1) Guarantee the operating expenses and investment payback, achieve market-oriented operation of waste collection, transportation, treatment, and recycling; 2) For investment in urban sewage and garbage disposal facilities, the project capital should not be less than 20 of the total investment, and operating period not more than 30 years3) Government gives necessary policy support to municipal solid waste treatment enterprises and projects constructions, including a discounted power supply for waste treatment; allocation of project construction land for new urban garbage treatment facilities; 4) operating cost compensation policy Governments should compensate for the cost of the construction of waste collection and transportation facilities and garbage disposal fees;
2002	Notification on the implementation of the municipal solid waste disposal charging system to promote the industrialization of garbage disposal	For waste treatment facilities that are in the construction for supplement waste treatment capacity, with the approval of the city government, household garbage treatment fee is allowed to support the construction. But the construction must complete and operation within three years.
2004	The decision of the State Council on the reform of the investment system	Allowing accesses for social capital to enter the infrastructure, public utilities and other industries and fields within laws and regulations permit.
2004	No. 126th Document from the Ministry of Construction	Defined franchise period no more than 30 years

	of the people's Republic of China	
2005	Industrial structure adjustment Guidance Catalogue	Government supports the Reduction, Recycling, Harmless Treatment and Comprehensive Utilization of Urban Garbage and Other Solid Waste Project
2005	People's Republic of China Law of Renewable Energy +	1) the nation encourages and supports power generation by renewable energy and its combination with the power grid; 2) enterprises on the power grid should sign contracts with those renewable energy power generation companies have legally obtained an administrative license or submitted for the record, provide easy accesses to grid combination, and acquire their full generated power; 3) power price should be decided according to local conditions based on economic and reasonable principle, and be published;
2006	Trial management of renewable energy power prices and cost-sharing	1) the subsidy price standard is 0.1 dollars per kilowatt-hour (equivalent to 0.65 yuan). Power generation projects enjoy the subsidy for 15 years from the date of production at the price of 0.25yuan/kwh; 2) the mixed fuel power generation projects consume conventional energy of more than 20% shall be deemed as conventional energy power generation projects and don't enjoy the subsidies;
2006	Regulations on the Administration of renewable energy power generation	For large and medium-sized renewable energy projects, direct accesses to the power grid for hydropower, wind power and biomass power shall be invested by the power grid enterprises
2010	Notification on printing and distributing "the technical guidelines for the domestic refuse treatment."	Incineration facilities relate to less land use, rapid stabilizing, effective waste reduction, easy odor control, and useful waste incineration heat
2011	Notification on Further Strengthening the work of	By 2015, the city garbage harmless treatment rate reaches higher than 80%. Each province builds more than one model city for garbage classification. 50% of the city achieves kitchen garbage classified collection. Municipal solid waste resource utilization ratio reaches 30%, and important cities plan to reach 50%. Establish improved

	municipal solid waste disposal	urban household garbage disposal supervision system. Promotion for waste product recycling, waste incineration for power generation, biological treatment and other solid waste resource utilization.
2012	Notification of the National garbage disposal facilities construction plan for the 12th Five-Year Plan	By 2015, the country's urban domestic waste incineration treatment facilities capacity reaches more than 35% of the total capacity of harmless treatment, of which the eastern region reaches more than 48%

Table 2.3: WTE development policies and regulations overview..

The success of WTE growth can be found in the adopted approach by the Central Governments. When the WTE investments were high capital and high-risk investment, they attracted few private investors. The Central government, to face the problem, has implemented mechanisms to share the high-risk associated with the WTE sector, along with supportive policies, tax incentives, and market tools. The most crucial market device utilized by China was the financial structure of funding WTE projects. The usual types of financial structures are Build-Operate-Transfer (BOT), Transfer-Operate-Transfer (TOT), and Public-Private Partnership (PPP) (Cheng, 2017). However, the most common financial structures used in China has been the BOT structure (Xin-gang et al., 2016). The BOT structure can ensure a financial burden sharing between public and private stakeholders, decreasing the risks for the private entities (Xin-gang et al. 2016). Introducing private companies in the WTE industry, it can decrease the construction time and reduce the cost, besides to improve efficiency. Moreover, BOT contracts help China to attract foreign capital. Through BOT contracts, the Chinese government is able to share the risks of a large WTE Project. Figure 2.1 shows an example of a BOT structure (Cheng, 2017). The government allows an enterprise to own the construction and operation phases. The enterprise is responsible for the investment (30% of the initial capital), financing, design, construction, and operation of the MSW incineration plant. After an operation period, usually, from 20 to 30 years (Y. Li et al., 2015), the owning of the plant is transferred to the government. In the meantime, the government pays waste disposal fees to the enterprise, and ensure that all the electricity generated can be sold to the national grid. Not only the investors can get a return on the investment by the operation period, but investors can also earn an additional revenue (Y. Li et al., 2015). These are the main reason behind the great WTE industry growth in recent years. The key WTE development success factor lies in the utilization of private capital and favorable market conditions to establish an environment of rapid growth.

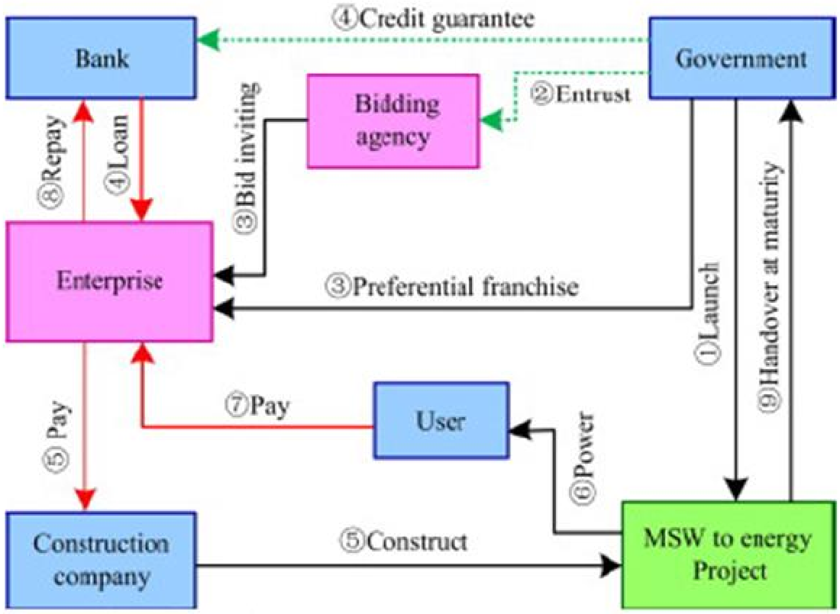

Figure 2.1: BOT structure (Zheng et al., 2014).

Moreover, every five years, the Chinese government released an economic development plan, which pointed out several economic targets to meet in the coming five years. In the *"12th Five Year Plan"* the government promoted resource utilization of MSW and the importance of MSW treatment to environmental protection and public health (Y. Li et al., 2015). Through the 12th plan, China planned a great number of WTE projects, highlighting the support of the Central government to WTE industry development (Cheng, 2017). The *"13th Five Year plan"* started in 2016 and it will end in 2020, It is expected that more MSW incinerator projects will be developed. Generally, an incineration plant is always a long-term "*put-or-pay*" agreement between the incineration plant owner (the investor) and the local government, ensuring the right feeding MSW level. If the MSW level is lower than a threshold, the governments have to give compensation to the incineration plant owner (Cheng, 2017). Unfortunately, this type of agreement encourages MSW generation ignoring MSW recycling.

2.3.1 Price and tax policies

Potential investors seek financial returns and economic benefits to undertake a WTE plant project. The Central government to meet investors and environmental requirements enacted two price policies (Zhang et al., 2015). The first one was the *"Trial Measures for Price Administration and Costs Sharing of Electricity Generated from Renewable Energy,"* released in 2006, in which the government tried to regulate the WTE production price.

The policy looked at the current price for MSW incineration power generation and added \$0.043 per kWh of electricity to be subsidized by the Chinese Government (Zheng et al., 2014). The adoption of the trial price assisted the WTE industry in developing on a grand scale. The second one price policy adopted was the *"Improvement of Feed-in Tariff Policy of MSW Incineration Power Generation"* adopted by the Central Government in 2012. This new policy looked to support the already existing subsidies by increasing the feed-in disposal fee for the MSW incineration plant to \$0.11 per kWh of electricity (higher than what coal-fired was receiving at \$0.005 per kWh of electricity) (Zheng et al., 2014). Moreover, the Central government to encourage the WTE generation and limit the use of traditional energy adopted a new method to calculate the purchasing price. The quantity of green WTE generate (Q_1) is calculated, then, Q_1 is compared to the quantity of traditional energy Q_2. If Q_1 is less than 50% of Q_2 the price of the WTE energy is the same as the traditional energy. If Q_1 is more than 50% of Q_2 the WTE energy is considered as renewable energy, and it is purchased at the price of renewable energy (renewable energy price is higher than traditional energy price) (Song et al., 2013). Undertaking these new policies, the Central government has encouraged the growth of renewable energy and increased the profit for MSW incineration projects (Cheng, 2017). Moreover, compared to the other developed countries, Chinese WTE development has been characterized as late-starting, large scale, and rapid growth (Zeng et al., 2013). To encourage the WTE industry development, the government has implemented preferential tax policies. Preferential taxes have been another primary tool utilized by the Central Government to address the WTE industry development in China. *"The Notice of Policies regarding the Value-Added Tax on Products Made through Comprehensive Utilization of Resources and Other Products,"* was enacted to refund value-added tax (VAT) to WTE incineration projects on January 1, 2001 (Zheng et al., 2014). The *VAT* is a general base consumption tax assessed on the value added to a good or service (EY, 2016). Since then, the policy has been concluded, and in 2009, a program was enacted, called *"Notice on Promulgation of the Catalogue for Enterprise Income Tax Preference for Environmental Protection and Energy and Water Saving Programs."* The program exonerated the WTE industry from paying income tax for three years, as of January 1, 2010 (Zheng et al. 2014). Through the enacted of these preferential tax policies, WTE industry profits were enormously favorited. These tax policies highlight the commitment of the Central government toward the supporting of the WTE industry development.

2.4 "Operation National Sword" plan

2.4.1 Chinese Waste Ban

"Do you know the difference between what we recycle and what we throw away? It's not the materials or composition of the product. It's money. If a product can be cleaned and sorted and sold, it's deemed recyclable," (Business Casual, 2019). Nevertheless, what happens to recyclable materials when no one wants to buy them has been a mystery for a long time. Many cities use single-stream recycling in the source-separated classification, where every type of recyclables -paper, plastic, metal, and glass- go in a single bin. Then, those recyclable wastes are collected and transferred into Material Recovery Facilities (MRFs), where they are sorted, processed, and bundled to be sold to buyers all over the world. Unsurprisingly, the biggest solid wastes buyer was China, principally because of China's main goal to become the largest manufacturing economy in the world. Sometimes, wastes are transferred through several countries, making it difficult to track where all the wastes end up. For example, Mexico sends much of its wastes to the U.S., and the U.S. exports waste mainly to China, often through Hong Kong and Shanghai. Therefore, it can happen that goods are shipped thousands of miles across the Pacific from China, used, thrown away, collected, and then making the whole trip back. It is interesting to think that much of these solid wastes will end up just a few miles away from where they were first manufactured in China. After that, wastes will be recycled, and the cycle starts again. In other words, China was providing an easy solution for the world's recycling. Indeed, the Western countries never felt the need to implement significant recycling plant capacity. For example, in the case of plastic, China was accepting around 70% of the world's waste plastic. In 2016, just the US exported 700'000 tons of plastic to China. It is essential to understand how much the economies of China and the USA are connected to understand the current solid waste situation in the world. Indeed, China is the importer of the first goods to the U.S, and the USA is the first Chinese customer. The USA represents just 4% of the world's population, but they generate 25% of the world's waste. On average, each American generates 4.4 pounds of waste per day (around 20 kg). *"It is cool and all when wastes magically disappear from your curb, but not so much when the city wants to build the dump in your backyard. Anywhere but not there"* (Not in my backyard syndrome). Buying stuff and transform them into trashes is easy, and current society is good at it, but it is not easy to make the reverse process. High labor and transportation costs make the *"reverse process"* to transform waste into recycled materials expensive, because of the necessity to drive across the country the wastes, to sort, clean, and reprocess them. Therefore, every week, hundreds of container ships left the Shanghai or Hong Kong harbors across the Pacific, towards the American West Coast, delivering every type of goods. Unfortunately, the U.S. had not so much to deliver back to China, and the ships would have to make the two-week return trip empty, doubling their one-way price. It is easy to imagine how inefficient it would be if every airplane had to return from its trip

without passengers. In other words, the US needed something to sent back to China, and luckily, there is something they are good at generating: wastes. Therefore, rather than sending the ships empty, it made sense to send back to China recyclable materials. The suppling of empty containers was so efficiently that it was cheaper sending waste from the USA to China than to nearby Arizona. Shipping a 20-foot container from Shanghai to Los Angeles could cost 1000 dollars, whereas the other way could cost 500 dollars. The trade deficit worked in favor of the US. Moreover, the nature of the Chinese economy made the deal lucrative. For example, China did not have its softwood lumber industry; indeed, they rely on importing recycled paper to fill their demand. *"The newspaper an American read and recycle today could be sold to China, printed, and read by a Chinese person six weeks later"* (Business Casual, 2019). Nevertheless, in 2016, a Chinese director released a documentary called *"Plastic in China,"* depicting the life of a young mother living in a plastic recycling plant. The documentary revealed the brutal reality of the Chinese recycling industry. Beijing quickly banned the film, but the damage was already be done. In 2017, the Communist Party to repair its public image announced that China would have stopped the import of waste starting from 4 categories, including waste paper and plastics. China called it *"Operation National Sword"* plan, and it was essentially an attempt to develop a better internal recycling industry, improving Chinese environmental and public perception. The shock was instantaneous; the entire plastic and paper recycling industry was stopped. Before the ban, MRFs could sell plastic a $300/ton, but without the Chinese demand, the plastic price decreased to $40/ton in just a few months. Unfortunately, the Western cities did not have the proper recycling capacity without the help of China. Consequently, many countries had no place to put their trash anymore. In Western states, such as Washington, Oregon, and California, recycling had to be sent to landfills, and Ireland, which sent 95% of its plastic in China, experimented waste crisis. In other words, the Western world had to find new solutions to deal with the Operation National Sword. Moreover, in 2018, it was announced the Blue Sky policy, adding stricter restrictions and a plan to ban all-recyclable imports by 2020. The answer is to improve the developed country recycling industry. Luckily for the West, better recycling technologies have been developed, for example, new recycling plants were built in Sweden and the Netherlands, using high-tech, more efficient optical sorters than human labor. The more green answer to the Chinese ban was to reduce the consumption and the generation of wastes, and countries like Canada have already implemented policies to ban single-use plastic, such as bags and straws. In addition, Thai and Vietnamese grocery stores have tested wrapping materials in banana leaves for a more sustainable approach. The Chinese waste ban can be considered as a bad thing, but even as a good phenomenon. Until now, rich, developed countries have had no incentive to not generate a giant amount of waste. The *"Operation National Sword"* plan could be an effective long-term wake-up call (Business Casual, 2019; PolyMatter, 2019).

2.4.2 The emergence of a global circular economy for solid waste

For many recyclable materials exist a global circular economy, such as paper, textile, and plastics: raw materials are extracted from resource-rich countries; products are made in low manufacturing costs country like China; final products are exported for consumption, principally in developed countries; and wastes are shipped away mainly in developing countries for recycling, reuse, and disposal (Geng et al., 2013; Stahel, 2016). In recent decades, China has been one of the main destinations for recycling, reuse, and disposal of solid waste from several developed countries. For example, in 2016, around 15 million tons of waste plastics, 16 million tons of waste papers, and 2 million of discarded materials were exported globally, and about 40% of those materials were exported to China (UN Contrade, 2018). Unexpectedly, in July 2017, the Chinese government issued a plan to ban the import of some determined wastes. This policy has had profound implications, not only for China but also for the entire equilibrium in the global circular economy (Qu et al., 2019). The main reason for the existence of the global circular economy is due mainly to economic reasons. Firstly, the separation of valuable recyclable materials from mixed wastes is labor-intensive; therefore, it makes economic sense to recycle in developing countries where the labor costs are lower than in other countries (Qu et al., 2019). Second, stricter regulations and enforcement in developed countries make more competitive carrying out recycling activities in developing countries. Third, developing countries with low recycling costs are likely also manufacturing hubs (e.g., China), making the reusing recycled materials more convenient and economical. Moreover, an essential factor is related to shipping companies, contributing to the generation of a global circular economy (Qu et al., 2019). Therefore, shipping companies, to avoid empty return cargos, offer competitive terms for return trips after shipping finished goods to developed countries. Consequently, also the low shipping costs help to transfer the solid waste from developed to developing countries. Finally, in developing countries, some recycled materials are used as a substitute for raw materials for low-value, low-quality goods. In developing countries, with enormous populations, those goods have enormous market potential, making them perfect waste recycler candidates (Qu et al., 2019). Generally speaking, in parts, the global circular economy contributes to global environmental sustainability by recycling recyclable waste reducing the demand for raw materials. Besides the economic and environmental benefits of the global circular economy, it also causes significant negative sustainability impacts. Solid waste recycling activities in developing countries are generally carrying out with minimum health and environmental protection, primarily because of poor regulations and enforcement (Qu et al., 2019). The developing countries' workers involved in recycling activities are often exposed to toxic materials without protective measures and residues generated from the recycling of recyclable materials are often dumped without appropriate treatment (Ewijk et al., 2018; Gu et al., 2017; Tojo et al., 2012; Williams, 2011). High-level international policies have been developed to prevent the transboundary movements of hazardous wastes and disposal, such as the Basel Convention (2018). Unfortunately, the enforcement of these policies has been a challenge for developed and developing countries.

2.4.3 China's ban on foreign wastes

The Chinese availability to accept foreign wastes was increasing along with its economic growth. Chinese rapid development has generated enormous raw materials demand in almost every industry, making China the primary destination of the world's solid waste exports (Qu et al., 2019). In 2016, China imported over 43 million tons of solid waste, largely from developed countries (Figure 2.2) (Qu et al., 2019). Recently, China has been gradually shifting its concentration to improve the quality of the development. The needing for sustainable development and better environmental condition motivated the Chinese government to ban the import of foreign wastes. Moreover, another important reason behind the Chinese ban is that the demand for raw materials in certain industries has slowed down after decades of rapid growth (Qu et al., 2019). Finally, recently, domestic solid wastes have become enough to replace the needing for wastes from other countries. By the end of 2017, the Chinese government released detailed regulations to ban the import of 24 types of waste in 4 categories, including unsorted scrap papers, waste plastics, discarded textile materials, and vanadium slags (they are considered as high environmental risks) (Ministry of Environmental Protection, 2017). In addition, it has been scheduled to further bans of other solid waste types by the end of 2018 and 2019 (Ministry of Ecology and Environment, 2018).

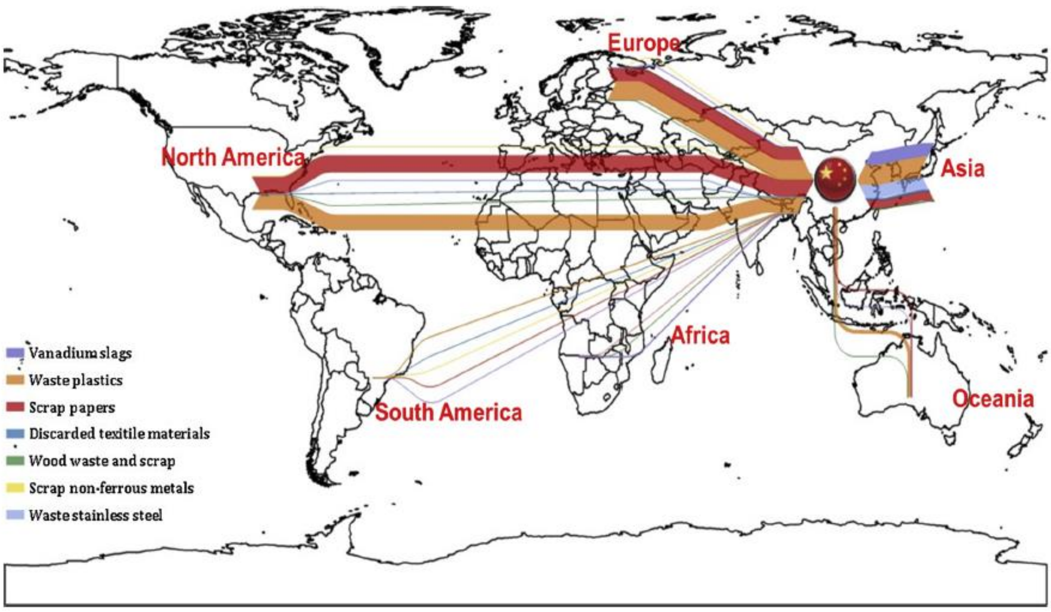

Figure 2.2: Major sources of solid waste imports to China in 2016 after adjustments for re-exports and re-imports (Qu et al., 2019).

2.4.4 Implications on the global circular economy for solid waste

The Chinese ban on foreign wastes is a significant change to the global circular economy system for solid waste and a signal to the global community to rethink this system. It is possible to consider that the Chinese ban policy has an integral part of China's campaign toward sustainable development (Qu et al., 2019). In a short period, also in China, the ban will generate a shortage of recyclable materials, increasing the price of relevant products through the supply chain. The companies relying their manufacturing process on foreign waste as their main materials will need to change toward raw materials, which are generally more expensive or domestic waste (Qu et al., 2019). Unfortunately, small companies without diversified sources of materials will face difficult challenges because of the increase in material costs. In the long run, the absence of foreign waste can stimulate Chinese MSW recycling activities. Indeed, the Chinese domestic recycling industry is predicted to grow with high potential, and domestic solid waste can be used more efficiently (Qu et al., 2019). In addition, it is not excluded that China will become a future waste exporter, as what happened to Japan in the 1980s. Generally speaking, the Chinese ban is an attempt of China to move itself up in the global value chain from being specialized in low-end, labor- and resource-intensive manufacturing to high-end, high-value industries. China's foreign ban has interrupted the existing global supply chain, leaving most of the developed countries without a destination where exporting waste. Because of decades of dependence on developing countries (especially China) on solid waste recycling and disposal (Xu et al., 2010), most of the developed countries have not built the proper capacity to recycle, reuse, and dispose of solid waste, relying principally on developing countries. For developed countries, landfilling can be cheaper than to recycle the banned wastes, leaving recyclable materials dumped without recovery. Chinese ban on foreign wastes has posed a significant challenge for developed countries in the short run, but on the other hand, it has created an opportunity for their domestic recycling industries in the long run. Stricter environmental policies are able to improve the resource productivity and competitiveness of industries (Ambec et al., 2013). In China's ban scenario, two potential policy enhancements can be beneficial for the global circular economy. First, the waste ban could be executed in a more gradual and more predictable manner, providing more time to other countries to adjust their waste management systems. Second, it could be helpful to adopt standards and evaluations for national waste management recycling capacity, but these data are still lacking, leaving the opportunities for countries to transfer environmental burdens using trade. International corporations (e.g., the Basel Convention) could regulate international solid waste movements that are considered environmental risky (Qu et al., 2019). Moreover, also the Extended Producer Responsibility can be modified to expand the responsibility across countries. The other countries that still accept waste banned by China will probably see a large flow in their recycling industries, and most of them are developing countries located nearby China, such as Thailand, Malaysia, Indonesia, and India (Figure 2.3) (Qu et al., 2019). The increasing demand for materials due to their growing manufacturing industries can help to attract solid waste from developed countries, making these countries the natural substitutes to host banned solid waste by China. Therefore, developing countries without stringent environmental regulations will become the new *"pollution heaven"* of solid waste for developed countries and emerging superpower economies such as China (Kellenberg, 2010). It should be enhanced the awareness about the implications of handling foreign wastes in these countries, ad proper policy should be developed to prevent unintended consequences. Otherwise, social and environmental problems related to foreigner wastes would be only relocated from Chine to other developing countries, which are hungry for economic growth with no considerations of environmental sustainability and social justice (Qu et al., 2019).

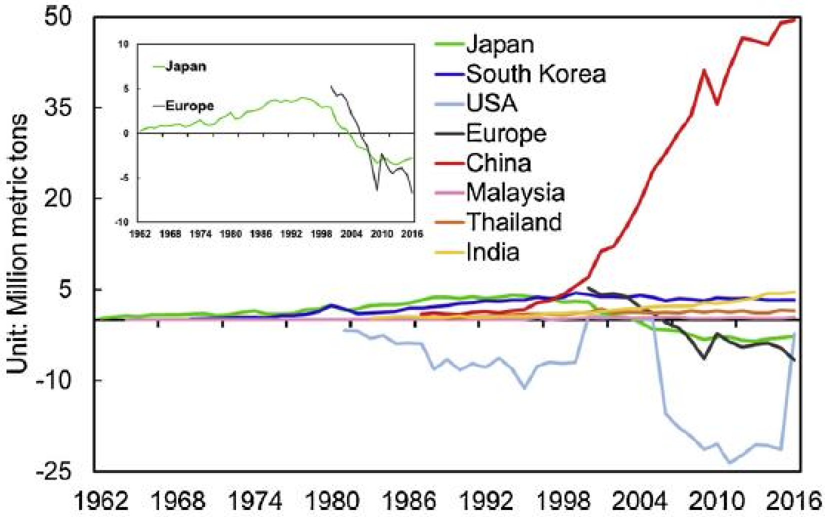

Figure 2.3: Scrap paper net imports by countries (Qu et al., 2019).

3 Municipal Solid Waste Management in China

3.1 China characterization

Nowadays, the USA is the only fittable country that fulfills the requirement to be considered a superpower (Herring, 2008). On the other hand, China is the first country defined as an emerging superpower (Figure 3.1). Indeed, Beijing's power is now beyond the classification of a Great Power (Martin, 2006; Cordesman, 2019). China has been defined as an emerging superpower because of its massive growth in population, economy, and military. A potential superpower is a country that has the economic and political potential to become soon a superpower. The EU and the BRIC economies comprising Brazil, Russia, and India are commonly considered as potential superpowers (Ho Chun, 2013). Together, the potential superpowers, the United States, and China account for 68% of global nominal GDP, more than one-third of the total land area, and more than 50% of the entire world's population (Meredith, 2007).

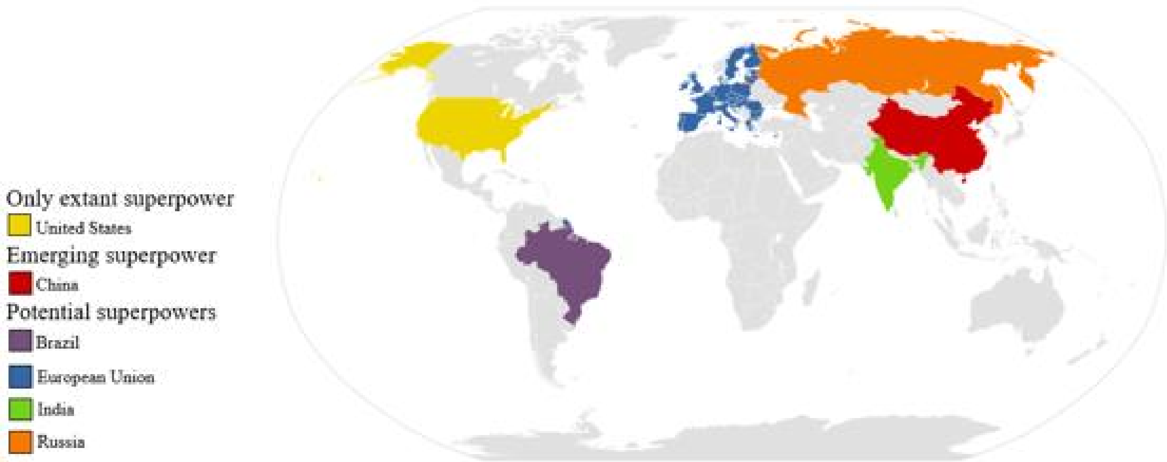

Figure 3.1: China as the first emerging superpower (Herring, 2008).

The People's Republic of China is part of the East-Asia Pacific region, and it is the most populated country all over the world, with a population of around 1.417 billion in 2019 (UN ESA, 2019). China's surface is approximatively 9'572'900 km^2, and it is the fourth largest country in the world by extension**.** China is governed by the Communist Party of China, and the highest level of the party is the Central Government (here, laws are written, and the fate of the nation decided) (Figure 3.2). Beijing is the ultimate authority, and it appoints everyone from secretaries to governors, but it would be a mistake to consider China as one, singular power.

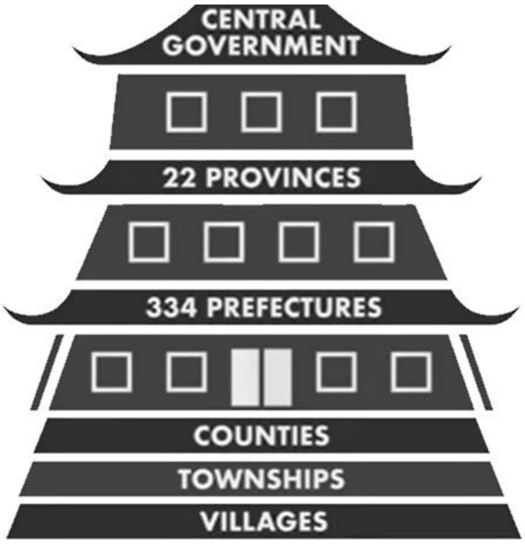

Figure 3.2: Chinese administrative divisions (PolyMatter, 2019).

Below the Central Government, the state exercises jurisdiction over 22 provinces, five autonomous regions (Guangxi, Inner Mongolia, Tibet, Xinjiang, Ningxia), four direct-controlled municipalities (Beijing, Tianjin, Shanghai, and Chongqing), and the special administrative regions of Hong Kong and Macau. These 31 provincial-level divisions, except for the special regions, are known as "Mainland China." The scope of the present thesis is mainland China, but often it will be used the name "China" to refer to Mainland China. Under those 31 provincial-level divisions, over 300 prefectures, followed by the less important counties, townships, and villages. China is also a member of numerous organizations, such as the Shanghai Cooperation Organization (SCO), WTO, APEC, BRICS, the BCIM, and the G20. Dividing China into different geographical regions can be useful for better understand the following analysis. The main Chinese regions are the Eastern regions, the Central regions, the Western region, and the Northeast regions. The eastern regions are Beijing, Tianjin, Hebei, Shanghai, Jiangsu, Zhejiang, Fujian, Shandong, Guangdong, and Hainan provinces. The central regions are Shanxi, Anhui, Jiangxi, Henan, Hubei, and Hunan provinces. The western region includes Inner Mongolia, Guangxi, Chongqing, Sichuan, Guizhou, Yunnan, Shaanxi, Gansu, Qinghai, Ningxia, and Xinjiang provinces. Finally, Northeast China includes Liaoning, Jilin, and Heilongjiang provinces. Figure 3.3 represents the distributions of the four regions.

Figure 3.3: The distribution of the four Chinese regions (Chen, 2019).

In 2018 China's GDP was 90 trillion Yuan (13.407 trillion dollars) (Kaza et al., 2018). Since the introduction of the economic reforms in 1978, China's economic growth has become the most rapidly in the world (Kaza et al., 2018). Since the late ninety years, the GDP annual % growth is consistently above 6% (Figure 3.4).

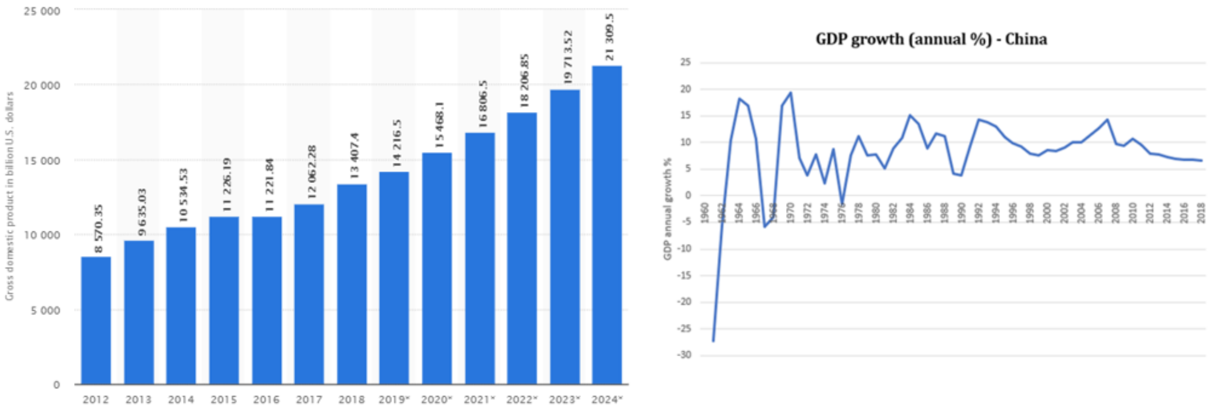

Figure 3.4: Chinese GDP in billion U.S and the GDP percentage annual growth (Buchholz, 2019).

Nowadays, China is the second country in the world by nominal GDP; the first position is still occupied by the USA (Kaza et al., 2018). Nevertheless, China is the first by Purchasing Power Parity GDP, with an adjusted GDP of $25 trillion (Kaza et al., 2018) (Figure 3.5). The Chinese economy is projected by the International Monetary Fund (IMF) to grow by 6.3% in 2019; the U.S. is foreseen to grow its $20 trillion GDP by 2.3% (Figure 3.5) (Buchholz, 2019). China and the U.S. will remain at the top of the ranking until 2024. By 2030, it is expected that India will overtake the U.S. as the second-largest economy on the planet (Buchholz, 2019). In 2030, it is also supposed that China will be the greatest economy in the world, also in terms of nominal GDP (record still held by the USA) (Buchholz, 2019). Moreover, China is also the first-largest exporter and second-largest importer of goods all over the world (Kazi et al., 2018). Compared to the developed countries, China can be considered as an upper-middle-income country. Nevertheless, thanks to the reform in 1978, people below the poverty line of one dollar per day threshold is decreased from 64% in 1978 to about 10% in 2009.

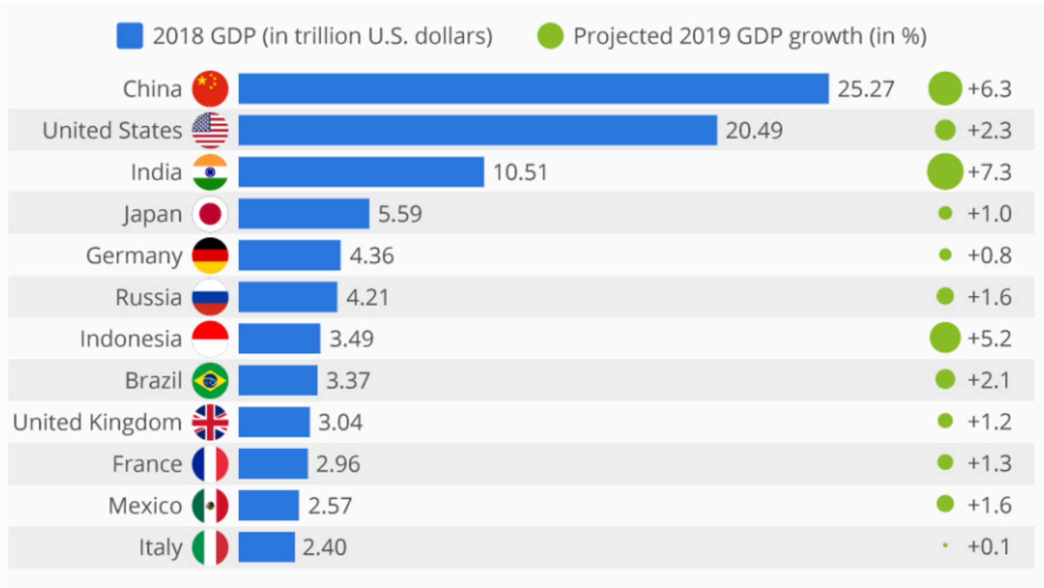

Figure 3.5: Countries with the biggest GDPs in the world and their growth outlooks (Buchholz, 2019).

Since 1978 enormous China's population has been a problem for the country because of the rapid consumption of natural resources. In 1979, the Government released the "One child policy" to contain the fast population growth rate, and it was left in 2013. The 2015 national census the China population was about 1'367'820'000 people; 17,5% were younger than 14 years, 67% were between 15 and 59 years, and 15,5% were more than 60 years (National Bureau of Statistics of China, 2016). Density population, in the same census, was about 139,6 ab./km^2. The percent of the country's population living in urban areas increased from 20% in 1980 to over 57% in 2016 (Kaza et al., 2018). It is foreseen that China's urban population will touch one billion by 2030, potentially equivalent to one-eighth of the world population (Kaza et al., 2018). Figure 3.6 shows the urban and rural population of China until 2017 (National Bureau of Statistics of China, 2019). In 2017, around 813 million people lived in urban and 577 million in rural regions of China. China has 160 cities with a population of higher than one million, including the seven megacities of Chongqing, Shanghai, Guangzhou, Beijing, Shenzhen, Tianjin, and Wuhan (Mian et al., 107). By 2025, it is foreseen that the country will be home to 221 cities with over a million inhabitants (Kaza et al., 2018).

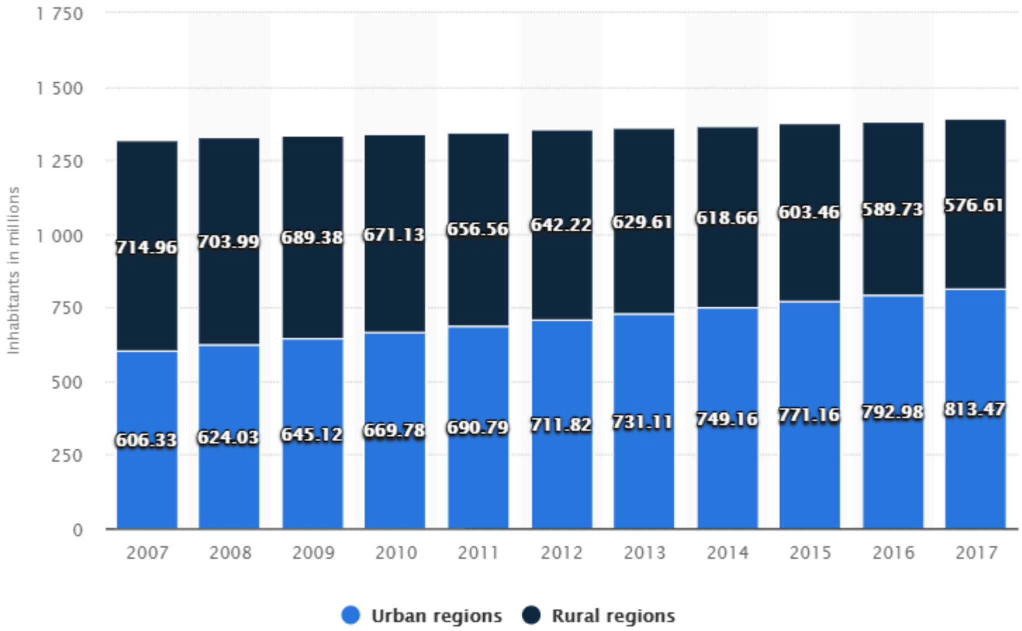

Figure 3.6: The urban and rural population of China until 2017 (NBSC, 2016).

The population is distributed in an irregular pattern; indeed, most of China's population is concentrated largely in the Eastern provinces, whereas the Western regions' population density is very low (Figure 3.7). The black line represented in Figure 3.7 is called the *"Hu Huanyong Line."* On the right side, there is 94% of the Chinese population, and consequently, only 6% is on the left side (National Bureau of Statistics of China, 2019). Moreover, the country offers a significant climate and landscape variety. Figure 3.7 shows the climate map of China; the representation highlights the aridity of western China and the humidity of the eastern area (this influences the MSW disposal, such as the leachate generation). Climate differences influence the different population density in the different Chinese regions and, consequently, the generation of solid waste.

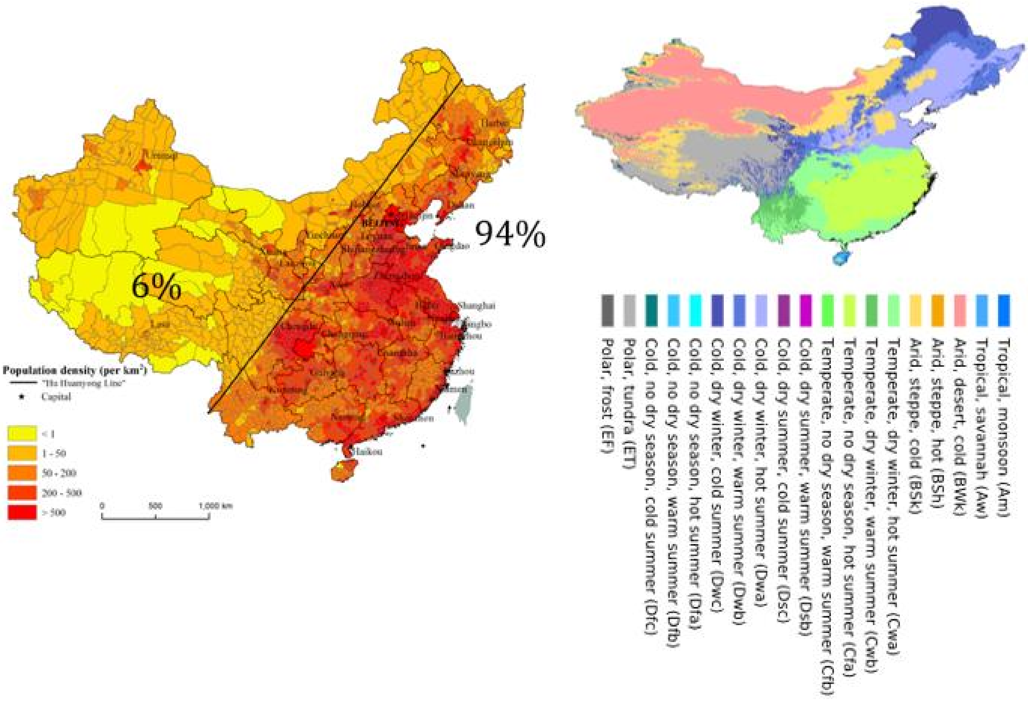

Figure 3.7: The distribution pattern of the Chinese population and climate characterization in China (NBSC, 2019).

3.2 The Municipal Solid Waste problem

Compared to the other Asian countries, the trend of increasing MSW generation is higher in China. Around 70% of MSW generated by the East-Asia Pacific region comes from China (Mian et al., 2017). China has become the first world waste generator in 2004, overcoming the US (Hoornweg & Bhada-Tata, 2012). The significant Chinese MSW growth is due to the high growth in GDP and the urban population that China is attending. Caused by considerable development both in the economy and society, China is struggling against an unprecedented increase in MSW. In 2017, it was generated over 215 million tons of MSW in China (National Bureau of Statistics of China, 2018). Moreover, the Chinese MSW amount generated is still increasing at the rate of 7%-9% every year (Zhao et al., 2016), accounting for 29% of the global MSW generation (Zhang et al., 2010). The enormous amount of MSW generation and MSW growth rate experienced by China have never been experienced by other countries (Zheng et al., 2014). Therefore, although MSW management is a severe issue for each country worldwide, it seems to be more serious in China. It has been foreseen that in 2030 China likely will generate twice MSW as much as the US. In 2050, the waste generation of the world will reach 3.4 billion, as Hoornweg et al. (2005) declared, a third of which will generate from Asia, contributed by large economic countries such as China and India. The environment is deteriorating, and improper treatment of MSW can increase air, soil, and water pollution (Arbulú et al., 2015; Simatele et al. 2017). China is under enormous pressure regarding MSW management. From the beginning of the 1990s, the investments in the Chinese MSW management equipment and infrastructures have been increasing (NBSC, 2016). In order to manage the MSW growth, it is crucial to implement proper management in terms of waste generation, collection system, recycling, treatment methods, and disposal taxation system. In China, the treatment methods are mainly landfill, thermal conversion methods (incineration, pyrolysis, gasification), and biological conversion method (anaerobic digestion) (Wang and Geng, 2015). In China, the most well-accepted technology is the WTE incineration because it is able to reduce the MSW volume and generate energy, such as heat or electricity, with affordable cost (Pavlas et al., 2011). Since the secondary pollution (coming from the incineration of MSW) can be effectively controlled by the modern incinerator plants, their development has been encouraged by the Chinese government (Gu et al., 2017). In 2015, the overall Chinese incineration capacity reached the amount of 0.19 million tons per day, and 1.6 GW electricity generated, saving 83.125 tons of traditional coal (Li, 2010).

3.3 Generation & Composition

China is considered the largest developing country with the greatest population, and it is undergoing a fast and large scale urbanization process, imposing increasing pressure on the city environment. The high urbanization growth and the related increase in MSW generation cause considerable pressure on the proper MSW disposal and management (Gui et al., 2019). China contains about 660 cities, which generate a large amount of MSW every year. China, as the first world MSW generator, contributes around 29% of the world's MSW (Zhang et al., 2010). The MSW generated in China has been increasing in the last decade (Figure 3.8), and in 2019 it has reached the amount of 222.2 million tons (Yuan et al., 2019). Given the high Chinese population, the MSW generation per day per capita is lower than those of developed countries, and in 2018 it was 1.02 kg per capita (the USA is the first country with a MSW generation of 2.58 kg per day per capita) (Kaza et al., 2018). From 2000 to 2005, the MSW generated increased from 118 million tons to around 156 million tons. It is interesting to notice that the MSW generation growth rate in 2001 was about 14,12%, but it was rapidly decreased to 1.48% in 2002. The main reason behind the rapid change was due to the issuing from the Chinese government of "*The Notice on Charging Urban Waste Treatment Fee and Promoting Industrialization of the Waste Treatment Industry*" (table 2.1). The latter has established a specific regulation about the Chinese MSW treatment charging system; in other words, it has been increased the costs for MSW generation by households and industries to control the generation of waste. Nevertheless, a positive MSW generation trend has been observed from 2006 to 2016.

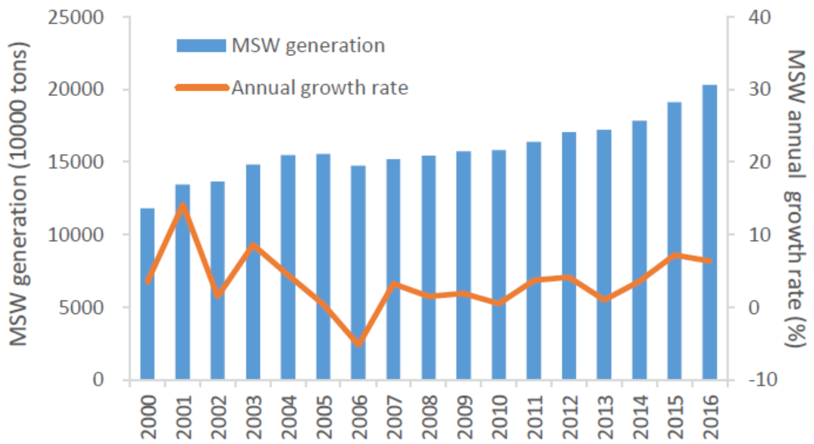

Figure 3.8: The amount and growth rate of national MSW generation, 2000-2016 (Chen, 2019).

Trends of MSW annual generation and annual growth rates are profoundly different among the four main regions. Annual MSWs generation has steadily increased in the eastern region since 2000, and the related annual growth rate has accelerated, overcoming those of the other regions (Cheng et al., 2019). In the central region, from 2000 to 2016, the annual MSW generated has not increased significantly. Since 2009 the annual MSWs generation of the western region has exceeded that of the central region(Cheng et al., 2019). Whereas, since 2000, the annual MSW generation of the northeast region has been decreasing. In 2016 the annual amount of MSW generated by the northeast region was about only one-fifth of that in the eastern region (Cheng et al., 2019). Figure 3.9 shows the different trends for each region.

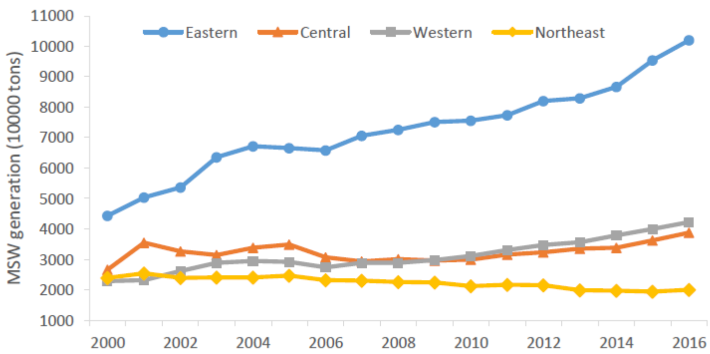

Figure 3.9: MSW generation in the four regions during 2000-2016 (Chen, 2019).

The Chinese volume of MSW is enormous, and its growth rate is fast, between 7%-9% in the last years. Consequently, the pressure on the management of MSW collection, transportation, and disposal is really high. With the acceleration of urbanization, economic growth, and the Chinese lifestyle, the pressure will increase (Gui et al., 2019). In 2005, the World Bank estimated that the Chinese MSW generated will be able to reach 480 million tons by 2030 (Figure 3.10).

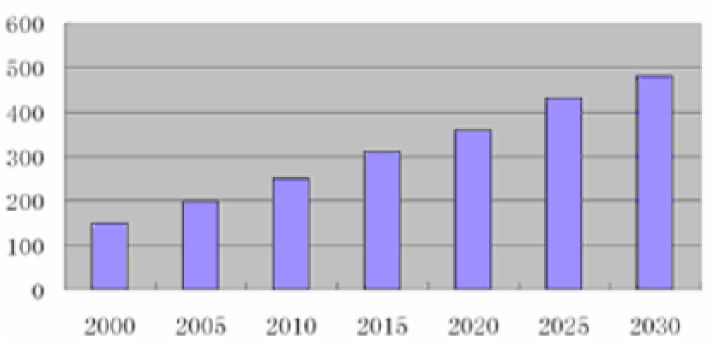

Figure 3.10: Total amount of MSW in China (projection from 2010-2030) (World Bank, 2005).

In addition, China is a developing country and is considered an upper-middle-income level country (Kaza et al., 2018). Indeed, MSW composition is dominated by 55.86% of organic matter (Mian et al., 2017). Most of the recyclable materials are collected by informal workers, but because of the lack of informal collections data, the total number of recyclable materials picked by the informal sector is not available (Mian et al., 2017). In China, since the late 1990s, income and quality life have been increasing, and also MSW composition has been changing, decreasing the organic matter part. From a national perspective, the main trend showed that recyclables, such as paper and plastics, increased, whereas organic matter decreased (Chen et al., 2009). Figure 3.11 shows two different compositions in 1996 and 2000, evidencing the organic matter decreasing trend replaced by an increasing of recyclable materials, which is a common trend among developed countries (Chen et al., 2009).

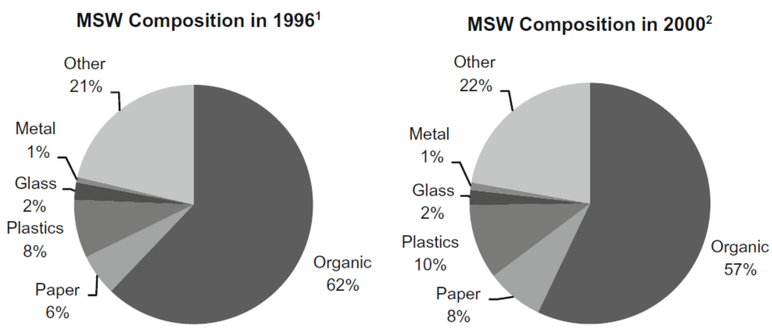

Figure 3.11: Waste composition in China – as generated. Note: Organic includes food waste, waste textiles, and wood; ash is categorized in "other" (Wang and Nie, 2001).

Compared to other countries, China has a greater organic matter part than high-income and upper-middle-income countries. Chinese MSW composition has a negative influence on WTE technologies and proper landfilling, having a high organic matter fraction, causing a lower low heating value in the incinerator, and a higher generation of pollution in landfills. In Figure 3.12, Chinese MSW composition is compared to those of other countries (Mian et al., 2017). The result of the comparison confirms that China has a greater organic matter part then high-income and upper-middle-income countries.

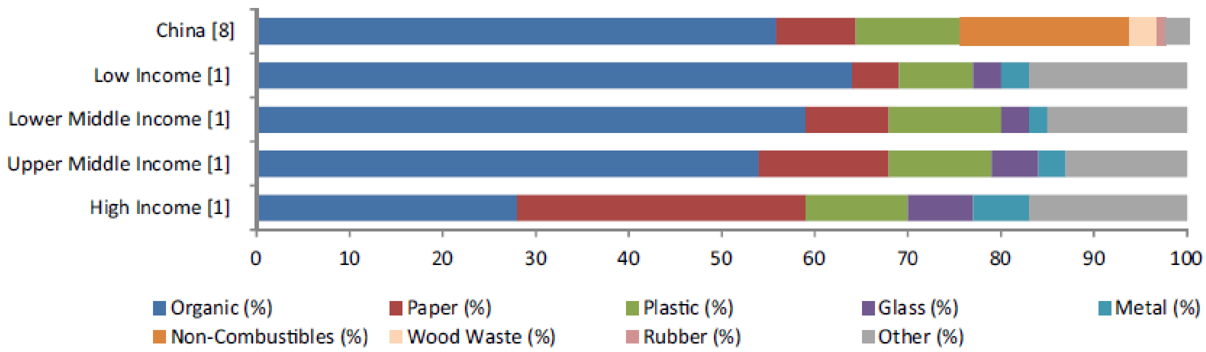

Figure 3.12: Composition of MSW in China and different income countries (Mian, 2017).

3.4 Recycling System

China's current recycling system has two main sub-components. The first is called the formal recycling sector, where government-run, with contracted companies, manage the collection, the recycling process, incineration, landfill disposal, and composting (Morrison W. & Schonberg A., 2017; Steuer et al., 2018). The second part of the system is entirely informal and involves millions of "informal" workers who collect, store, and sell recyclables materials. Nevertheless, in recent years, a new method to recycle recyclable materials has started to be utilized known as the innovative model (Xue et al., 2018), and it could be a solution to ameliorate the current situation of the formal recycling system, and in the same time could be the key to integrate the informal recycling system in the formal sector. It is an emerging recycling mode, and it is evolving fastly along with the development of information technology.

3.4.1 Informal recycling sector

Based on the experience of several Chinese cities, it has been possible to identify three different Chinese stakeholder groups involved in the informal recyclable collection activities (table 3.1)(Steuer et al., 2018). Firstly, the category of Waste Pickers (WPs), who wander through the streets by foot and seek recyclable materials in public and residential bins. The WPs have a limited capacity, and they can collect a small quantity. Waste Merchants (WMs) are the second group involved in the informal system. They focus their activities on doorstep collection directly from households and are able to transfer collected recyclables over relatively long-distance using tricycles. The third informal group is represented by Middle Men (MM), who buy recyclables from both WPs and WMs and use trucks to transfer recyclable materials to their depots. There, MM pre-process the materials (storing, cleaning, separation and sorting, refurbishing, material extraction) and then sell them to manufacturers or recyclers (Steuer et al., 2018). Moreover, in the informal chain, there are essential infrastructural nodes called Trading Points (TPs) for exchange materials. These nodes are mainly of small and scattered nature, similar to small markets, being composed of small booths and trucks with mobile ground scales. TPs are open at least half a day, and there, informal recyclable stakeholders (residents, WPs, MM) are able to exchange materials for money. MM operates as buyers, who pre-process MSW recyclable materials before transferring them to recycling or industry (Figure 3.13) (Steuer et al., 2017). TPs are a bottom-up solution idealized by informal stakeholders to avoid long transport distances. For example, Beijing's sub-district Haidian_has a TP-to-resident proportion of around 0.87 TPs per 10,000 residents (Steuer et al., 2018). The TPs' spatial distribution facilitates the collection and transfer activities of the involved informal workers. The efficiency of the informal recycling sector is related to how its stakeholders engage with the households. Indeed, informal collection workers adopt a pro-active stance to establish a relationship with households (Steuer et al., 2018). For instance, WMs, wandering through residential areas, offer their services through verbal announcements. Another practice to build a relationship with households is that they set up cardboard signs close to the residential areas, on which they state the recyclable materials that they collect and their mobile phone number (Steuer et al., 2018). Further, collectors make use of business cards to allow a better connection with their customers. Many WMs declare that excellent communication is crucial to ensure a high level of efficiency. Indeed, most of them arrange waste picking appointments with their customers by phone call, making the service more flexible and able to align collection time and routes with actual household demand (Li, 2002; Steuer et al., 2015).

Stakeholder	Waste Pickers	Waste Merchants	Middle Men
Means of transport	By foot	Tricycle	Truck
Source of recyclables	Public bins, bins in residential quarters	Households (doorstep collection)	Small enterprises, households, Trading Points
Waste management activity	Collection, selling at Trading Points	Collection, selling at Trading Points	Buying at Trading Points, storage, sorting cleaning, bailing material extraction selling to industry or recycling

Table 3.1: Informal stakeholder characteristics in urban Beijing MSW (Steuer et al., 2018).

The core WMs strategy, behind these practices, is pursuing the creation and the development of a loyal customer base, and therefore mutual reliability and trust should be encouraged. For households, the main reason to cooperate with the informal recycling sector can be found in the Chinese value concept applied to recyclables. Differently from western societies, Chinese people look at discarded recyclables not as garbage, but as valuable marketable materials (Zhang and Wen, 2014). The previous reasoning can explain why households prefer the informal recycling sector services instead of formal activities, offering them a pecuniary reward or compensation in exchange for waste recyclables (Steuer et al., 2018).

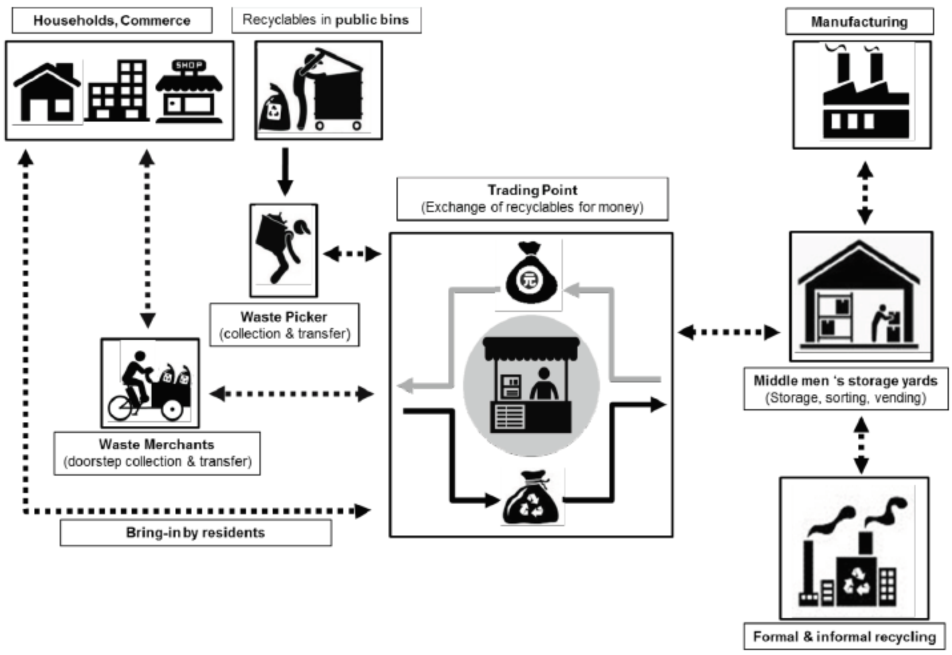

Figure 3.13: Chinese informal recycling system [Grey arrows indicate monetary flows, black arrows refer to recyclable flows, and two-directional arrows indicate the exchange of money for recyclables] (Steuer et al., 2017).

Indeed, WMs, during their door-to-door service, have to pay or be paid to get the recyclables materials from residents in relation to the value of the recyclable materials (Steuer et al., 2018). Often WMs develop different material preferences based on prince and market demand, having a significant impact on the informal recycling activities. For example, WMs will ask for a payment for the removal of iron, but they are able to give money to residents to collect paper and cardboard (materials with high demand because of the rise of e-commerce and growing need for packaging) (Steuer et al., 2018). Table 3.2 highlights a possible price configuration of different recyclables materials in Beijing, but prices can differ from city to city and from period to period.

Material	Selling Price*	Unit
Plastic bottles (branded)	0.22	RMB per piece
Plastic bottles (other)	0.10	RMB per piece
Other plastic	0.80	RMB/kg
Polyethylene	0.60	RMB/kg
Polypropylene	0.80	RMB/kg
Plexiglas	0.95	RMB/kg
Waste iron	0.90	RMB/kg
Sheet metal	0.20	RMB/kg
Brass	9.30	RMB/kg
Copper	15.00	RMB/kg
Aluminium cans	0.11	RMB per piece
Glass bottles	0.10	RMB per piece
Paperboard	0.70	RMB/kg
Newspaper	0.95	RMB/kg
Books & Periodicals	0.70	RMB/kg

Table 3.2: Recyclable materials price configuration in Beijing 2010 (Chen at al., 2010).

Government response to the too great importance of the informal sector

The heavy and enduring presence of the informal sector on the overall Chinese recycling system, damaging the formal sector, has brought the municipal government to respond. The Chinese central government, in the mid-1990s, established a formal institutional structure to tackle the challenge of MSW. Nevertheless, major legislative pieces such as the *"law on solid waste"* left the portion of collection undefined; therefore, the municipal governments addressed the collection problems and attempted to manage the informal recycling system dilemma. Two different approaches to address the collection problem can be individuated, such as a prohibitive approach and an integrative approach (Steuer et al., 2018). The first one aims to expel informal activities, while the integrative approach includes the organization of the informal sector activities under the formal official authorities and cooperation between the formal and informal sectors. What is shown in the legislative pieces of municipal governance is that local governments have adopted a mostly prohibitive stance against the IRS (Steuer et al., 2018) (Figure 3.14).

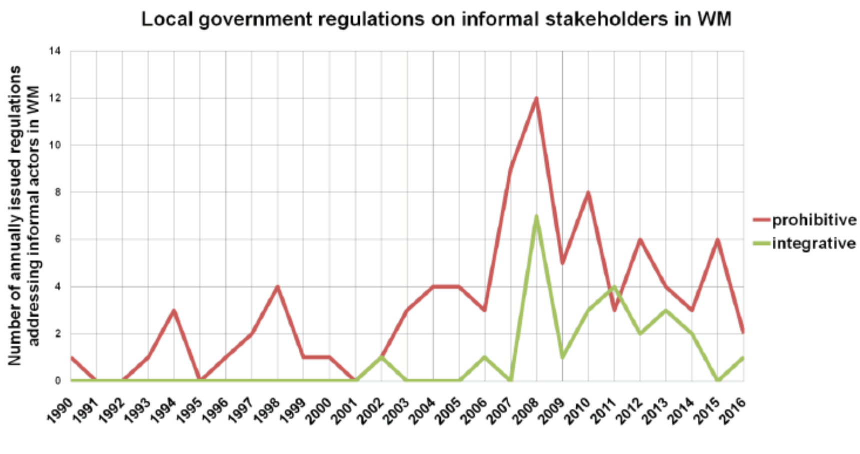

Figure 3.14: Local regulations regarding the informal sector in urban China (Steuer et al., 2018).

The implication of the chosen approach can be noted in the daily practices of local governance. These measures impact on the informal recycling system operation. Local governments, since the 2000s, have implemented pilot programs to set up a parallel formal MSW collection system (Steuer et al., 2018). The main objective of this step is to establish a direct link between generators and formal MSW system and at the same time, cut off the informal recycling system from the access to recyclables. Instead, the integrative approach adopted by local governments seeks to incorporate the informal recycling system within the formal sector through issuing licenses and create a top-down organization via the municipal government (Steuer et al., 2018). Adopting the integrative approach efforts were made, but they were rejected by the informal recycling system. The informal sector rejected them because they were perceived as highly negative due to the high-cost burdens that officials demanded the licensing process (China. com, 2007; Chen at al., 2010; Zhou, 2010).

3.4.2 Formal recycling sector

Formal sector steps can be classified into three stages: delivery, collection and transportation, and final treatment (Zhu et al., 2009). In the first stage, MSW goes into public containers. These containers are set out for the storage of mixed wastes and are fixed in designated locations for scheduled pickup. For most of the Chinese cities, the formal MSW collection system in China is mixed (there is not the recyclable materials stream). Informal sector stakeholders mostly collect high commercial value recyclable materials (Tai et al., 2011). Therefore, the most of lower value recyclables and not-recyclables MSW are thrown to the public waste collection point and then collected by the formal sector (by sanitation vehicles), together with the small not separated fraction of high valuable recyclable materials (those recyclables not picked by informal workers) (Tai et al., 2011). After then, these materials go through transfer stations, and finally, they enter in the last stage. In the last stage, the "formal system recyclables" (most of them are low-value recyclables because most of the high-value recyclables have been taken by the informal sector) are turned into renewable products through processing centers and then reuse factories (recycling plants), while mixed MSW ends up in landfills or incineration factories (Tai et al., 2011). The processing centers are involved in the sorting and initial processing of the recyclable materials. It can happen that some materials do not need to initial processing, and they undergo directly from transfer stations to reuse factories (Fei et al., 2016). Instead, reuse factories include recycling companies and manufacturing companies. Formal reuse factories are those compliant with the relevant provisions of the country and have the qualifications of recycling and reuse (Fei et al., 2016). For example, usually, the reuse of waste paper is operated by formal reuse factories, whereas the reuse of waste plastic is executed by the informal factories. The reason behind the previous difference is that the reuse of plastic is easier than other recyclables because it only needs to melt, granulation, and injection molding (Fei et al., 2016). Nevertheless, this causes serious pollution hazards. The informal reuse factories do not have to pay for environmental pollution, allowing them to gain an economic advantage (Fei et al., 2016). In Figure 3.15 is shown a scheme that summarizes the functioning of the formal recycling system.

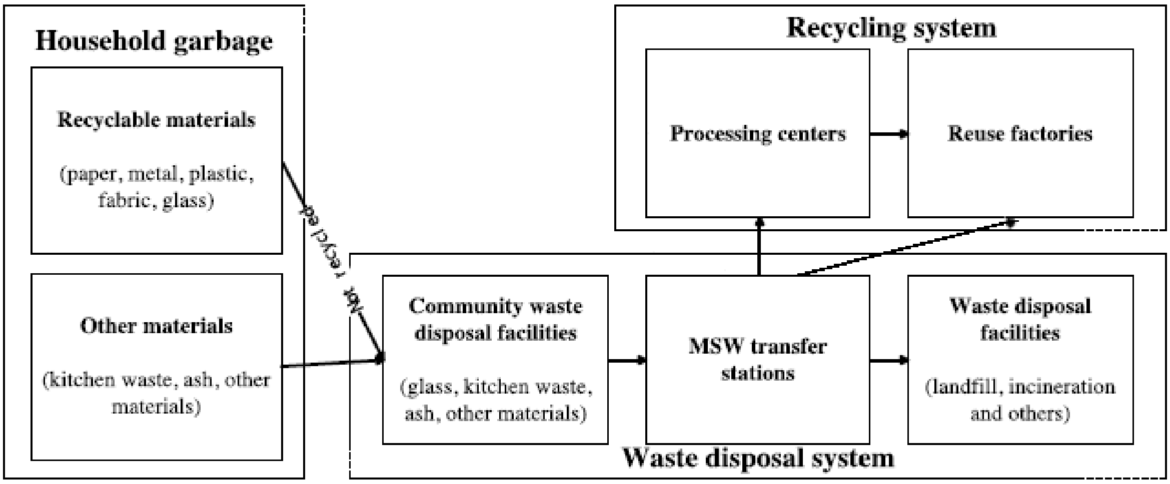

Figure 3.15: Chinese Formal recycling system (Fei et al., 2016).

The MSW source-separated collection, in most of the Chinese cities, is excluded from municipal responsibilities, which affect the efficiency of the Chinese MSW formal recycling system (Tai et al., 2011). In many developed countries, the source-separated collection is included within the MSW management system scope (Mian et al., 2017). Recently, some Chinese cities have introduced some pilot projects for the MSW source-separated collection (Mian et al., 2017). In 2017, in Beijing, Shanghai, Guangzhou separately MSW collection was partially implemented, and in Shenzhen, Hangzhou, Nanjing, Xiamen, and Guilin source separation waste collection was initiated (Xiao et al., 2007).

3.5 Chinese first program in the source-separated collection

3.5.1 Indicator definitions

In developed countries, all the recyclables materials go into formal municipal recycling systems, but this is not valid for developing countries (Tai et al., 2011). In China, because of the informal recycling system, almost only high-value recyclables materials are collected by informal workers. The collection of recyclables has been the source of income for a great part of unprivileged people. Therefore, the largest part of recyclables is collected by informal recyclers, and the remnants go into the formal recycling system (Tai et al., 2011). The relation can be written as follow (Tai et al., 2011):

$$Q_t = Q_r + Q_{t-r} = Q_{r1} + Q_{r2} + Q_{t-r}\,;$$

Where the following applies:

- Q_t is the total amount of MSW generated [tons/year];
- Q_r is the total amount of recyclable materials separated at source (public bins) [tons/year];
- Q_{t-r} is the total amount of residual MSW that can contain some recyclables not separated at the source [tons/year];
- Q_{r1} is the number of recyclables collected by the informal recycling system workers at the source [tons/year];
- Q_{r2} is the amount of recyclables materials collected by the MSW collection crew [tons/year];

Given that the Q_{r1} is collected by the informal recycling workers, it was difficult to find this amount. Tai et al. (2011) were able to find Q_{r1} with the help of the Environmental Sanitation Agency of each pilot city. It was estimated by a sampling survey of different types of household wastes (Tai et al., 2011). Therefore, Q_{r1} and Q_{r2}+Q_{t-r} were estimated by sites visiting and investigation. Then, for each family was calculated the percentage of Q_{r1} versus Q_t. Finally, multiplying this percentage to the total amount of MSW generated, it was possible to estimate Q_{r1}. Moreover, to understand the effectiveness and the development of the MSW collection in the eight pilot cities, other definitions should be addressed. One of the most important indicators is the MSW source-separated collection rate (SCR), which represents the quantity of separated waste divided by the total waste generated (Tai et al., 2011). In China, SCR can be described utilizing two more subindicators: informal recycling collection rate (HCR), and municipal collection rate (MCR) (Tai et al., 2011). As the expressions show:

$$SCR = \frac{Q_{r1} + Q_{r2}}{Q_t};$$

$$HCR = \frac{Q_{r1}}{Q_t};$$

$$MCR = \frac{Q_{r2}}{Q_t};$$

The last important indicator for the following studying is the percentage of household separation (PHS), which represents the percentage of households encouraged by the municipality to separate MSW divided by the total amount of households in the urban areas (Tai et al., 2011). It can be considered as the effectiveness of MSW source-separated collection in residential areas. Finally, the easy access to recycling facilities, public education, and the color-coded bins contribute to the success of the source-separated collection (Tai et al., 2011).

3.5.2 The pilot program

To ensure the control of the pollution generated by MSW and reduce the pressure of MSW disposal, some cities in well-developed regions, such as Shanghai and Beijing, have started the source-separated program over the past three decades. Moreover, in 2000, eight important Chinese cities - Beijing, Shanghai, Guangzhou, Shenzhen, Hangzhou, Nanjing, Xiamen, and Guilin – were selected as pilot cities to explore the benefits of the MSW source-separated collection system (Table 3.3) (Tai et al., 2011). China has long considered MSW classification as one of the main pillars in MSW management policies and regulations. The Ministry of Construction has issued some regulations to accelerate the implementation of the MSW source-separated collection system in the eight pilot cities. These regulations consist of "*The classification signs for municipal solid waste*" and "*Classification and evaluation standard of municipal solid waste*" (Tai et al., 2011). Besides, national policies and regulations, the local governments of each pilot city have issued their policies and regulations as a measure to promote the MSW source-separated collection system implementation (Tai et al., 2011).

No.	Name of the city	Area of the city (km^2)	GDP per capita (10,000 RMB[a])	Number of population in urban area (10,000)
1	Beijing	16411	63029	1695
2	Shanghai	6341	73124	1888
3	Guangzhou	7434	81233	1018
4	Shenzhen	1953	89814	862
5	Hangzhou	16596	60414	797
6	Nanjing	6501	50327	525
7	Xiamen	1569	62651	249
8	Guilin	27800	17435	60

[a] RMB is China's official currency. According to recent exchange rate, 1 US$ = 6.7 RMB.

Table 3.3: Social and economic background of the eight pilot cities in 2008 (Tai et al., 2011).

Therefore, citizens in each city voluntarily (because in the pilot program the households were encouraged to attend the MSW source-separated collection)chose to separate waste in different bins at home, putting them in designated locations for scheduled pickup by municipal sanitation vehicles. The main principle under the MSW source-separated collection required that large amount of waste and hazardous waste should be first separated, and then the remaining MSW should be classified in detail (Tai et al., 2011). After eight-year from the enacted of the pilot program, each city has consistently adjusted the MSW classification according to their different local conditions. Moreover, each city had to consider different budget and equipment facilities availability; consequently, there were slight differences in the waste sorting categories implemented across the eight cities (Tai et al., 2011). Therefore, in 2008, Citizens in Beijing, Shenzhen, and Hangzhou were encouraged to classify waste as kitchen waste, recyclables, hazardous waste, and other waste (other waste: includes recyclables and food remnants that have not been selected, which flow respectively into further disposal facilities) (Tai et al., 2011).. Residents in Shanghai were encouraged to implement a four-category classification system, and the four categories were recyclables, hazardous waste, glass, and other waste. Indeed, in most of the residential areas were implemented four containers, each with a different color to encourage the MSW classification by residents (Tai et al., 2011). Moreover, Shanghai is the only city that classified glass as one category, because of the fused glass can generate a hazardous effect on the incinerator, and the incineration is one of the major MSW treatments in Shanghai. Further, it is due to the low economic profit coming from recycling glass. In Guilin, citizens were encouraged to separate waste into recyclables, kitchen waste, hazardous waste, and other waste. In Xiamen, residents were encouraged to sort waste into recyclables, hazardous waste, and other waste and in Nanjing, into recyclables, non-recyclables, and hazardous waste. In Table 3.4 are schematically shown the different classification system across the eight pilot cities (Tai et al., 2011).

No.	Name of the city	MSW source-separated classification
1	Beijing	Residential waste (RW): recyclables, kitchen waste, other waste
		Catering waste: recyclables, kitchen waste, other waste
		Institutional waste (IW): recyclables, other waste
		Village waste: ash, compostable waste, recyclables, hazardous waste, other waste
2	Shanghai	RW: hazardous waste, glass, recyclables, other waste
		IW: hazardous waste, recyclables, other waste
		Public places: recyclables, other waste
3	Guangzhou	RW: recyclables, hazardous waste, bulky waste, other waste
		IW: plastic bottles, paper, retort pouch(TetraPak), other waste
4	Shenzhen	RW: kitchen waste, non-kitchen waste, bulky waste, hazardous waste
		Commercial areas, road and public places: recyclables, non-recyclables, bulky waste, hazardous waste
5	Hangzhou	RW: dry waste, wet waste, kitchen waste, non-kitchen waste
		Road and public place: recyclables, non-recyclables
6	Nanjing	Recyclables, non-recyclables, hazardous waste
7	Xiamen	Recyclables, hazardous waste, other waste
8	Guilin	Recyclables, kitchen waste, hazardous waste and other waste

Table 3.4: MSW source-separated classification in the eight cities in 2008 (Tai et al., 2011).

In China, generally, MSW was divided into the following categories: organic matter, inorganic matter, paper, fiber, timber bamboo, plastic, rubber, glass, and metal (Li et al., 2001). The eight pilot cities, particularly Beijing, Shanghai, Guangzhou, and Shenzhen, while experiencing great economic growth, were even challenging a proportional MSW generation increasing. Through Table 3.6, it is possible to see the MSW generated in 2008 for each city, since 2008 the MSW quantity is increased along with the development of the city (Tai et al., 2011). In Table 3.5 are shown, for each city, the respective composition after entering the MSW recycling system (e.g., the formal recycling system) (Tai et al., 2011). The MSW composition in these cities was similar, and the food remnants reached an average of 60% among cities, which increased during the summer. Poor management of kitchen waste is a serious problem in China, and it is usually related to leachate percolation, causing many environmental problems such as groundwater contamination, the risk of explosion in landfill areas, and unpleasant odors (Mor et al., 2006).

Name of the city	Food remnants	Paper	Plastics	Glass	Metal	Texture	Wood /bamboo	Tile	Ash	Others
Beijing	66.19	10.89	13.11	1.00	0.40	1.19	3.28	0.40	3.50	0.04
Shanghai	71.14	7.04	15.33	2.57	0.26	2.13	1.53			–
Guangzhou	52.00	9.00	21.30	1.20	–	13.00	–	2.60	–	0.90
Shenzhen	51.10	8.40	14.7	3.00	1.10	6.90	5.90	2.10	6.80	–
Hangzhou	53.00	35.50					9.50			2.00
Nanjing	70.59	8.32	14.18	1.45	0.08	3.05	1.04	0.70	0.58	0.01
Xiamen	74.63	22.73					2.60			0.04
Guilin	61.31	4.96	28.18	1.94	–	1.80	–	1.52	–	0.29

Table 3.5: Physical characteristics of MSW in the municipal recycling system of the eight pilot cities in 2008 (Tai et al., 2011).

Because of the informal recycling sector, the amount of recyclable paper, plastic, and glass entering the MSW management system (i.e., the formal recycling sector) were relatively small. Most of the recyclables are collected by informal workers before entering the MSW management system (Tai et al., 2011). Further, the low calorific value of the MSW is related to the high percentage of food remnants, resulting in incineration difficulties. Concluding, it is possible to declare that the MSW recycling system of the eight cities was characterized (in 2008, after eight years the implementation of the piot program) by low calorific value, a high proportion of organic matter, and high moisture content (Tai et al., 2011). Table 3.6 highlights that the total quantity of recyclables varies among the eight cities (Tai et al., 2011). The SCR varies from 8,9% to 40,1%. Besides, most of the recyclables are collected by residents. Indeed, the HCR is always greater than the MCR for each city; in other words, HCR contributes more to SCR than the MCR, confirming the great impact of the informal recycling sector on the MSW recycling system. Also, the effectiveness of MSW source-separated collection differs across the pilot cities. Citizens in different cities demonstrated different initiatives in doing MSW classification.

No.	Name of the city	Q_t (t/yr)	Q_r (t/yr)			HCR (%)	MCR (%)	SCR (%)	Q_{t-r} (t/yr)
			Q_{r1} (t/yr)	Q_{r2} (t/yr)	Sub-total (t/yr)				
1	Beijing	1096.6	385.9	54.1	440.0	35.2	4.9	40.1	656.6
2	Shanghai	827.0	136.5	12.2	148.7	16.5	1.5	18.0	678.3
3	Guangzhou	516.9	159.7	5.3	165.0	30.9	1.0	31.9	351.9
4	Shenzhen	587.6	142.2	4.7	146.9	24.2	0.8	25.0	440.7
5	Hangzhou	245.0	34.8	2.0	36.8	14.2	0.8	15.0	208.2
6	Nanjing	195.0	27.9	1.3	29.2	14.3	0.7	15.0	165.8
7	Xiamen	99.6	11.7	0.8	12.5	11.8	0.8	12.6	87.1
8	Guilin	24.8	2.0	0.2	2.2	8.1	0.8	8.9	22.6

Table 3.6: Quantity of MSW in the eight pilot cities in 2008 (Tai et al., 2011).

Figure 3.16 shows the growth trend of PHS from 2000 to 2008. PHS increased more in Beijing and Shanghai than the other cities, which had a PHS still under 15% in 2008, showing the imperfection of MSW separation facilities and lower public awareness of source separation (Tai et al., 2011).

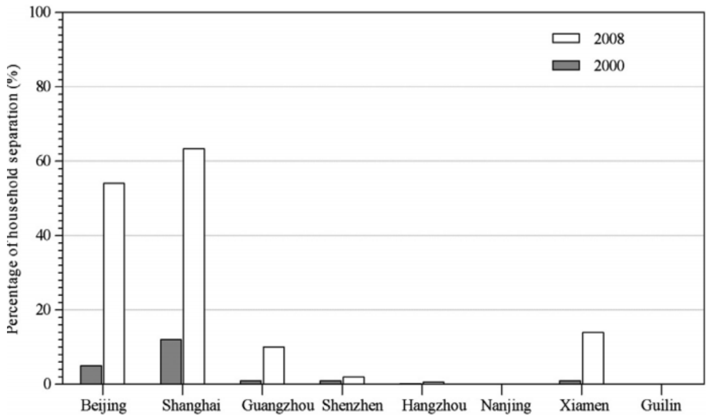

Figure 3.16: The Percentage of Household Separation (PHS) of the eight pilot cities in China in 2008 (Tai et al., 2011).

Moreover, the collection vehicles adopted in the pilot cities were related to different types of collection containers and the width of the road (Chiplunkar et al., 1981). In Shanghai and Beijing, it was required to use particular collection vehicles to avoid ''separate at the source but mix in the midway''. Finally, Tai et al. (2011) compared the MSW source-separation performance of eight cities and found that only Shanghai and Beijing had a comparatively positive result, and drown out the conclusion that MSW source-separation should be the key priority to improve a sustainable MSW management. In Beijing, PHS reaches 54%, and eighteen districts were covered. In these districts, residential communities, offices and public places were equipped with ordinary classified bins and different types of vehicles. After sorting kitchen waste at the source, SCR rises to 40.1%. In addition, Shanghai has played a leading role in encouraging MSW source-separated collection. From 2000 to 2008, encouraged communities were increased, and in 2008 these communities covered 63.3% of Shanghai (Tai et al., 2011). Unfortunately, because of the limited number of classified bins in residential areas, MSW was often disposed of in a mixed way, reaching a poor SCR (18%). Although the overall results after eight-year implementation were not so satisfactory, the concept of MSW source-separated collection had to be better introduced, and public awareness raised in the pilot cities (Tai et al., 2011). The different results depending on several factors, such as the social-economic background, the behaviors of residents, scavengers, and the MSW disposal and final treatment. After the pilot eight cities program, in 2006, the ministry of commerce of China introduced a program of Recyclable Waste Recycling systems in more pilot cities, in which 26 cities were included in the first batch of cities (MOC, 2006). Later, 29 pilot cities and 35 pilot cities were announced as the second the third batch in 2009 and 2012 (MOC, 2009, 2012). Figure 3.17 shows the distribution of these cities all over Mainland China, and most of them are located in rich and developed Chinese areas (in addition, Figure 3.17 shows all the cities encouraged to implement a source-separated collection nowadays) (Xiao et al., 2018).

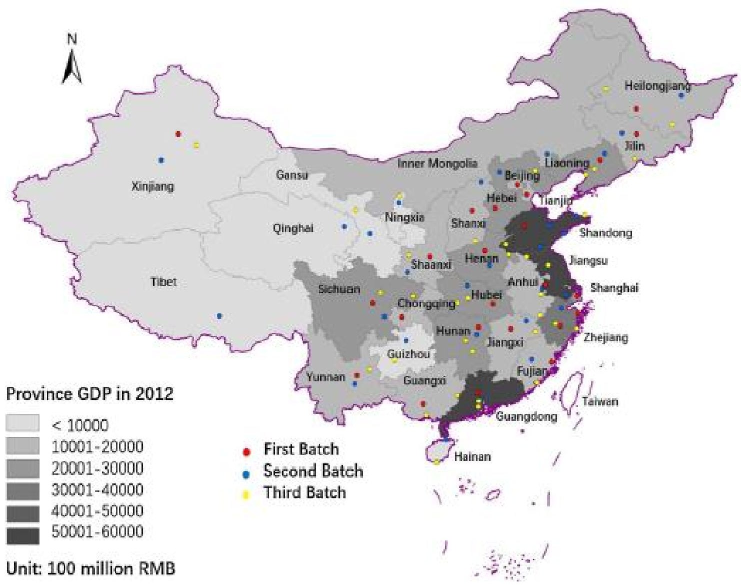

Figure 3.17: The distribution of RWR pilot cities (Xiao et al., 2018).

The statistical data highlight that 51’550 recycling sites, 341 collection centers, 63 terminal markets, and 123 recycling & processing facilities were implemented under the three batches of pilot city projects (ChinaRN.com, 2014). The objective of the program was to address the construction of a formal recycling system, strengthen the enforcement of the regulations on Recyclable Waste Recycling, and standardize the qualification requirement for recycling companies and individuals (Xiao et al., 2018). The involved governments should summarize successful experiences, and then share them to facilitate the development of a formal recycling system in other Chinese cities. All the pilot cities were required to elaborate on implementation schemes, make annual plans, and prepare their MSW policies by considering the local realities (Xiao et al., 2018).

3.6 Recycling system current situation – Challenges & Solutions

After several decades of development, China has improved its formal recycling system. The recycling of different common MSW has been ameliorated. For example, waste paper is one of the essential recyclable resources, and the formal paper recycling rate increased from 27.5% in 2001 to 46.7% in 2015 (Figure 3.18) (Xiao et al., 2018). Instead, waste plastic had a lower recycling rate, then waste paper, ranging from 20% to 30%. However, in the current state, the informal recycling system has still a crucial role in recycling materials. The informal recycling system still collects and processes the most considerable fraction of recyclables materials, whereas the formal source separation and the overall formal recycling system is still at a relatively small scale (Linzner and Salhofer, 2014). Taking as an example the city of Suzhou, in 2013, the informal recycling system collected 60% of MSW recyclable materials, while the formal recycling system only accounted for 16% (Fei et al., 2016).

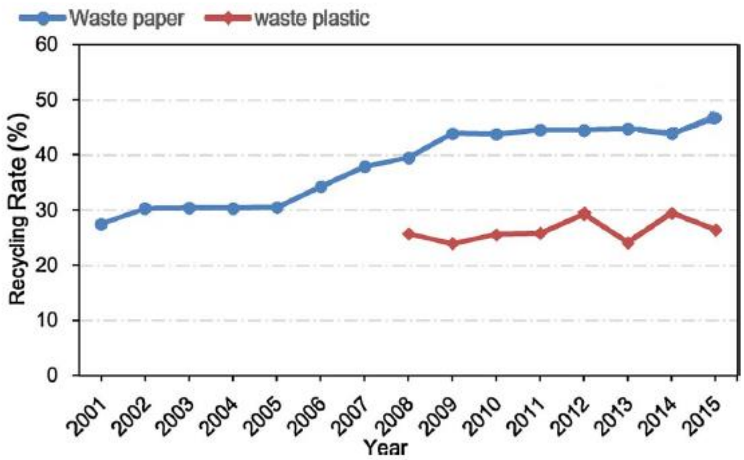

Figure 3.18: Ther recycling rates of the two main recyclable waste in China: papers and plastic (Xiao et al., 2018).

One of the most significant challenges of the formal recycling sector is *the lack of stable recycling markets*. Before establishing effective recycling markets, there still exist several challenges since the informal recycling workers are the dominant actors of the current recycling market yet (Chi et al., 2011; Tong et al., 2018). The informal recycling sector has the advantages of being more flexible and having low operation costs. Therefore, the informal sector is more competitive than the formal sector, which forbids the development of formal recycling markets. Further, recycling rates, both formal and informal, are related to the value of recyclable materials, and most of the low-value MSW recyclables have relatively low recycling rates due to their high recycling costs and low recovery benefits (Xiao et al., 2018). Concluding, the current state of the informal recycling system and the low recycling rates of lower value materials are the principal barriers for the establishment of a China's formal recycling market, and it requires government intervention (Xiao et al., 2018). The other main challenge facing by the formal recycling system regards the *insufficient grade of MSW separation*. The MSW is the main source of recyclable materials (approximately 30% of recyclables), even though it has a large fraction of organic matter. Unfortunately, in the current state, the overall Chinese MSW separation rate is still low (Xiao et al., 2018). In the pilot eight cities, the source separation rates varied from 8.9-40.1%, and only Beijing and Shanghai were able to reach favorable levels of source separation rates (Xiao et al., 2018). The main reasons include two factors: the low level of household awareness, and the absence of recycling incentives (Zhuang et al., 2008). Indeed, there is almost no promotion or guidance on Recyclable Waste Recycling, and most of the citizens do not have enough knowledge to classify recyclable MSW. Moreover, the only incentive for recycling comes from the informal recycling sector, being the citizens paid from informal collectors to get their valuable recyclable materials. Second, there are not adequate or convenient recyclable facilities, and it represents a considerable barrier to recycling behavior (Xiao et al., 2018). For example, some households do not have a proper space to hold their recyclable materials. Enhancing the accessibility of recycling facilities can have a positive effect on encouraging people to take recycling action (Zhang et al., 2016). Capital is fundamental to improve the formal recycling system. For instance, Japan's urban recycling projects were allowed by government finance (Van Berkel et al., 2009). Because of the low financial returns of the recycling industry and the presence of the informal recycling sector, the formal recycling system is less attractive for capital investments. In addition, governments have a limited financial budget to support recycling facilities and network development (Xiao et al., 2018). Therefore, financial innovation became one of the most critical factors in establishing a soundness formal recycling sector. Public-private partnership (PPP) can be considered as an innovative form of public financing that combines public and private sectors, rather than relying only on the public sector (Broadbent and Laughlin, 2003). The PPP is an arrangement among two or more public and private entities; typically, the PPP is a long term nature agreement. Moreover, PPP agreements are mainly used for infrastructure provisions, such as the building and equipment of hospitals, transport systems, and schools (Hodge et al., 2007). The concept of PPP is close to the concept of privatization and contracting out of government services. Common themes behind PPPs agreement there are the risk-sharing and the development of innovation. The PPP innovation is considered a flexible and efficient tool in solving the financial problems for high-investments projects (Chen et al., 2010), especially in fields such as infrastructures, transportation, and environmental protection (Chen, 2009; Zhang et al., 2015; Zhang, 2014). Since 2015, PPP has been in part utilized in China to ameliorate the formal recycling sector. Therefore, the PPP has increased the financial resources for the formal recycling system relying in part on private sector investment in recycling infrastructure and new recycling technologies (Xiao et al., 2018). There are already successful programs accomplished by PPP, for example, Yichang Supply and Marketing Cooperatives Jixin Assets Management Co., Ltd, and Guangdong Zhishun Chemical and Environmental Protection Equipment Co., Ltd employed a PPP to recycle waste plastic in Hubei province (Sanxia Daily, 2016). This program can be considered as a successful example of an application of PPP in China. Another fundamental financial measure utilized for encouraging the formal recycling sector is the policy of tax exemption. Favorable tax is a crucial pillar to ensure the survival of recycling companies in the formal recycling system. Indeed, economic returns for recycling companies are smaller than the other companies in other industries, making it impossible for a recycling company to bear the same tax rate (Xiao et al., 2018). Currently, the government is discussing an appropriate tax rate to promote the development of the formal recycling system. In addition, the accessibility to recycling facilities and convenience are significant factors to influence the recycling behavior in developed countries (Davis et al., 2006; Gonzalez-Torre and Adenso-Diaz, 2005; Miliute-Plepiene et al., 2016). It has been studied that households with accessible recycling facilities are 25% more possible to recycle than those with no easy access (Zhang et al., 2016). Therefore, it is essential to implement convenient recycling sites to promote the formal Chinese recycling system. In any case, it could be challenging to establish a mature formal recycling system in a short time. It could be useful to strengthen emerging innovative recycling practices integrating the recycling system with modern technologies to address this problem (Xiao et al., 2018). The advantages of adopting innovative technologies in the recycling system are convenience and low cost, and they are considered the main barrier for the current development of the formal recycling system. The government has identified this innovative solution for the Chinese formal recycling system, supporting this approach in the "*Circular economy promotion plan in 2015*" (NDRC, 2015). The innovative recycling mode applies modern technologies such as the internet, big data, and mobile phone apps to make more accessible the online trade, which is convenient and cheaper to operate. In any case, this new model is still in the infancy, but likely it will play a crucial role in promoting China's formal recycling system. Following this topic will be the object of detailing.

3.6.1 Intelligent collection

The intelligent collection is a new model to collect recyclables, using the assistance of Internet and Communication Technologies (ICTs) and the Internet of Things (IoT). There are four main categories of tools involved in intelligent MSW management (Hanna et al., 2015). They are (Xue et al., 2018):

- Spatial technologies, including Geographic Information Systems (GIS), Global Positioning Systems (GPS), Remote Sensing (RS);
- Identification technologies involving barcodes, Radio-frequency identification (RFID);
- Data acquisition technologies, including sensors and imaging devices;
- Data communication technologies relying on Global System for Mobile Communications (GSM)/GPRS, Zigbee, Wi-Fi, Bluetooth, Very High-Frequency Recorder (VHFR).

Combining these tools is possible to manage several waste management problems more effectively, reducing costs, time, risk, and environmental burdens (Lu et al., 2013). The collection of waste paper by means of GIS techniques experimented in Spain (Lopez Alvarez et al., 2008). An intelligent waste management system, named as IEcosys, was followed in Portugal, which converts the paradigm of households waste disposal from "Pay as You Throw" to receiving credits for MSW separating and recycling (Reis et al., 2015). ICTs and IoTs applications are helping to design new MSW management and formal recycling systems. Most of the implemented intelligent collection systems are in developed countries, still at a firsts stage (Xue et al., 2018). Unfortunately, there are not enough data to discuss the real efficiency of those internet-based systems. Intelligent collection and internet-based solutions are not well exploited in developing countries (Rada et al., 2013). Nevertheless, China represents an exception, choosing to explore the intelligent collection tools for MSW management in some developed provinces early in 2009 (Rovetta et al., 2009; Wen et al., 2018). Recently, intelligent collection technologies for collection have been improved fast in China (Zhou, 2015), and the reason can be the preference for internet-based businesses. Another utilized term to refer to the intelligent collection is "Internet + Recyclable Resource." In its general functioning, the informal recyclable collection includes at least four stages, such as from generator to collector, to the middleman, to the separation station, and the recycling plants (recycling companies)(Xue et al., 2018). The first one is the most complicated phase because it is a multi-actors and high-frequency process. The quantity and quality of the recyclables collected in the first stage can influence the whole recycling process efficiency. In China, the intelligent collection consists of innovation in the initial collection step, and it can take place through two different architecture. They are defined as Human-Machine interaction collection (HM), and Human-Human interaction collection (HH). HM interaction collection refers to a collection system that involves a machine to collect recyclables (Xue et al., 2018). The machine adopts different technologies, such as sensors, barcodes, and data communication devices. Figure 3.19 shows the HM collection process, and it is composed of four main steps (Xue et al., 2018):

1. *Identify account*: The machine identifies the generator which has registered in the company system;
2. *Hand over recyclables*: The generator thrown inside the machine the recyclables, following the machine statements;
3. *Send account/recyclable information*: The machine send the information about the generator's account and of the recyclable materials to the server;
4. *Offer credit*: The server sends credits to the generator's account.

The HM collection system uses different ICTs technologies. The barcode identifies the information about the generator's account and of the product; the sensor monitors the recyclables data and communicates with the server through GSM/GPRS; the volume and weight sensors to monitor the status of the machine stock. HM collection often is used to collect standard recyclable, such as PET bottles. The HM machines are located in public areas, including office areas, schools, and shopping malls (Xue et al., 2018).

Figure 3.19: The procedure of HM interaction collection and the collection procedure of PET bottles collection machine (Xue et al., 2018).

Whereas, HH interaction collection refers to a way to collect recyclables by human collectors via the assistance of ICTs. The generators have to register themselves on the collection company smartphone application. As Figure 3.20 shows, the HH collection system is composed of five main steps (Xue et al., 2018):

1. *Make an appointment*: The generator make an appointment about time and items to collect;
2. *Give order*: The system assigns the appointment to the closer free collector;
3. *Collect at the door*: The collector picks up the recyclables at the generator's door;
4. *Send info*: The collector inserts the information of the collected recyclables;
5. *Offer credit*: The system gives credits to the generator account.

Also, HH interaction collection needs several ICTs tools. Either the generator and collector need a smartphone, and the collectors execute the identification and submission of the recyclables information to the server. Moreover, data communication is made through WIFI or GPRS. Into this model, every collector is in charge of collection service for a determined residential area. When the collector gets the collection order from the server, he goes to the appointment time at the generator's door to execute the collection (Xue et al., 2018).

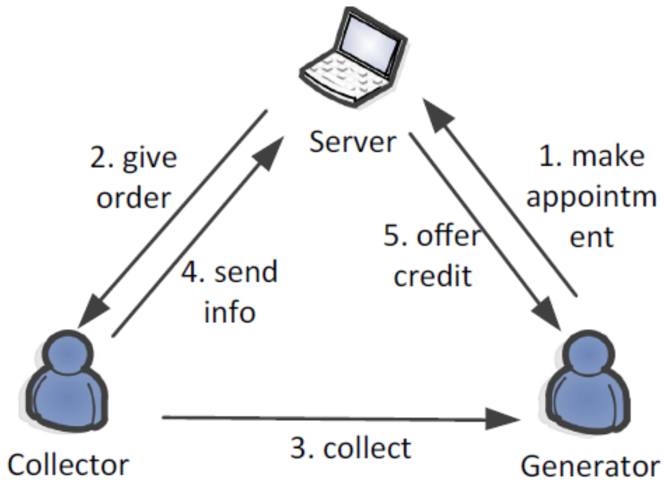

Figure 3.20: Procedure of HH collection (Xue et al., 2018).

Finally, the two different architecture of intelligent collection have different advantages and applicability. Table 3.7 highlights the ICTs technologies, applicability, and forms of the three solutions precedently called HM collection, HH collection, and informal collection (Xue et al., 2018). HM collection is applicable for standard MSW items and for serving public areas. HH collection is more applicable to any recyclables in the residential areas. Utilizing intelligent collection, a MSW generator does not get cash but credit or some other electronic currency, spending in online shopping. Whereas, the informal collection by informal collectors is carried out randomly and using cash (Xue et al., 2018).

Table 4
Comparison of HM, HH and informal collection.

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

Table 3.7: Comparison of HM, HH, and informal collection (Xue et al., 2018).

The intelligent collection is an organized collection and provides the organizational safeguard to integrate the informal collection. Figure 3.21 represents the intelligent and organized collection versus the random informal collection (Xue et al., 2018). The informal collection is unorganized, and the main collector actors are waste pickers (WPs) and waste merchants (WMs). The WMs wander the streets seeking for residents who bring to them recyclables, while WPs pick up recyclables from garbage bins. The collection prices, time, and places are random, and the collectors are unstable too. One collector can operate within a 20 km area, but at any time, he can leave the area and take another job at any place (Xue et al., 2018). In China, recyclables materials have a market price, when there is a high demand (and therefore high prices) for recyclables, the number of collectors and recyclables collected will increase, and vice versa. Instead, when the market demand is low, the recyclables will be left to the MSW management system (formal sector and they can be recycled by formal resource recovery facilities or ends up in incinerators or landfills) (Xue et al., 2018). Unfortunately, this informal sector behavior creates problems for the sustainable MSW management system, further that environmental, social, and healths burdens. Intelligent collection can standardize and monitor collection procedures. Through ICTs tools, it is possible to quick and easy access and recording the collection place, time, and frequency, regularizing the collection service (Xue et al., 2018). Moreover, every collector will be charged with fixed residential areas, and he will be able to cultivate relationships with residents. Service regularity helps to improve residents' recycling behavior, ameliorating the quantity and the quality of the recyclables. Concluding, an organized collection owned by an intelligent collection company gives the collection legitimacy, helping to eliminate social and health problems related to the informal collection (Xue et al., 2018).

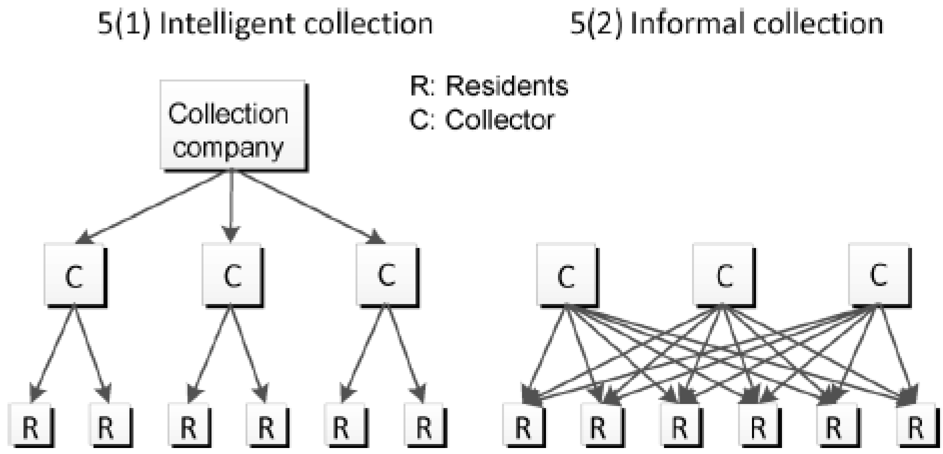

Figure 3.21: Organised intelligent collection and random informal collection (Xue et al., 2018).

Moreover, in the informal collection process, the recyclables are transferred and traded at least four times from the generator to the recycling plants. In each step, a trade deal is made, and consequently, the price rises. Therefore, the trade-for-cash nature of informal collection causes a low efficiency of the whole system. Figure 3.22.1 shows material and cash flow in the informal collection process. Instead, in the intelligent collection, both recyclables transferring and trade frequency happen less than what happens in the informal collection (Xue et al., 2018). Trading takes place just at two phases: when the recyclables are collected from the generator, and when they are sold to recycling plants. Figure 3.22.2 shows material and cash flow in the intelligent collection (Xue et al., 2018).

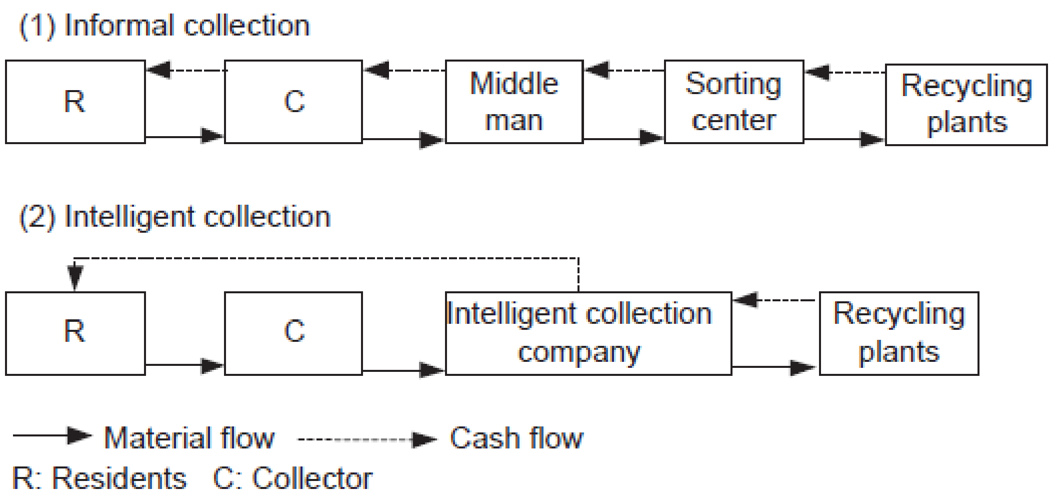

Figure 3.22: Material flow and cash flow in the intelligent collection and informal collection (Xue et al., 2018).

For those collection companies that own also recycling plants, trade takes place only once, in the first stage. In the intelligent collection, tradings can take place in virtual currency instead of cash, bringing less cash flow pressure on the company. Concluding, the material and cash flow in the intelligent collection is comparatively more efficient than that of informal collection. ICTs tools can help to monitor and ameliorate recyclables transportation to reduce logistic costs. In a few words, the less trade and material exchange make the intelligent collection more efficient than the informal collection (Xue et al., 2018). In addition, in the informal collection system, no one actors keep statistics or records of their recyclable trading; some of them have just a cash book of purchases and sales to monitor their profit (Xue et al., 2018). This system does not allow to keep accurate statistical data for China’s recycling industry. Academicians and policymakers can draw out conclusions on the recycling industry only on estimations. Through the intelligent collection and ICTs tools, it is possible to identify, communicate, and store a range of relevant data (Xue et al., 2018). First, it is possible to identify the location and track the logistic routes of recyclables. Second, the intelligent system records all recyclables information from the moment they are picked up by the collectors, and the data are accurate, traceable, and instant. Figure 3.23 illustrates the system of INCOME company that displays the real-time and accurate data of its collection system (Xue et al., 2018). It shows the locations and status of 5000 PET bottle collection machines. Green spots show 4577 machines are in good condition, red spots show 120 machines are in full stock, and yellow spots show 303 machines are not avaiòable (Xue et al., 2018). Moreover, the system presents statistics of the active users and real-time PET bottles collected. It shows that 12’522 PET bottles are collected on that day, and lists the top 5 most active collection machines. Hence, ICTs help to solve the problem of the data lacking from the informal collection. Finally, intelligent collection facilitates business management for the company and supports better administration of MSW management for the government (Xue et al., 2018).

Figure 3.23: Intelligent collection system monitors 5000 PET bottle collection machines in Beijing (Source: INCOME) (Xue et al., 2018).

Finally, the informal collection process can be defined as a single linear profit system (Figure 3.22.1) (Xue et al., 2018). The actors in the informal collection at each phase are able just to earn profit from the price margin of trading with others. The informal recycling system is affected by the vulnerability of the price fluctuation of the recycled materials market (secondary materials market). Instead, the organized behavior of intelligent collection can help to develop a multi profit-making business model, allowing the intelligent collection company to earn profit from 4 sources (Figure 3.24) (Xue et al., 2018).

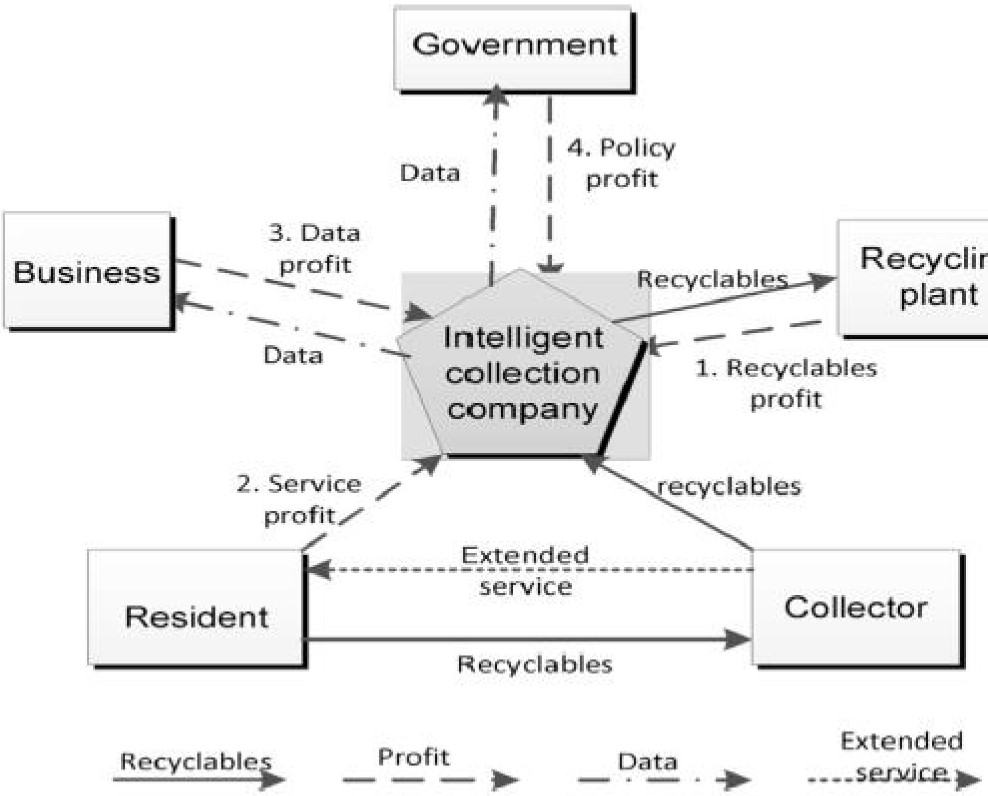

Figure 3.24: Multi profit-making model of the intelligent collection (Xue et al., 2018).

First, it can make a profit from trading or recycling the recyclables. Second, it can make a profit from providing extra service to residents. This profit is represented by the fee paid by residents when the collectors provide extra services to them. Particularly, in HH collection, the collectors can help to deliver the daily living goods and provide housework services. Third, the collection company can earn a profit from the data. The ICTs devices utilized in the intelligent collection are able to provide massive amounts of data of recyclables generation, residents' consumption, and recycling behavior (Xue et al., 2018). These data can be useful for producers and retailers. In other words, the intelligent collection company can earn profit mining data for producer and retailer enterprises. For example, INCOME company monitors its thousands of PET bottle collection machines, tracks, and analyses the beverage consuming behaviors, and makes a significant profit by sharing the information with the producer (Xue et al., 2018). Finally, the last profit source is the policy profit, and it regards subsidies that intelligent company can get from the government. These companies can collect a massive recyclables database, full of useful information for the policymaker, helping them to formulate the proper policies and take proper management actions. Moreover, the intelligent collection can obtain subsidies to their contribution to waste source separation and reduction (Xue et al., 2018). The intelligent collection has several comparative advantages compared to the standard informal collection in terms of organization, trade, data accumulation, and profit-making business model. It can partially solve the environmental, social, and efficiency problems related to the informal collection system. The new proposed collection system could have the potential to integrate the informal sector into the formal recycling system. Two different integration approaches can be individuated, such as depth integration and collaboration integration (Xue et al., 2018). With the first approach, depth integration, the intelligent collection company hires the informal collectors from the informal sector, equipping them with smartphones and other intelligent devices and training them about the intelligent collection. The collectors can have social insurance and welfare benefits from the collection company (Xue et al., 2018). Moreover, they can see their social status ameliorated. All the previous benefits are absent for standard informal collectors. Therefore, it seems that depth integration can be considered a win-win strategy, bringing satisfaction to both sides. The second approach, the collaboration integration, consists of the informal collectors, who are able to join the company's intelligent collection platform as collaborators instead of employees. They get the collection order from the system, executing the collection they receive awards from the system (Xue et al., 2018).

3.7 Landfilling

In 2000, there were 696 MSW facilities, and the largest part was composed of landfills. Usually, landfills were built by relatively low construction and operating costs (Robinson et al., 2003). Chinese landfill status is changed over time, and the quality of landfill is increased instead of quantity. The increase in landfills' capacity is higher than the increase in landfills number. The explanation can be that larger landfills allow reducing the costs of the land, and they can be equipped with better pollution control systems. Table 3.8 represents an overview of how the number of landfills and their capacity changed from 2004 to 2014 (Mian et al., 2017), during this period landfills increased by 1.4 folds, which contribute to 1.6 folds higher MSW capacity disposal by landfill. In 2004, 44.42% of the total collectible MSW was disposed of by landfilling, whereas 60.16% in 2014 (Figure 3.25), increasing the disposal capacity per day by 1.63-folds (Raninger B., 2009). Figure 3.25 shows the number of the sanitary landfill until 2017, which were 654 units. Unfortunately, because of the poor protective measures of the sanitary landfills, the water, farmland, and air were becoming to be polluted (Mian et al., 2017).

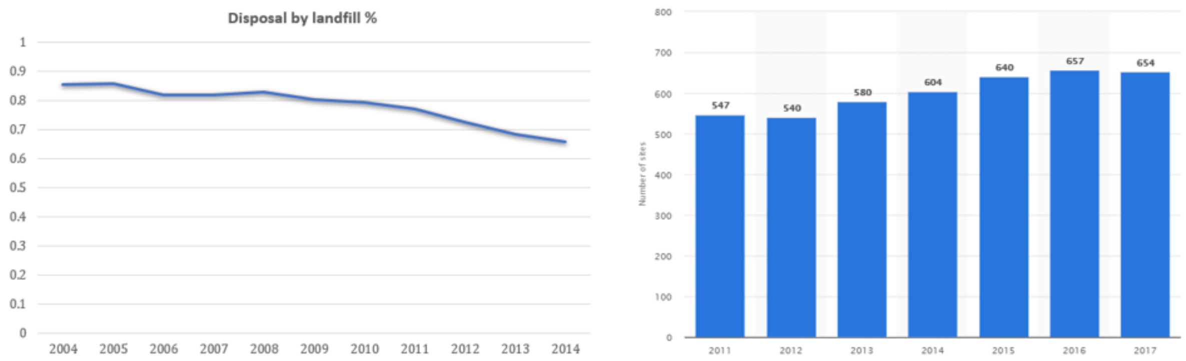

Figure 3.25: The percentage of the MSW disposed of by landfill and the number of landfills (Mian et al., 2017).

Year	Waste treatment unit			Treatment capacity (ton/day)			Volume of wastes disposed (10,000 tons)			Percentage of collected waste treatment (%)
	Landfill	Incinerate	Others	Landfill	Incinerate	Others	Landfill	Incinerate	Others	
2004	444	54	61	205,889	16,907	15,347	6889	449	730	52.1
2005	356	67	46	211,085	33,010	11,767	6857	791	345	51.7
2006	324	69	20	206,626	39,966	9506	6408	1138	288	52.2
2007	366	66	17	215,179	44,682	7890	7632	1435	250	62.0
2008	407	74	14	253,268	51,606	5386	8424	1570	174	66.8
2009	447	93	16	273,498	71,253	6979	8899	2022	179	71.4
2010	498	104	11	289,957	84,940	5480	9598	2317	181	77.9
2011	547	109	21	300,195	94,114	14,810	10,063	2599	427	79.7
2012	540	138	23	310,927	122,649	12,692	10,513	3584	393	84.8
2013	580	166	19	322,782	158,488	11,030	10,493	4633	268	89.3
2014	604	188	26	335,316	185,957	12,182	10,744	5330	320	91.8

Table 3.8: MSW management treatment units and disposal capacity in China (Mian et al., 2017).

In China, till 2001, most of the landfills were not equipped with gas recovery systems, releasing in the atmosphere odor and greenhouse gasses such as NH_3, H_2S, CO_2, and CH_4 (Wang et al., 2001). Recently, the landfill gas recovery has been introduced and utilized to generate electricity in some landfills. For example, the Shuige landfill is the largest landfill of Nanjing, which has a GEF-funded landfill methane power plant with a capacity of 1200 kW. In many Chinese provinces landfill, gas-to-electricity projects are underway, such as Hangzhou, Guangzhou, Nanjing, Xian, Beijing, Changsha, Wuxi, and Jinan. Till 2008, 28 Chinese LFG (landfill gas) facilities projects had been completed, and 18 of them include facilities for electrical power generation using landfill gas, with an overall capacity of about 40 MW (Mian et al., 2017). The price of the electricity generated by landfill equipped with gas-to-energy facilities is around 0.25 Yuan RMB/kW, which is more than the price of the electricity generated by coal (Habil, 2017). In a sanitary landfill site, the biodegradation of the MSW organic matter fraction is a crucial dilemma, generating acidic and alkali organic pollutants (Kusterer et al., 2006) and other pathogens. The acidic situation boosts heavy metal leaching from the landfill site. The leachate can be generated by biodegradation and/or rainfall. The improper leachate treatment by non-engineered landfills causes surface and groundwater contamination. Till 2006, 47 % of landfill in China did not treat leachate before discharge, 10 % discharge leachate into the sewage system, whereas biochemical methods are used in 20 % landfills, 3 % used membrane liners and 20 % landfills used other methods (Xu et al., 2006). Instead, in some Chinese cities, leachate was treated partially; for instance, in the Chongqing area, landfilling treated a negligible amount of leachate before discharging it into groundwater. This behavior contributed to water, air, and land pollution, decreasing nearby land value, and increased risk for public health (Yuan et al., 2006). One of the most important factors causing leachate pollution is the co-disposal of biological waste in landfill sites. The MSW management of developed countries tends to separate biological waste from landfilling (Mian et al., 2017). The European Union Directive provided a goal to reduce Biodegradable Municipal Waste (BMW) landfilling to below 35 % within 2016, but most of the EU countries had already achieved that target, and many of them have now zero BMW landfilling (Eurostat, 2012). Another challenging question faced by China is the problem of landfill site selection. The value of the urban land area has been increasing because of the rapid urbanization growth. It means that built a new sanitary landfill in an urban area could be not economically feasible (Mian et al., 2017). With a high value of the urban area, it could be necessary to build the landfill at a great distance from the main collection points, causing higher transfer costs and infrastructure investments. Moreover, most of the current landfills, in the main cities of China, had been built in the nearly 1990s, and have almost reached the end of their operational life. Choosing the appropriate landfill location and infrastructure is fundamental to improve Chinese MSW management (Mian et al., 2017).

3.8 Incineration

3.8.1 Global review

By 2015, there were 1179 MSW plants, all with power generation around the world and a total capacity of around 700’000 Mg/d (Lu et al., 2017). Table 3.9 shows the information about all the world’s incineration plants, dividing them and the related capacity by country (Lu et al., 2017). The table focuses on MSW incineration plants with power generation. Therefore, small scale plants without energy recovery or using non-incineration methods are not considered. For instance, Japan has around 1200 MSW incineration plants, but almost 100 of them use non-incineration methods, and 900 of them are small scale plants without power generation (Japan MOE, 2015). In the overview proposed by table 3.9, only 234 Japanese MSW incineration plants are considered for the comparison (Lu et al., 2017). Accordingly, with table 3.9, Figure 3.26 helps to understand the overall world status of incineration with power generation techniques. Most of the plants are located in the EU, the US, and East Asia, whereas the Africans countries rarely use incineration techniques. Countries in Northern and Western Europe with a good economic level have higher incineration capacities than other European regions. Usually, an incineration plant contains two or three incinerators. The average plant and incinerator capacity gives information about their dispersion degree. Most countries prefer adopting incinerators with a capacity greater than 200Mg/d and plants with a capacity close and higher than 400 Mg/d (Lu et al., 2017). The main reasons behind these choices are higher thermal efficiency and better pollution control. In Japan, the average capacity of the incinerator is the smallest one because Japan operates a great number of plants distributed in prefectures and subordinate divisions. For example, the area of Tokio, composed of 26 cities and 23 districts, has 27 incineration plants able to generate power and 20 non-power generation other plants. Unfortunately, this distribution pattern of the incinerators plants with the subdivision of the country limits the cooperation among MSW incineration plants within the country and limits the energy recovery potential (Lu et al., 2017). Instead, in China, building small dimension MSW incinerators is not permitted. The Central Chinese Government imposed that the capacity of MSW incinerators cannot be less than 200 Mg/d (China Standardization Administration, 2008). The objective of the rule is to ameliorate the cooperation of MSW management among counties in a prefecture-level city. Understand the efficiency of incineration plants is important, especially for decision-makers at a national level. The utilization rate is an important indicator helpful in understanding the running status of incinerators. This indicator is calculated by dividing the amount of MSW incineration treated in one year by design capacity and using 8000 operating hours annually:

$$Utilization\ rate = \frac{\text{Amount of MSW incineration } [10^3 * \frac{Mg}{y}]}{\text{Design capacity } \left[\frac{\text{Mg}}{\text{d}}\right] * 8000[\frac{\text{h}}{\text{y}}]} * 24 \left[\frac{h}{d}\right];$$

The smaller this indicator is, the less an incinerator plant is working at its full potential, due to either idle capacity or unsteady operation. The utilization rate shows an important concept: if a shortsighted decision-maker chooses to increase the MSW incineration capacity, in response to the present growth of MSW, it could lead to a lower utilization rate if the recycling program will divert MSW from incineration. Table 3.9 shows that utilization rates in Taiwan, Sweden, and Denmark are relatively low, and If small scale plants or the non-incineration techniques plants are considered, Japan has a low utilization rate too (59%) (Lu et al., 2017). For example, the Taiwan government choose to build 29 MSW incineration plants (Tsai and Chou, 2006), but just 24 plants are functioning, and the utilization rate is low also to the success of Taiwanese MSW recycling programs. Increasing utilization rates can be done by implementing different strategies. In Sweden MSW incineration plants annually treat 2.5 million Mg of industrial and other waste (Williams, 2011), and 0.8 million Mg of waste are imported from Norway (PRI, 2012). Instead, in Denmark, MSW incinerators also treat about 1.3 million Mg of industrial waste as MSW substitute (Consortium, 2013). If MSW substitutes are involved, such as waste from industries and abroad, the utilization rates in Sweden and Denmark are respectively 98% and 99%. So, if in a country there is an excess in incineration capacity, it can be helpful to incinerate appropriate substitutes, allowing a better utilization rate (Lu et al., 2017).

Region	Number		Total capacity (Mg/d)	Average capacity (Mg/d)		Amount of MSW incineration (10^3 Mg/a)	Utilization rate (%)
	Plants	Incinerators		Plant	Incinerator		
China (2015)	268	552	231,600	864	420	61,755	80
EU (2012)	469	917	207,104	442	226	59,023	85
Germany	79	192	52,554	665	274	17,192	98
France	127	248	45,334	357	183	11,951	79
Netherlands	13	42	18,660	1435	444	4515	73
Italy	52	97	17,825	343	184	5529	93
Sweden	34	67	14,477	426	216	2233	46 (98)
Denmark	29	64	10,900	376	170	2307	63 (99)
U.S. (2014)	80	210	88,765	1110	423	29,665	100
Japan (2013)	234	551	92,203	394	167	33,729	110 (59)
South Korea (2013)	39	72	13,580	348	189	4475	99
Taiwan area (2006)	24	62	24,650	1027	398	4036	49
Other regions (2013)	65	144	49,903	768	347	–	–
Total	1179	2508	707,805	600	282	–	–

Table 3.9: Status of MSW incineration around the world (Lu et al., 2017).

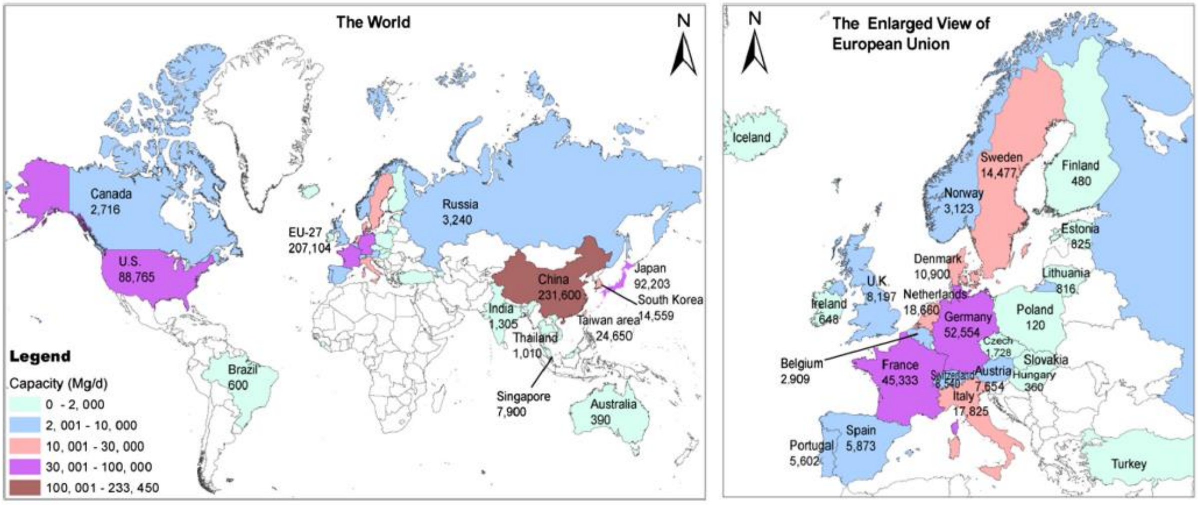

Figure 3.26: Global map of MSW incineration (Lu et al., 2017).

3.8.2 Municipal Solid Waste incineration in China

The total capacity of Chinese incineration plants, both under construction and in operation, is 439’000 Mg/d (Lu et al., 2017). Most of them are located in the eastern province, along with more developed economies with and a higher level of urbanization (Figure 3.27) (Lu et al., 2017). Indeed, the eastern region took up 64.7% of construction tasks on MSW incineration from 2012 to 2017 (China State Council, 2012). Most of the eastern prefecture-level cities such as Fujian, Jiangsu, Shandong, and Zhejiang, have at least one incineration plant. Nevertheless, only a few cities in the Central and Western provinces are able to afford MSW incineration because of the financial restrictions. Consequently, MSW incineration plants tend to serve mostly urban areas, but some of them also serve rural areas, especially in the eastern provinces (Lu et a., 2017).

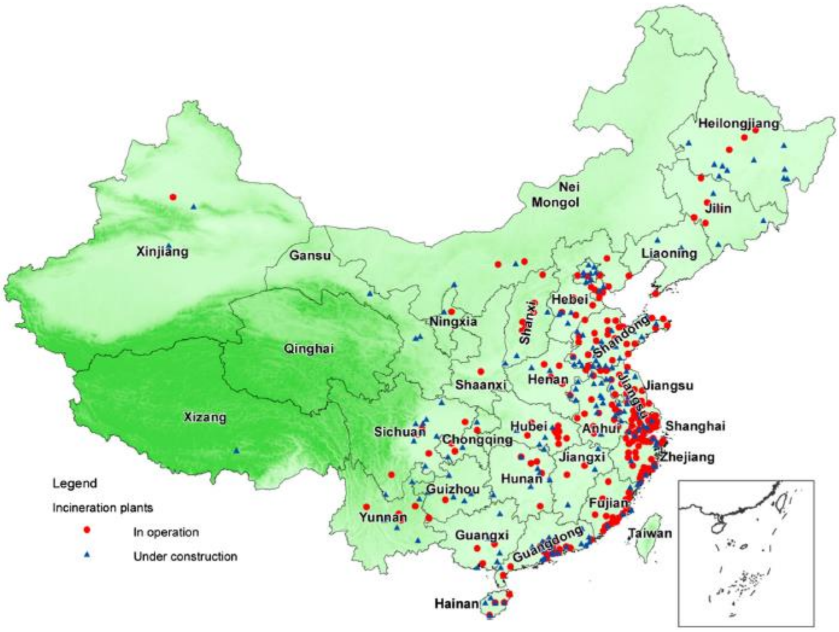

Figure 3.27: Current and future distribution of MSW incineration in China (Lu et al.,2017).

The development of MSW incineration started at the end of the 19th century, and the first commissioned one was in the U.K. in 1870, in response to eliminate germs (Vehlow, 2004). MSW incineration was not the first waste management option, and it was often blamed for destroying nutrients and recyclable materials and generating odors and pollution (Jones and Spadafora, 2014). Nevertheless, in the second half of the 20th century, MSW incineration was promoted to contrast the MSW steadily increasing. Developed countries have started to building MSW incineration since the 1960s, and during the 1980s, they have accelerated the process. However, at the end of the 20th, the expansion of MSW incineration in the developed countries started to decrease. In the first years of the 21st century, MSW incineration was strongly promoted in China as a less harmful and more effective option than landfill (Lu et al., 2017). Particularly, MSW incineration was a good management option to tackle the problem of improper disposal, such as unsanitary landfills without impervious linings. Moreover, the incineration was officially supported by the *"12th Five-Years plan"* on waste management (China State Council, 2012). Consequently, the Chinese MSW incineration capacity increased from 15,000 Mg/d in 2003 to 231,600 Mg/d in 2015, assuming an important role in MSW management. Figure 3.28 shows the cumulative capacity of solid waste incineration of China and the other developed countries (Lu et al., 2017).

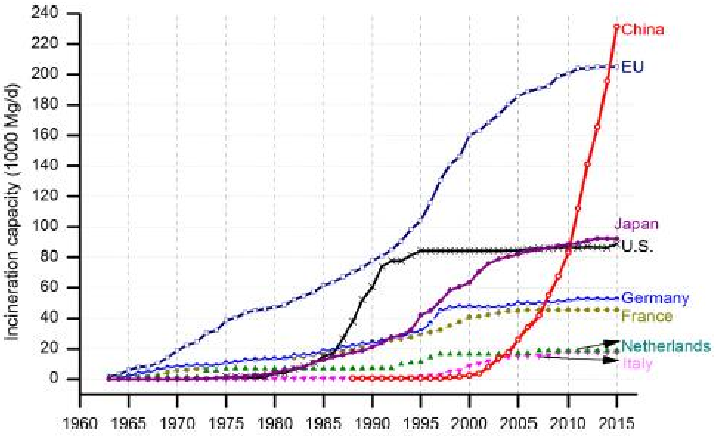

Figure 3.28: Cumulative capacity of solid waste incineration in representative regions (Lu et al., 2017).

Figure 3.29 highlights the variation of MSW treatment and disposal among China and other developed countries, including the EU, the USA, and Japan (Lu et al., 2017). The priority in China was to reduce the amount of MSW disposed of by improper disposal (open dumping), and promoting MSW incineration was helpful to increase the capacity of harmless treatment and sanitary disposal. In the EU, MSW incineration is gradually replacing landfill (in contrast with what is happening in China).

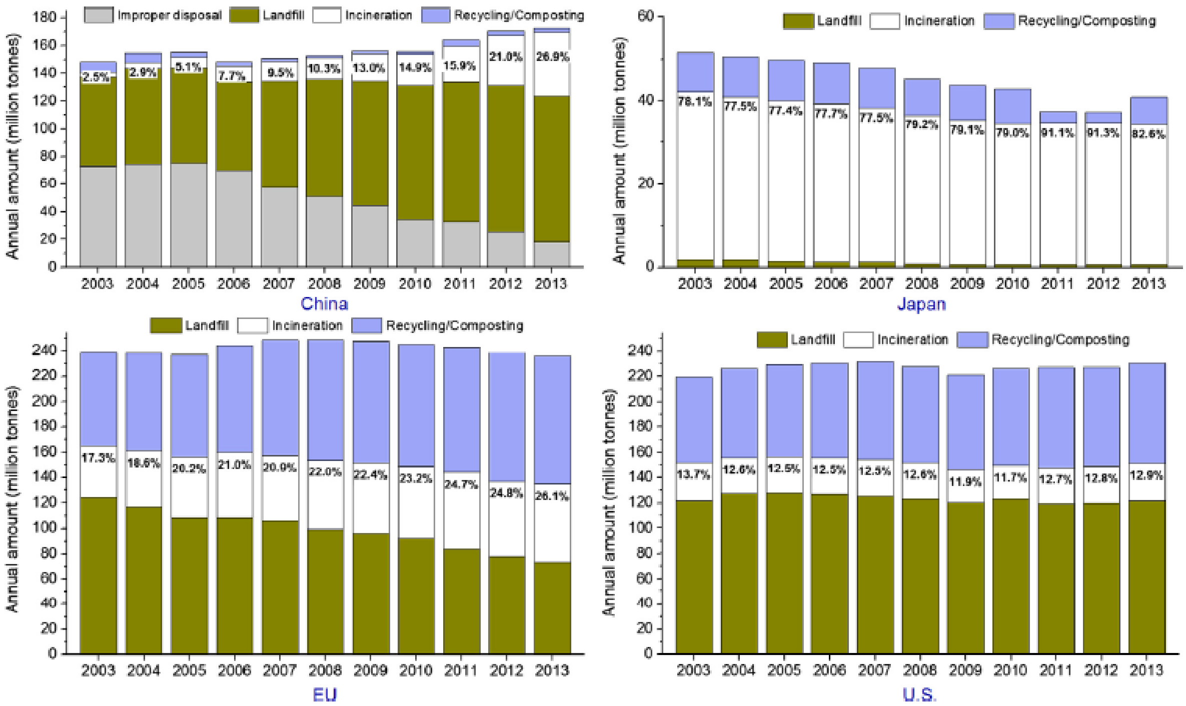

Figure 3.29: MSW treatment and disposal in China and the main developed regions in the world (Lu et al., 2017).

A tax imposed on landfills increases the cost of landfill. For example, the landfill tax rate for MSW is $103 per Mg in the U.K (CEWEP, 2014). The tax rate is greater than the average tipping fee of the landfill (about $26 per Mg) and near to the average tipping fee of incineration, which is about $102 per Mg according to (UK Defra, 2013). Instead, in the U.S., the MSW incineration amount is stable, and one of the main reasons for explaining the incineration stability is that landfilling is cheaper than incineration because of the requirements of the emission standard. The average tipping fee of a landfill in the U.S. is $43 to $49 per Mg (Klean Industries, 2012), lower than the tipping fee of incineration. Another reason is that small scale incinerator has left a bad image of incineration that currently persists (Psomopoulos et al., 2009). MSW incineration plants in the U.S. are distributed in regions with high population density and high urbanization level (ISWA, 2013; Michaels, 2014). In Japan, MSW incineration still dominates among the MSW treatment and disposal options, especially because of its scarcity of landfill space. Generally speaking, the historical retrospect highlights that MSW incineration is still a mainstream and effective waste management option despite MSW prevention and recycling at the source (Lu et a., 2017). In the last two decades, MSW has become a significant problem in China, having a great impact on the environment (Chu et al., 2016). In 2017, in China, about 201.9 million tons of MSW were produced in 202 Chinese cities (The Ministry of Environmental Protection of China. 2017). It is foreseen that generated MSW will reach 222.2 million tons in 2019. Considering the rapid urbanization and improvement of living standards, the Chinese MSW generation will keep its rapid growth in the future (Chu et al., 2016; Gui et al., 2019). Fortunately, MSW collection and transportation have been improving in the past 15 years. The harmless MSW treatment, including incineration, sanitary landfill, and composting (which are considered the three major methods), has been effectiveness ameliorated (the *"13th Five-Year Construction Plan for National Urban Domestic Solid Waste Harmless Disposal Facilities,"* 2016) (Figure 3.30). Moreover, WTE capacity will increase from 235’200 tons/d in 2015 to 591’400 tons/d in 2020 (Yuan et al., 2019).

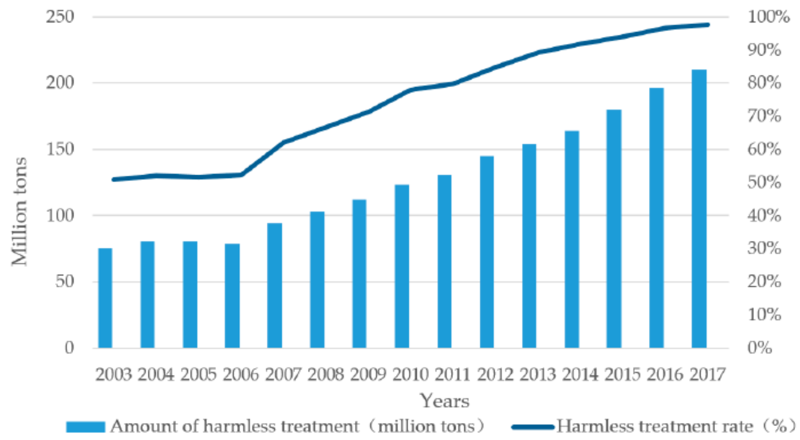

Figure 3.30: Harmless treatment of MSW in China in the past 15 years (Yuan et al., 2019).

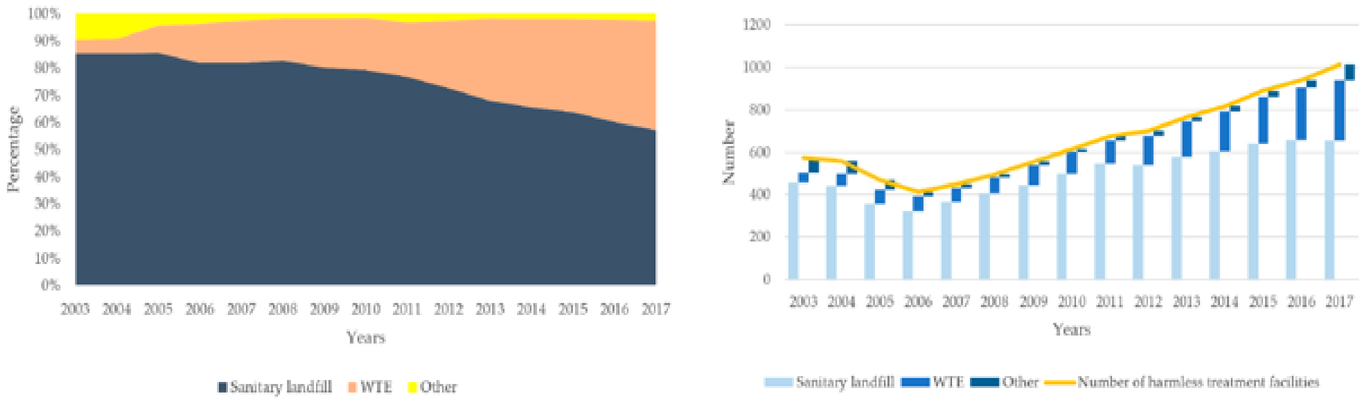

Figure 3.31: The proportion of MSW treatment in China in the past 15 years and the number of harmless treatment facilities of MSW in China in the past 15 years (Yuan et al., 2019).

In China, the main methods to treat MSW and the related treatment facilities have considerably changed (Figure 3.30 and 3.31) (Yuan et al., 2019). The percentage of MSW disposed of by sanitary landfills was reduced from 84.88% in 2003 to 57.23% in 2017. The number of sanitary landfills showed a slight increase from 457 to 654 from 2003 to 2017. However, the percentage of waste-to-energy was increased from 4.90% to 40.24% in the past 15 years. The number of incineration plants shows rapid growth from 47 to 286 in the same period 2003-2017 (China Statistical Yearbook, 2018). Compared with developed countries, Chinese MSW treatment is still at the beginning phase, primarily based on sanitary landfills. Currently, about two-thirds of Chinese cities have serious problems to dispose of MSW. Moreover, one-fourth of the cities do not have proper landfill sites, considering that MSW have occupied more than $5*10^8$ m^2 of land in China (Yuan et al., 2019). Given the current problems, it seems that WTE is the most effective method to deal with MSW in China. It is estimated that by the end of 2020, WTE capacity will account for more than 50% of the total capacity of harmless treatment. In addition, WTE will account for 60% of the total capacity in the eastern regions, allowing to achieve the "zero landfills" goal in some developed Eastern cities. From a national point of view, the Chinese government put great effort into the standardized management of WTE industry development (Yuan et al., 2019). Figure 3.32 shows the processes and the related authorities for MSW collection, transportation, and incineration (Yuan et al., 2019). The Construction Authority is responsible for managing MSW disposal facilities. Instead, the Environmental Protection Authority is responsible for the authorization of Environmental Impact Assessment (EIA), environmental monitoring, and management of the facilities (Yuan et al., 2019).

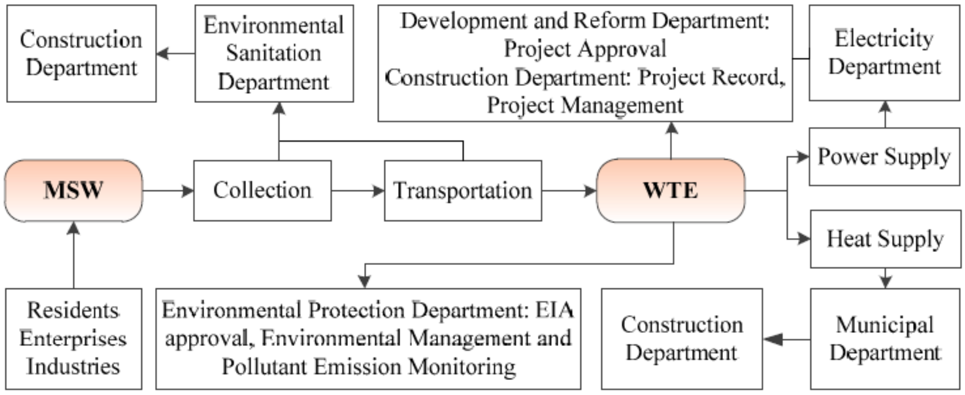

Figure 3.32: The procedure of a WTE facility and corresponding government (Yuan et al., 2019).

China, as a developing country, has a different MSW composition from developed countries due to economic level, and dietary habits. Figure 3.33 highlights a comparison of proximate analyses among regions through a ternary diagram (Lu et al., 2017). The MSW in the EU and the US is composed of more combustible matter than Asian regions because combustible matter derives mainly from paper and plastic, which can reflect their economic level.

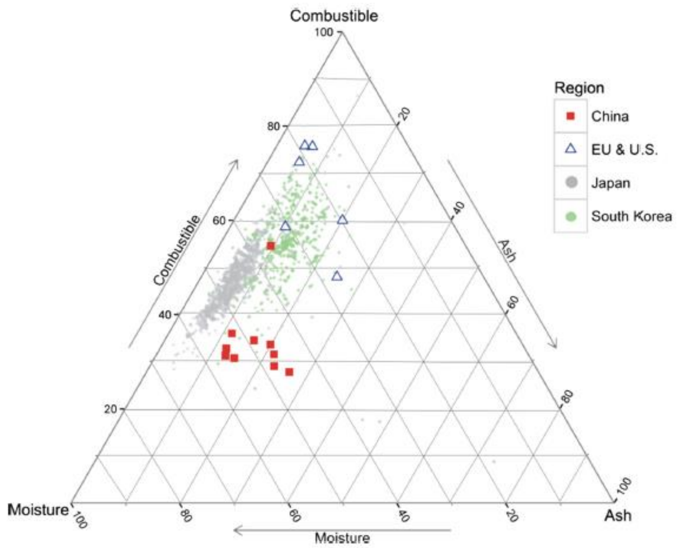

Figure 3.33: Comparison of proximate analyses among representative regions (Lu et al., 2017).

Moreover, East Asia is characterized by more moisture content in the MSW because of vegetable debris and cooking liquid are usually mixed with MSW. Unfortunately, the high moisture content in MSW generates pollutant fluctuations and combustion instability. Japan and South Korea have similar dietary habits to China, but their moisture and ash content is minor, benefiting from proper waste prevention and recycling (composting) (Lu et al., 2017). Moreover, Taiwan has almost the same Chinese dietary habits, but the combustible ratio improved from around 33% (Liu et al., 1996) to 40% (Shu et al., 2006), utilizing waste management hierarchy principles. The ternary diagram helps to find the right calorific value. Figure 3.34 shows a comparison of the lower heating value (LHV) among representative countries (Mian et al., 2017). MSW in the EU, the US, and Japan have a LHV of over 10'000 kJ/kg. The MSW Chinese LHV is the lowest among the represented countries because of its great part of moisture and ash contents more than 65%. Nevertheless, storing MSW before combustion several days, it is possible to reduce the moisture content increasing the LHV from 1500 to 3000 kJ/kg (Lu et al., 2017). Moreover, incinerating MSW with industrial waste can also increase the LHV. For example, in Dongguan City, the incineration of MSW with clothing and textile waste improved the LHV from 5000 kJ/kg to 9000 kJ/kg. The main reason for the low energy recovery is attributable to the improper composition of incineration raw materials, having a mixture of organic and inorganic MSW (Chen Y, 2009). Several studies (Zhuang et al., 2008; Xiao et al., 2007; Yuan et al., 2006; Liu et al., 2006; Solenthaler et al., 2006) shows that the lower Chinese net calorific value is caused by the high moisture content of the incineration raw materials. The Chinese MSW average calorific value in China is 5 MJ/kg (Solenthaler et al.,2006). The minimal average calorific value should be around 7 MJ/kg, and should never fall below 6 MJ/kg (Zerbock, 2003). It is needed to achieve a LHV compatible with that of developed countries to reach a proper degree of efficiency and a sustainable economic outcome of the Chinese incineration plants. However, some metropolitan Chinese cities have begun to adopt proper source-separated collection, improving the quality of the raw incineration materials. Further, in these megacities are used a high percentage of paper, plastics, and multi-laminates as incineration raw materials, which show a higher energy recovery (Mian et al., 2017).

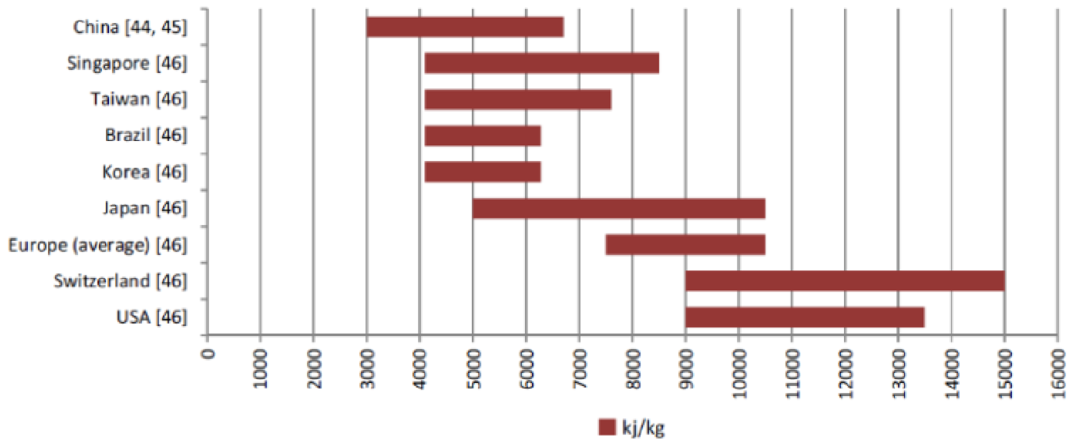

Figure 3.34: MSW incineration energy recovery in different countries (Mian et al., 2017).

Energy recovery is one of the most crucial merits of MSW incineration. The potential energy recovery corresponds with the LHV. Energy recovery consists of heat supply or power generation. New or large scale incinerators tend to generate electrical power, while incinerators in some cold areas could prefer heat supply. In addition to the LHV, electrical energy recovery efficiency depends on the temperature and pressure of the superheater of the heat recovery boiler (Lu et al., 2017). Theoretically, the higher the temperature and pressure within the superheater higher will be the efficiency of the energy recovery. In any case, the maximum temperature is limited by the performance of metallic materials. The MSW incineration plants commonly involve boilers with medium pressure (3.8-5.3 MPa) and medium temperature (e.g., 400°C) (Table 3.10) (Lu et al., 2017). In China, almost all the combustion systems involve average values of superheated steam parameters (i.e., 4.0 MPa and 400 °C), to ensure the steady and the safety of energy recovery. Nevertheless, the MSW incineration plant in Guangzhou is the first plant that employs the sub-high pressure boiler in China (i.e., 6.5 MPa and 450 °C) (Lu et al., 2017). Unfortunately, the high pressure and the high temperature make the maintenance complex. The owners of the incineration plant in China have the objective to maximize the subsidize revenue from green power generation, which has a higher price ($ 0.02-0.06 per kW h) than coal-based electrical power (Lu et al., 2017).

Region	Pressure (MPa)			Temperature (°C)			
	0.7–3.8	3.8–5.3	5.3–13.0	180–250	250–349	350–449	450–520
EU	29	58	14	11	9	73	7
Germany	16	61	23	6	6	70	18
France	59	37	3	23	19	57	2
Italy	25	62	14	5	14	74	7
Denmark	0	66	34	0	0	96	4
Netherlands	30	60	10	5	10	85	0
Sweden	50	38	13	38	3	50	9

Table 3.10: Percentage of boilers with various steam parameters in MSW incineration plants of the EU (Lu et al., 2017).

The combustion system is the principal part of an incineration plant. The leading combustion technologies consist of the movable grate and fluidized bed (Lu et al., 2017). The movable grate is compatible with the mass burning of as-received and inhomogeneous MSW, whereas fluidized bed is better for burning pretreated and homogenized MSW (World Bank, 1999). Table 3.11 highlights that the movable grate is considered a mature technology and dominates over all the other combustion systems in each country considered in the table (Lu et al., 2017). The main reasons because of the less diffusion of the fluidized bed are following reassumed (Lu et al., 2017):

- The availability of the incinerators using the movable grate is higher than those using the fluidized bed. For example, in the U.K. MSW incinerators using movable grate have the availability of 87%-92%, about 20% higher than the fluidized bed (Nixon et al., 2013);
- Pretreat MSW for the fluidized bed to meet the requirements for size, calorific value, etc., is more expensive because shredding before combustion consumes a

significant amount of energy. The operating energy consumption is higher for fluidized bed than movable grate (Nixon et al., 2013);

- The fluidized bed generates more significant quantities of fly ash, which is considered hazardous waste and requires more treatment costs.

Region	Total capacity (Mg/d)	Movable grate	Fluidized bed	Others
China (2015)	231,600	68.1	28.9	3.0
EU (2012)	203,211	87.9	4.5	7.6
Germany	51,870	93.5	0.3	6.2
France	45,161	88.1	2.5	9.4
Netherlands	18,660	94.2	0	5.8
Italy	17,561	85.6	5.3	9.1
Sweden	14,477	75.5	20.1	4.4
Denmark	10,900	88.4	0	11.6
U.S. (2014)	88,765	76.3	19.6	4.1
Japan (2013)	92,203	87.8	11.8	0.4
South Korea (2013)	13,580	86.8	5.7	7.5
Taiwan area (2006)	24,650	100.0	0	0

Table 3.11: Capacity percentages of different incinerator types in representative regions (Lu et al., 2017).

In China, the movable grate is the most common combustion system dominating the other combustion technologies. The movable grate technology is mostly imported from developed countries such as Germany, Danmark, Switzerland, and Belgium, and it is mainly used in the developed cities of China (Lu et al., 2017). In a research made by Tien et al. (2012) in Cina, it is noted that 64% of plants using movable grate have imported the related technology. The main technologies of imported movable grate used in China include Martin, Von Roll, Volund, and Seghers. Nevertheless, China has the highest fluidized bed capacity in the world, and the main reason is that decision-makers wanted to apply home boiler technologies for the sake of lower costs. Indeed, the fluidized bed using domestic technologies allows lower capital investments and operating costs (Lu et al., 2017). Moreover, this type of combustion system allows the co-firing of MSW with coal, which is abundant in China. About 80% of incinerator plants using fluidized beds were established from 2001 to 2005, and they apply home technologies (Chen and Christensen, 2010), and the investment of fluidized bed is just 70% of that one of the movable grate (Chen and Christensen, 2010). Another reason is that some provinces such as Shanxi, Shaanxi, Ningxia, and Jilin have enough coals to support the MSW combustion with relatively low LHV. Generally, incinerator plants using fluidized bed technologies are mainly located in the Eastern medium-scale cities and the Central and West regions of China (Tian et al., 2012). Unfortunately, MSW incinerator plants using fluidized beds did not perform well in China because of various reasons. Using fluidized beds needs the right MSW pretreatment, such as MSW sorting and shredding before combustion, and very few incinerators using a fluidized bed can execute these pretreatments well (sorting increases the costs and make the operation complex) (Lu et al., 2017). This ineffective tends to cause heterogeneous combustion, which generates more pollutants (the fluidized bed is a technology suitable with homogeneous combustion). Some eastern cities of China, such as Ningbo, Dongguan, Taixing, have dismantled their MSW incineration plants using a fluidized bed because of the environmental burden of that technologies with heterogeneous combustion (Lu et al., 2017). Moreover, the authority recommends the available time of a MSW incinerator plant should be greater than 8000 h per year (China MOHURD, 2010), but it is difficult for fluidized beds to meet this requirement. The ratio of fluidized beds under construction is just 10%, while the ratio of them in operation is close to 30%. Further, there are a few numbers of incinerators using other technologies in China. In the Dongguan City of South China, there is a plant using a rotary kiln. This plant has a treatment capacity of 900 Mg/d and has three lines, and each of them uses a home rotary kiln technology (Lu et al., 2017). Nevertheless, this plant will be closed as soon as some new alternative technologies are put into operation because it does not have an excellent performance. Guizhou, a province in the West China region, planned to construct 47 incinerator plants using cement kiln (Guizhou Province, 2013). Finally, decision-makers should select a fittable combustion system by comprehensive assessments, and not just by costs. The experiences in the past decades and the localization of incineration technologies could help decision-makers to make the right decisions in the future. Figure 3.35 highlights the different treatment capacity and the capacity percentage of MSW combustion technologies for each Chinese city (Lu et al., 2017).

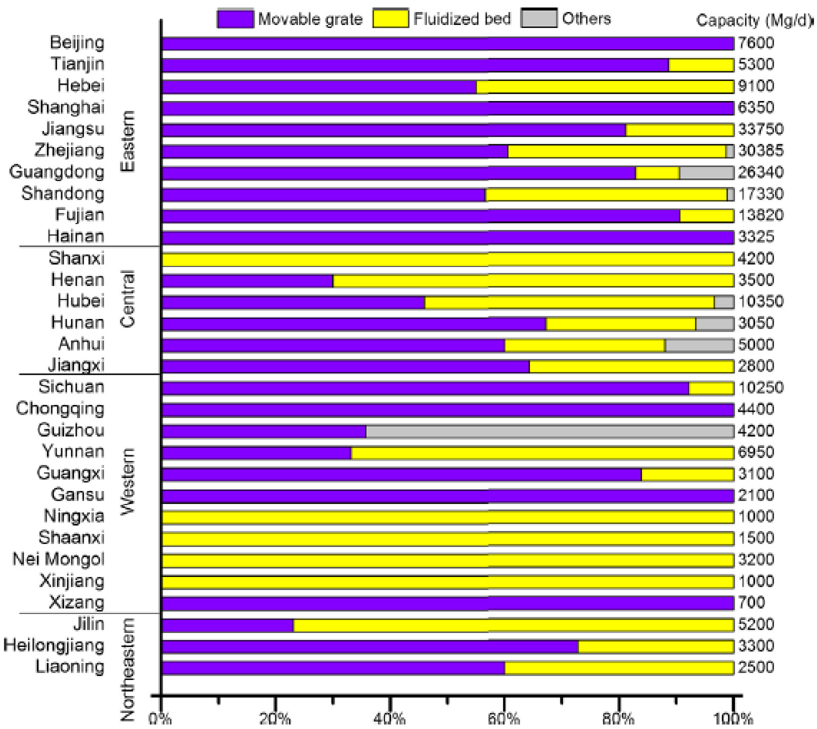

Figure 3.35: Capacity percentages of MSW combustion technologies in China in 2015 (Lu et al., 2017).

Table 3.12 shows the emission limits of MSW incineration in China (old standard and current standard) and a comparison of the limits in different representative regions, such as EU, U.S., Japan, and South Korea (Lu et al., 2017). To ensure a proper comparison, all the emissions limits for each representative region have been converted to the European equivalent (which is on a dry basis and referenced to 11%oxygen content, 0°C, and 101.3

kPa) (Lu et al., 2017). The MSW incineration in China has a significant environmental burden, suffering substandard emissions in most of the Chinese incineration plants. Several studies investigated the emissions performance of the MSW incineration industries, studying the PCDD/Fs emissions from 15 less than 50 Mg/d Chinese incineration plants. He found that about half of the results exceeded 1.0 ng I-TEQ/Nm^3 (i.e., the limit value of China's old standard). Ni et al. (2009) examined the PCDD/Fs emissions from 19 incinerators in the range of 150-500Mg/d, discovering that 16% of the results overcame 1.0 ng I-TEQ/Nm^3 and 68% of the results surpassed 0.1 ng I-TEQ/Nm^3. Hai et al. (2015) explored the PCDD/Fs emissions from 26 MSW incineration plants and got 82 observations from 2008 to 2012. 15% of the results surpassed 1.0 ng I-TEQ/Nm^3, and 55% of them exceeded 0.1 ng I-TEQ/Nm^3. Moreover, more than 50% discharged substandard emissions according to the supervisory monitoring data of 40 MSW incineration plants (Wuhu Ecology Center and Friends of Nature, 2016). These researches highlight that a significant fraction of Chinese MSW incineration plants is substandard from an emission point of view. Closing all the substandard plants is almost impossible because without them, the capacity of harmless treatment will dramatically decrease, and it will be not sufficient for Chinese needings (Lu et al., 2017). China promotes incineration to eliminate the improper disposal problem, which causes more serious pollution than the current MSW incinerators. Ameliorating the MSW incineration plants with a more restrictive standard can be a better option. China's new emission standard, which was fully implemented in 2016 (China MEP, 2014), established a much more restrictive emission limit threshold than its old version. Chinese limit value of PCDD/Fs is equal to the EU threshold emission standard. While, in China, other indices such as NOx and PCDD/Fs are more restrictive than the U.S. standards (Lu et al., 2017).

Region	Dust	CO	SO_2	HCl	NOx	Cd + Tl	Hg	Pb + Sb + As + Cr + Co + Cu + Mn + Ni + V	PCDD/Fs ng I-TEQ/Nm^3
	mg/Nm^3	mg/Nm^3	mg/Nm^3	mg/Nm^3	mg/Nm^3	mg/Nm^3	mg/Nm^3	mg/Nm^3	
China's current standard (China MEP, 2014)									
Daily ave.	20	80	80	50	250	–	–	–	–
Hourly ave.	30	100	100	60	300	–	–	–	–
Measured ave.	–	–	–	–	–	0.1	0.05	1.0	0.1
China's old standard, which has been completely replaced by China MEP (2014) from 2016									
Hourly ave.	–	150	260	75	400	–	–	–	–
Measured ave.	80	–	–	–	–	0.1	0.2	1.6	1.0
EU (European Union, 2010)									
Daily ave.	10	50	50	10	200 400[a]	–	–	–	–
Half-hourly ave.	30	100	200	60	400	–	–	–	–
Measured ave.	–	–	–	–	–	0.05	0.05	0.5	0.1
U.S.[b] (US EPA, 1995, 2006)									
Existing & Large	19.1	89	60	32.5	270	0.027	0.038	0.305	≈0.6(ESP) ≈0.5(FF)
Existing & Small	53.5	89	162.6	280	No limit	0.076	0.061	1.223	≈2.0
New & Large	15.3	89	61	28	219	0.008	0.038	0.107	≈0.2
New & Small	18.3	89	61	28	No limit	0.015	0.061	0.153	≈0.2
Japan (Japan MOE, 2006)									
Relatively large scale incinerator[c]	44.4	38.2	Varies	777.7	522.6	–	–	–	–
South Korea (Seo, 2013)									
	20	57.3	78.5	29.9	131.7	–	–	–	0.1

Notes: The emission limits of each region are all converted to the European equivalent, which is on a dry basis and referenced to 11% oxygen content, 0 °C, and 101.3 kPa.
[a] Exsiting incinerators of less than 6 Mg/h.
[b] In the U.S., large scale refers to larger than 225 Mg/d, while small scale refer to larger than 35 Mg/d.
[c] In Japan, relatively large scale refers to larger than 4 Mg/h or discharging more than 40,000 Nm^3/h of flue gas.

Table 3.12: Emission comparison of MSW incineration in representative regions (Lu et al., 2017).

The Chinese government released three environmental standards related to the air pollutant emissions of waste-to-energy plants (Table 3.13) (Lu et al., 2017). The limits are becoming more severe with the technological innovation of the waste-to-energy and pollution control. For instance, compared with HJT18-1996, the maximal emission concentration of particulate matter (PM), NOX, SO2, and HCl in GB 18485-2014 decreased by 70%, 40%, 66.7%, and 88%, respectively. The emission concentration of Hg and its mixes, Pd, and others, and PCDDs also decreased by 75%, 37.5%, and 90% in the latest environmental standard (Lu et al., 2017). Most environmental indicators for WTE in China are now aligned with international requirements.

Pollutants	Unit	Small Incinerator Pollutant Emission Standard	Domestic Waste Incineration Pollution Control Standard	Domestic Waste Incineration Pollution Control Standard
		HJT18-1996	GB18485-2001	GB18485-2014 (Effective)
PM/soot	mg/m^3	100 (mean value)	80 (mean value)	30 (hourly mean)
NOX	mg/m^3, hourly mean	500	400	300
SO2	mg/m^3, hourly mean	300	260	100
HCl	mg/m^3, hourly mean	500	75	60
Hg and its compounds	mg/m^3, mean value	\	0.2	0.05
Cd + Ti	mg/m^3, mean value	\	0.1	0.1
Pd and others	mg/m^3, mean value	\	1.6	1.0
PCDDs	mg/m^3, mean value	\	1.0	0.1
CO	mg/m^3, hourly mean	1000	150	100

Note: Domestic waste incineration pollution control standard GWKB 3-2000 is the revision of Small Incinerator Pollutant Emission Standard HJT18-1996, but it was replaced by Domestic waste incineration pollution control standard GB18485-2001 one year later. These two standards have the same contents. The later one is displayed in this table.

Table 3.13: Standard pollutants emission limits for different periods in China (Yuan et al., 2019).

In addition, the ineffective Chinese managing of MSW incinerator is responsible for MSW incineration fly ashes problems due to the contamination of the MSW raw materials with dioxin, furan, and heavy metals (Zhao, 2010). In China, fly ashes are classified as hazardous waste (Tian, 2012), and over 3000 tons/day of them are generated from MSW incineration activities (Cheng 2010). In a previous study made by Zhou (2015), the general Hg concentrations in fly ash were investigated in 15 Chinese cities, discovering that it ranged from 1 to 24 mg kg^{-1}, whereas the 47% are 0-5 mg kg^{-1} with an overall average of 10 mg kg^{-1}. Nevertheless, the resulting range is lower than Taiwan and Japanese fly ash (Zhou, 2015). On the other hand, Pan et al. (2013) declare after studying 15 MSW incineration plants in China that 67 % of plants leached Cd surpassing their regulatory threshold, whereas the additional amount of Zn and Pb leaching can be observed in 40 and 53 % plants, correspondingly. The intensities of Zn, Pb, Cu, Cr, Cd, and Ni in the studying were found to be greater than Japanese fly ash but lower than Taiwan fly ash. Chinese MSW incineration fly ash is disposed into the landfill or reused for construction in some cities (e.g., Chongqing, Shenzhen). The solidification/stabilization, separation process, and thermal treatment are often used for fly ash treatments (Karagiannidis, 2013). The most used fly ash treatment by China operators is the solidification process. Unfortunately, this type of treatment requires a great amount of cement and land resources to increase the volume and weight of fly ash. Further, this treatment generates a slow release of heavy metals during the wet season, which makes it hazardous to the environment (Yang et al., 1996; Andac et al., 1998; Alba et al., 2001). The physical/chemical separation and thermal treatment are also used for managing fly ash. The thermal treatment is expensive and have environmental burden due to volatilization of heavy metals during gravitating, and melting process (Sakai, 2000; Kuo, 2004; Wei, 2006), Physical/chemical process achieve limited success in terms of heavy metal extraction from fly ash (Hong, 1996; Katsuura, 1996).

3.9 Food Waste Management

Food waste is a crucial problem in MSW management, which has direct economic, environmental, and social impacts (Dahiya et al., 2017; Stenmarck et al., 2016). The Circular Economy has been introduced in China to reduce, reuse, and recycle Food Waste (FW) (Dodick and Kauffman, 2017). China is still considered an agricultural country with a population of about 1.4 billion people. Considering that the most MSW is composed of organic matter (food waste), the food throwing away annually worth over 200 billion Yuan (Li et al., 2018). Moreover, population and economic development growth result in the rising generation of FW (Li et al., 2016; Zhang et al., 2014). Currently, the main problem related to FW are odors and greenhouse gas (GHG) emissions (Cerda et al., 2018), which are considered the main obstacles to the sustainable development of the food production system (Thi et al., 2015). In addition, it is required timely and effective management of FW in order to keep the energy contents and minimize the environmental impacts associated with FW (Salihoglu et al., 2018). The recent Chinese economic development growth and the environmental consciousness increasing by the government and the citizens have led to the fast development of FW treatment capacity. Indeed, between 2011 and 2015, 100 pilot projects were established to ameliorate FW resource recovery (Li et al., 2018). In China, the main FW treatments are anaerobic digestion (AD), composting, and animal feeding. Unfortunately, there is still a great gap between treatment capacity and the generation of FW. However, the FW generated in different regions or seasons varies in terms of total solids (TS), volatile solids (VS), crude protein (CP), Carbohydrate (CA), and ether extract (EE) compositions (Galanakis, 2015). The composition differences among regions of FW and the high generation level have made of FW problem a great challenge in China. The fast treatment capacity construction during the 12th plan has been terminated, while the 13th plan has recently been issued (2016-2020) (Li et al., 2018). Within the 12th plan, it has been built 242 FW treatment facilities in 31 provinces of Mainland China. By the end of 2016, the total FW treatment capacity reached 30'220 tons per day for a special fund of 10.90 billion Yuan authorized by the government. FW treatment facilities are frequently built in more economically developed regions, such as the Eastern region (Li et al., 2018). Indeed, Eastern China, with the highest GDP and population density, has the highest FW treatment capacity (15'220 tons per day) and facilities number (98). The average capacity of the facilities is highest in Eastern China (155 tons per day), followed by Northeast China (144 tons per day), and Central China (86 tons per day) (Li et al., 2018). Instead, according to the 13th five-year plan (2016-2020), the Chinese government has been providing a special fund amount to 18.35 billion Yuan, in implementing new processing capacity of 34'400 tons per day. After the implementation of the designed capacity, the Chinese FW treatment capacity will reach 64'620 tons per day. It could be reached an increase of 64-128% of the total designed treatment capacity by the end of 2020 compared with the value at the end of 2015 (Li et al., 2018). The main treatment methods preferred by the 13th plan are the following: anaerobic digestion (AD), composting, and animal feeding. Moreover, to ameliorate the efficiency of the FW treatment, it is needed to conduct proper MSW sorting activities to improve the quality, and the quantity of the FW collected (Li et al., 2018). Currently, FW is still mostly mixed with other fraction of MSW in China, especially because of the inadequate source classification system. In 2015, an estimated 56.57 million tons of FW was generated in China, ranging from 40 to 90 million tons reported in the literature (De Clercq et al., 2016; Zhang et al., 2014). Figure 3.36 shows the estimated value of the FW generation by regions. Eastern China produced the largest portion of the FW generated in 2015 (43.18%), followed by Western and Central China (Li et al., 2018). In addition, only 8% of the FW generated in 2015 was produced by Northeast China. Considering the FW generation estimation in 2015, if it will be no variations in the FW generation pattern, it could be treated about 40% of FW generated by the end of 2020 (Li et al, 2018).

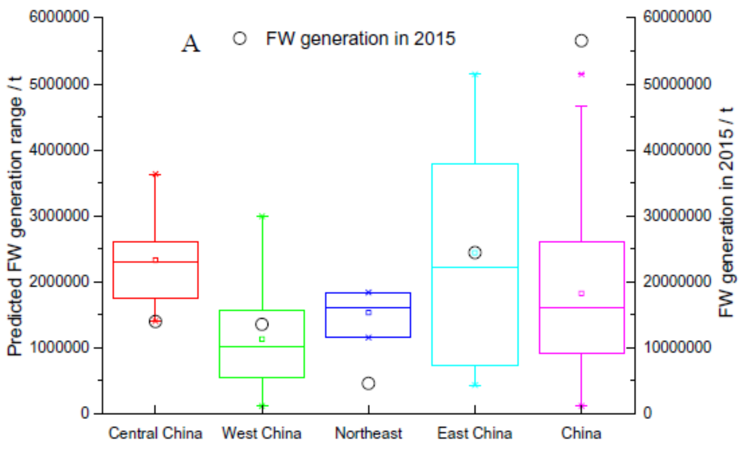

Figure 3.36: FW generation in four regions of China in 2015 (Li et al., 2018).

The pretreatments are utilized to separate non-biological impurities (e.g., bones, plastics, and metals) from FW and ameliorate the FW stabilization by promoting the biodegradative properties (e.g., thermal pretreatment) (Li et al., 2016). In many developed countries (e.g., Germany), FW sorting is required. Although MSW source-separated system has been introduced in some cities, such as Beijing and Hangzhou, the MSW classification is not well-implemented in China (Zhang et al., 2010). Indeed, FW is often mixed with other non-biodegradable MSW fractions in the Chinese MSW management system. In the future, an important step to ameliorate the overall MSW management system should be to improve the source separation quality to reduce the impurities in FW. The not-well established MSW classification makes the recycling and the reuse of FW ineffective in China. Currently, most of the Chinese MSW generated is disposed of by landfills or incinerators (Zhang et al., 2010). Unfortunately, due to the high moisture and organic content of FW, neither landfilling nor incinerator are environmentally and economically efficient method (Kalia, 2016). After pretreatment steps, the primary FW applied processes are anaerobic digestion, composting, and animal feeding. Figure 3.37 shows the current state of FW treatment and the number of facilities and shows the number of FW treatment facilities with different capacities using AD in China (Li et al., 2018).

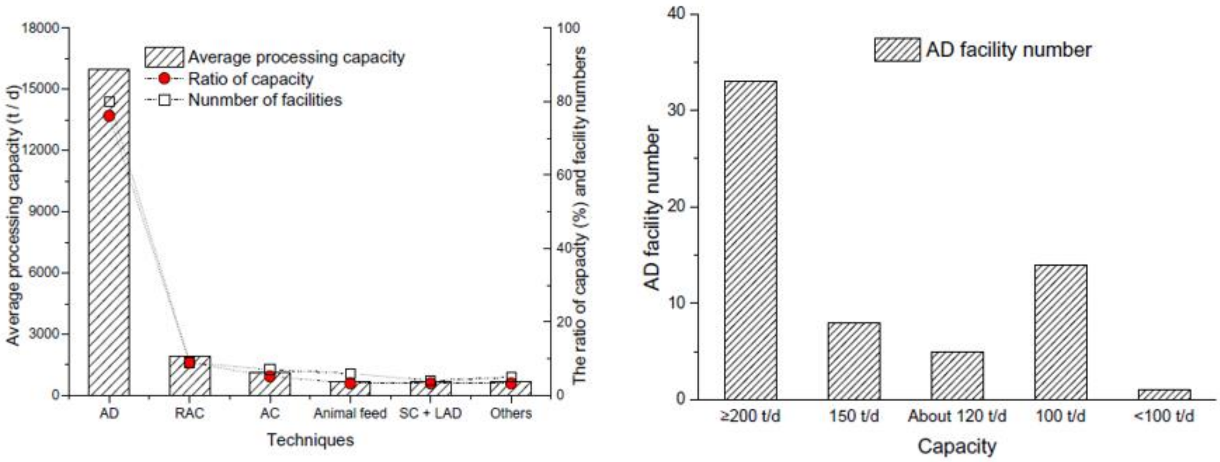

Figure 3.37: State of FW treatment with different technical routes, including current capacity and numbers of facilities [SC+LAD: solid-phase FW composting with liquid phase anaerobic digestion] (Li et al., 2018).

The anaerobic digestion has been broadly applied in the EU and some Asian countries since 2006 (Ma et al., 2011). The most common treatment method in China is anaerobic digestion in terms of the number of facilities and treatment capacity (Figure 3.37) (Li et al., 2018). Indeed, anaerobic digestion accounted for 76.1% of all biological treatment capacities (as of September 2015) (Wei et al., 2016). 54.1% of the anaerobic digestion facilities had a capacity greater than 200 tons per day, whereas only 1.6% had a treatment capacity lower than 100 tons per day. The main output of anaerobic digestion is the biogas, and it is typically utilized to produce energy through several conversion systems (e.g., heat, transportation fuels, or electrical) after removing impurities (e.g., hydrogen sulfide, ammonia, and siloxanes) (Abbasi et al., 2012). It was calculated that 847 kWh of bioenergy could be achieved if one ton of FW was treated in China (Dung et al., 2014). If 16’150 tons of FW was treated by anaerobic digestion in China, it could be generated about 14 GWh. However, currently, in China, biogas is mainly used to produce heat, but there is no financial support applied to AD (Li et al., 2018). Moreover, FW is compatible with composting (or aerobic digestion) because of its high organic matter content. Composting can be utilized as a fertilizer, applied to the soil to ameliorate carbon storage capacity, and reduce GHG emission (Cerda et al., 2018). Recently, FW composting has caught significant attention in China, considering its capacity to divert poor quality or inadequately separated FW to anaerobic digestion. Also, FW can be used as an animal feed due to its great energy content (e.g., carbohydrates, lipids, and proteins) (Lin et al., 2011). Currently, there exist several treatments to convert FW to an animal feed, such as boiling to produce a feed, producing a dry feed by dehydration, drying, disinfection, and crushing in sequence; and biological treatment (Chen et al., 2014). As Figure 3.37 showed, there are just six animal feed treatment facilities with a capacity of 700 tons per day, and they represent only 3.24% of total treatment capacity in China. The rate is lower than those of Japan and Shout Korea, accounting respectively 35.9% and 42.5% (Salemdeeb et al., 2017). In China, by the end of 2020, FW treatment capacity could reach 64’620 tons per day, treating for 40% of the FW generated annually. No specific guidelines or regulations exist in China about FW management. Pretreatment of the FW is crucial to eliminate impurities and to ensure a good efficiency of the FW treatments (especially for Anaerobic Digestion). Moreover, anaerobic digestion and composting are the main treatment utilized in China to recycle FW (Li et al., 2018). In Eastern China were achieved more significant FW generation and treatment capacity along with higher GDP and population. To ameliorate the FW treatment efficiency, it is recommended to improve source separation, pretreatments quality, and more legislation, and end product utilization is proposed (Li et al., 2018).

3.10 Municipal Solid Waste management systems comparison

The 3R's approach and the hierarchy of MSW management are the same internationally (Mian et al., 2017), reduced/source reduction, reuse, recycle/composting, recovery/energy from waste, and finally disposal/landfill. The current status of MSW management methods differs from country to country (Mian et al., 2017). Figure 3.38 represents the situation of the MSW management status in China and other developed and developing countries in 2017 (Mian et al., 2017). Unfortunately, reduce and reuse of the MSWM hierarchy are not considered in the diagram because of the lack of information regarding the individual or overall reuse, and a specific year waste reduction. The leader countries in recycling/composting are Germany and Korea, and they have been able to achieve respectively 62% and 61% waste recycling (Mian et al., 2017). The diagram highlights that developed countries have a higher MSW recycling rate, consequently it has a positive effect on MSW generation reduction. Norway, Denmark, and Japan have the highest incineration rates, 50%, 54%, and 79%, respectively (Mian et al., 2017). Their advanced technologies and incineration plants are considered as environmentally friendly. Japan is one of the leading nations for MSW incineration. The USA and China have the highest landfilling rates, respectively 53.8% and 57.23%. Unfortunately, there are still developing countries with a large portion of open and illegal waste dumping, such as Bangladesh and Thailand. Also, in China, there is still a small portion of open dumping or untreated discharging. In 2014, in China, there was a collected waste rate of 91.8% (Mian et al., 2017). However, the percentage of collected and treated has been increasing day by day. Moreover, in China, MSW incineration has become the priority, but it is required to consider the effects on the environment and use advanced incineration plants with no environmental pollution, ensuring economic feedback. Because of the informal sector, recycling is not clearly identified in China. Chinese MSW management has to focus on higher waste recycling to reduce the load on waste generation and disposal. It should be helpful to implement a better household taxation regime to decrease the generation of waste in China (Mian et al., 2017). In China, MSW management tax is a flat rate charging system; for example, in Chongqing's, the MSW disposal fee per household is 3 RMB/month ($0.4/month) (Yuan et al., 2006). In Beijing, the city disposal fee is 2-3 RMB/month concerning the residency status. In Guangzhou, the monthly MSW collection fee is 10 RMB/household. Instead, in other provinces, residents do not have to pay any MSW disposal tax. Previous research discovered that the construction cost of the MSW disposal facility in Beijing was far higher than the collected fees (Xiao et al., 2007). Because of the fix fee system, the taxation does not affect the MSW recycling in china; the residents pay the same charge for any generated amount of MSW disposal. The leading countries in MSW recycling have adopted a volume base or weight base taxation system (Mian et al., 2017). In China, volume or weight taxation base could persuade people to decrease their MSW generation and disposal and increase waste recycling. It could be a good practice to offer less taxation to separate MSW in biological and non-biological. Mian et al. (2017)

declare that imposing a proper taxation system for MSW disposal could improve MSW recycling and provide economic feedback for management.

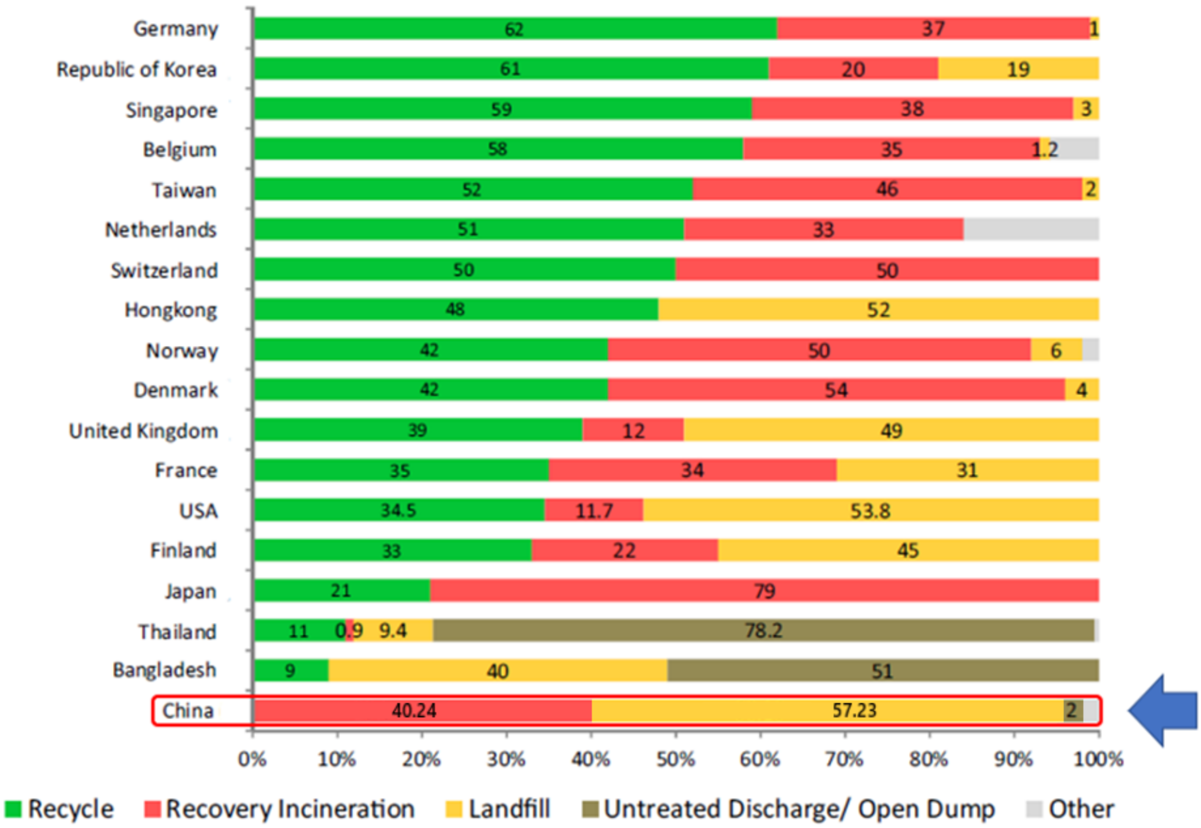

Figure 3.38: MSW management hierarchy in different countries (Mian et al., 2017).

3.11 Conclusion on the Municipal Solid Waste Management of China

The Chinese MSW management system has some significant limitations, such as an ineffective MSW source-separated collection system, low incineration energy recovery caused by MSW composition and the related emissions and fly ashes, ineffective management of landfilling leachate, emissions and location sites, formal against the informal recycling system, and the absence of valid MSW disposal tax. China is the first MSW generator in the world, but because of its boundary conditions, simply taken best MSW practices from developed countries is not enough. After the assessment of the Chinese MSW management system will be represented recommendations to ameliorate the current status and reduce the damages of the previously cited limitations. First of all, accordingly to the waste hierarchy, it should be reduced waste generation. Chinese people should generate less waste by consuming fewer products and maximizing the reuse of waste resources. It is fundamental a Chinese mindset changing, and the awareness of the people about the environmental themes should be improved to reach this objective. Moreover, Extended Producer Responsibility has a crucial role in MSW source reduction. However, the Central Government has the leading role in promote waste reduction, and it should address the problem by the adoption of more effective policies and taxation regimes. Indeed, effective taxation in China is not available. It is required to change the low and flat taxation system to improve the effectiveness of Chinese MSW management. Implementing a volume or weight base disposal charge could encourage people to increase recycling and the reuse of their waste (reducing the waste generation). As a general rule, different taxation should be implemented for each municipality related to the economic condition of the households and the quality of disposal facilities of the respective municipality. The current tax regime does not permit to cover the cost of MSW collection or disposal. Moreover, improve the formal recycling sector is fundamental to a sustainable MSW management system. Also, through recycling, it is possible to reduce the MSW generation; indeed, the leading MSW management countries are prioritized on MSW recycling. It is required to recycle all types of recyclable waste and increase waste recycling industries to ameliorate the MSW recycling rate in China. The MSW source-separated collection should be taken under Municipal Government responsibility in the formal MSW management system because it can affect the entire MSW management process. MSW source-separated collection is one of the first important steps to reach an effective formal recycling system. From the pilot program in 2000, several improvements in MSW source-separated collection have been made, but the recycling level is still far from being considered effective and comparable with the developed countries. Nowadays, around 90 Chinese cities are encouraged to classify waste, but the soundness of the formal recycling system is still low. It is not possible to simply copy the experience of the developed countries in recycling mainly because of different Chinese boundary conditions. In China the main barriers to formal recycling improving are caused by the informal recycling sector, the absence of a stable recycling market, and a lack of people awareness in the MSW classification. Integration through innovative collection technologies, financial innovation as Public-Private Partnership and tax exemption for recycling industries, and ameliorating the accessibility to resource recovery facilities and authorities support to ensure people awareness (respectively), have been proposed as solutions to improve the current situation of the formal recycling system and remove the previously cited barriers. Landfilling is still the most utilized MSW treatment, but in the last decades, the WTE (incineration) treatment capacity has been improved, and it is gradually replacing landfilling. The WTE capacity growth was largely supported by the governments by national support, BOT contracts, Price and tax exemption policies. The existing *"put-or-pay"* agreements between authorities and incineration plants should be changed because they do not discourage MSW generation. The most of incineration plants have sub-standard emissions, but through the adoption of the last new emission standard in which China aligned with EU standards, it is projected an ameliorating. In addition, the Chinese Energy recovery is low (it was the lower among the other considered countries) mainly because of the significant part of moisture and organic contents. It should be ameliorated the quality of the MSW source-separated collection to decrease the percentage of organic matter in incineration plants and, raw waste materials should be better prepared, ensuring low moisture and ash, and improve the combustible ratio to improve energy recovery. Chinese MSW landfills need to be ameliorated, making them safer and ensuring a complete sanitary landfilling. Chinese MSW landfills should separate organic materials from landfills to stop leaching, odor, and other environmental disturbance like the European landfilling strategy. Moreover, before selecting a landfill site, it should be considered the landfill costs and burdens on the health and environment. Notably, it should be calculated the present and future value of the site, transfer, maintenance, infrastructure, and other costs, short-term and long-term impacts on the environment, and the lifetime of the landfill. Finally, to ameliorate the FW treatment efficiency, it is recommended to improve source separation, pretreatments quality, and more legislation, and end product utilization is proposed

4 Shanghai Case Study

4.1 Shanghai characterization

Shanghai is located on the East China Sea coast in the proximity of the estuary of the Yangtze River, and the Huangpu River flows through the city. Shanghai city has a population of 24.2 million as of 2018, and it is the most populated city in the world (Statistical Communiqué of Shanghai, 2018). Nowadays, about 157’900, Shanghai’s citizens are foreigners (Shanghai Municipal Statistics Bureau, 2019), and the city is also a domestic immigration target, about 40.3% (9.8 million) of the city’s residents are from other Chinese regions (Statistical Communiqué of Shanghai, 2018). In addition, Shanghai's metropolitan area has an estimated population of 34 million (Statistical Communiqué of Shanghai, 2018). Shanghai is considered a global center for finance, innovation, and the Port of Shanghai is the world’s busiest container port. The city is regarded as the *“showpiece”* of the enormous Chinese economic growth. The main reason behind the global aspect of Shanghai city is the economic reforms issued by Deng Xiaoping in the 1990s, resulting in a substantial redevelopment of the city. Particularly the Pudong district, encouraging finance and foreign investment to the city. Consequently, the city has become a hub for international trade and finance, hosting the Shanghai Stock Exchange and the Shanghai Free-Trade Zone. Shanghai, together with Beijing, Chongqing, and Tianjin, is one of the four Chinese municipalities under the direct control of the Government of the People’s Republic of China (Central Government). The city is administratively considered as a province, and it is divided into 16 county-level districts. Figure 4.1 shows the geographical composition, whereas Table 4.1 shows the population amount of each district..

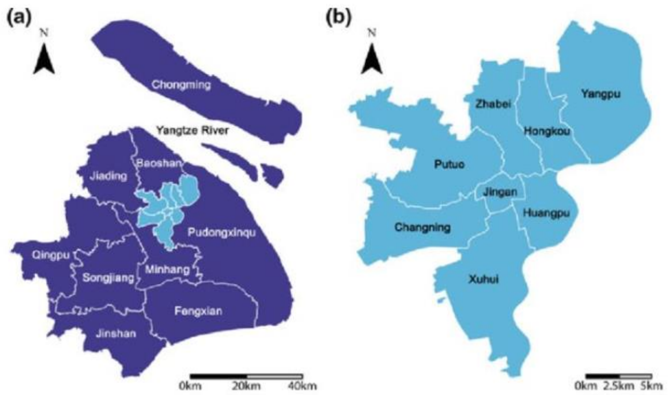

Figure 4.1: Administrative divisions of Shanghai (Statistical Communiqué of Shanghai, 2018).

District	Area [km²]	District population 2017	Population density [Population/Km²]
Huangpu	20.46	654,800	32,004
Xuhui	54.76	1,088,300	19,874
Changning	38.3	693,700	18,112
Jing'an	36.88	1,066,200	28,910
Putuo	54.83	1,284,700	23,431
Hongkou	23.46	799,000	34,058
Yangpu	60.73	1,313,400	21,627
Minhang	370.75	2,534,300	6,836
Baoshan	270.99	2,030,800	7,494
Jiading	464.2	1,581,800	3,408
Pudong	1210.41	5,528,400	4,567
Jinshan	586.05	801,400	1,367
Songjiang	605.64	1,751,300	2,892
Qingpu	670.14	1,205,300	1,799
Fengxian	687.39	1,155,300	1,681
Chongming	1185.49	694,600	586

Table 4.1: District population density (Shanghai Municipal Statistics Bureau, 2019).

Even though every district has its urban core, the city hall and major administrative units are located in the Huangpu District and near to the famous Nanjing Road. Other important Shanghai's areas are Xintiandi, Huaihai Road, and Xujiahui. Most of the universities are located in Yangpu District (Tongji University) and Putuo District. In 2018, Shanghai had a GDP of 3.27 trillion yuan (494 billion dollars), and it accounts for 3.63% of China's GDP. Shanghai's GDP per capita was 135'212 yuan (20'425 dollars). Finally, Shanghai's resident average annual disposable income was 64'183 yuan (9695 dollars) per capita, making the city the wealthiest one in China, but even the most expensive city in Mainland China (Economist Intelligence Unit, 2017). Table 4.2 highlights the previous information and how they have changed over time.

Year	GDP [Trillion Yuan]	Per capita GDP [1000 Yuan]	Per capita disposable income	GDP Annual growth rate
2018	3.27	135	64,183	6.60%
2017	3.06	124.6	58,988	6.90%
2016	2.82	113.73	54,305	6.80%
2015	2.57	103.8	49,867	7%
2014	2.41	97.37	47,710	7.10%
2013	2.23	90.99	43,851	7.80%

Table 4.2: Shanghai's GDP (Economist Intelligence Unit, 2017).

From 1949 to 2010, Shanghai experienced rapid industrialization and urbanization growth, changing its population pattern profoundly. Shanghai city population increased from 5.03 million people in 1949 to 14.12 million people in 2010, along with 8.98 million floating people (i.e., people who reside in Shanghai for a certain amount of time but are not considered part of the official census) (Statistical Communiqué of Shanghai, 2018). In Shanghai, during the period 1970-2010, population density has significantly increased from 1734 people per km^2 to 3632 people per km^2, with an average increasing rate of 419 people per km^2 per decade. Figure 4.2 shows Shanghai's population over time, from 1980 to 2035. It is expected that Shanghai's population will reach 34.34 million people by 2035.

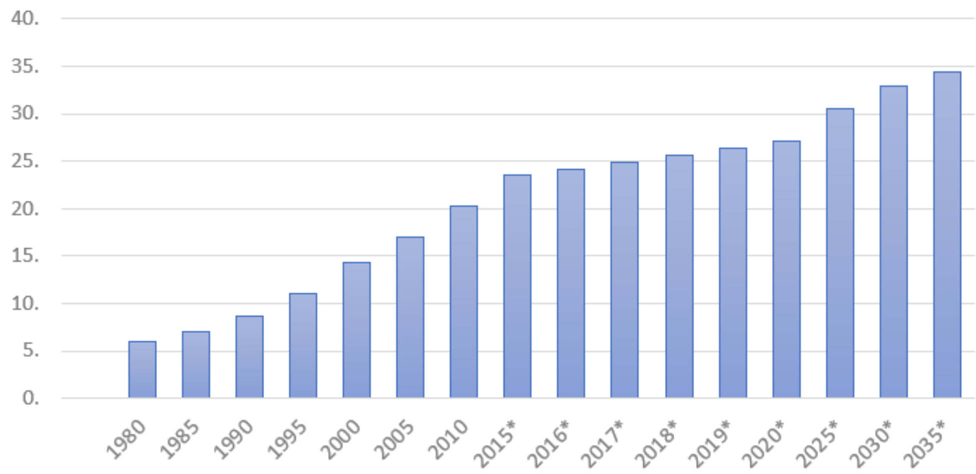

Figure 4.2: Population of Shanghai metropolitan area in China 1980-2035 China: population of Shanghai from 1980 to 2035 (in millions) (Statistical Communiqué of Shanghai, 2018).

4.2 Generation & Collection

Currently, Shanghai generates an amount of MSW close to 9 million tons per year, and this amount is gradually increasing, accounting for around 2% of the total amount of the country (MEE, 2019). According to data released by the environmental protection department (2019), about 25'800 tons of dry and wet MSW are generated in Shanghai every day. In 2017, the annual growth rate of MSW generation was 3.1%, and the average growth rate from 2015 to 2016 was close to 7% (influenced by emerging consumption such as online shopping and takeout, the generation of waste packaging increased hugely). Figure 4.3 shows the generation and growth of MSW in Shanghai overtime.

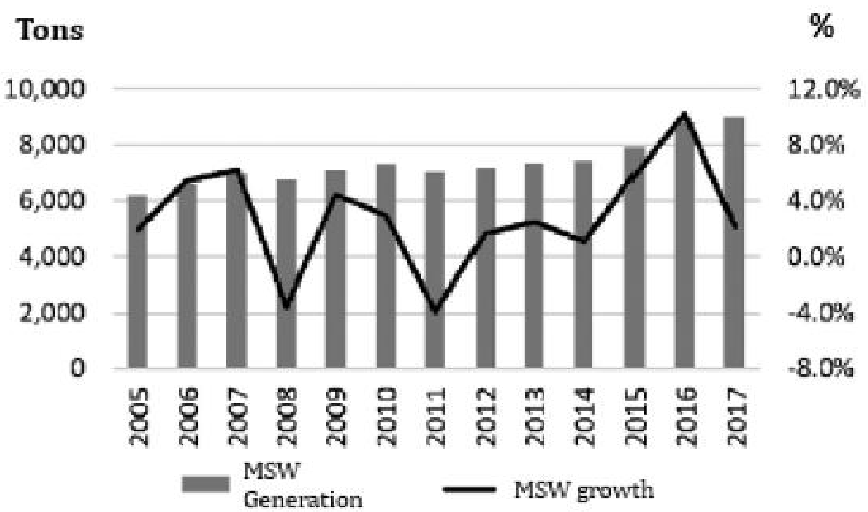

Figure 4.3: MSW generation and annual growth (MEE, 2019).

It is fundamental to avoid environmental, social, and health problems being able to manage the massive quantity of MSW generated by Shanghai city. The Shanghai formal sector is an associate government system, in which contracts for each district are won by MSW management providers (Fan et al., 2019). The MSW collection company has the crucial responsibility to collect and transport the garbage from all the city corners to the MSW treatment facilities. How to collect and transport the MSW is essential to guarantee a *"clean, tidy, and orderly"* urban environment. Nowadays, the Shanghai collection rate is around 100%, but in the suburbs, there are still many temporary open garbage dumps, highlighting that the MSW collection service has not yet been well implemented in the suburbia. Table 4.3 shows the number of collection points of each district from 2012 and 2015, whereas Figure 4.4 represents the district coverage rate of MSW in 2015 (NDRC & MHUD, 2019). Shanghai is divided into 16 administrative districts. The central urban area includes Huangpu District, Pudong New Area, Xuhui District, Changning District, Jing'an District, Putuo District, Hongkou District, and Yangpu District. Based on the stable coverage of Huangpu District as the reference data, assuming the MSW coverage rate in Huangpu District is 100%, the number of garbage collection points per 10000 permanent residents in each district is used as coverage ratio (NDRC & MHUD, 2019). In 2015, except for Huangpu District, Chongming County, as a rural waste demonstration site, had a coverage rate of 100%; Xuhui District, Jing'an District (including the original Zhabei District), Changning District, Hongkou District, Baoshan District, and Jiading District had a high coverage rate more than 60%; however, the coverage rate of domestic garbage collection in some administrative regions is very low, such as Pudong New Area, Putuo District, Songjiang District, etc., less than 30% (MHUD, 2019).

	2012	**2013**	**2014**	**2015**	**Coverage Ratio**
Total	31625	32018	32122	32209	
Pudong New Area	4420	4298	4212	4251	20.23523
Huangpu District	2023	2014	2014	2014	100
Xuhui District	2129	2131	2140	2137	51.67403
Changning District	1547	1539	1556	1555	58.98955
Jingan District	906	905	906	906	22.36176

Putuo District	954	953	956	957	19.60318
Hongkou District	1717	1642	1677	1705	56.15572
Yangpu District	1540	1535	1525	1525	30.55549
Minhang District	2848	2870	2898	2925	30.37276
Baoshan District	3577	3647	3647	3651	47.31089
Jiading District	2886	2890	2890	2890	48.0798
Jinshan District	338	920	1005	1005	33.00146
Songjiang District	1068	1034	1049	1032	15.50728
Qingpu District	1376	1364	1368	1368	29.86808
Fengxian District	1142	1140	1139	1149	26.17229
Chongming County	2109	2111	2111	2111	79.97787

Table 4.3: Coverage ratio (MHUD, 2019).

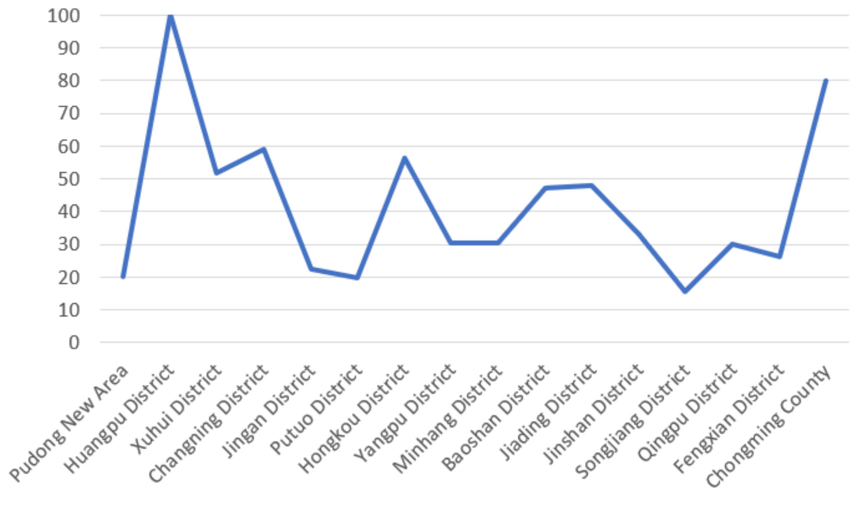

Figure 4.4: Coverage ratio (MHUD, 2019).

The formal recycling system

It is necessary a green changing the consumer lifestyle and consumption mode to reverse the MSW generation growth trend, but it cannot be achieved overnight. In the short term, the reduction of MWS generation can be reached by recycling. The functioning of Shanghai's formal recycling sector is similar to the Chinese model explained in chapter three. In Figure 4.5 is represented as an overview of Shanghai's formal recycling system (between the collection and treatment phase, there can be one or more intermediate steps in transfer stations). According to the statistics of the Shanghai Circular Economy Association, in 2017, the formal resource utilization rate of waste in Shanghai was only 18.80% (SMPG, 2019)(if compared with a similar mega city like Singapore with an overall recycling rate of 60% in 2018)(also considering the organic matter recycling as anaerobic digestion and composting), and the recycling rate of low and medium value wastes is still low (such as waste glass). It is not convenient recycling low-value wastes because of the high operational costs compared with the low benefits of a low value recycled material. Indeed, recycling rates, both formal and informal, are related to the value of recyclable materials, and most of the low-value MSW recyclables have relatively low recycling rates due to their high recycling costs and low recovery benefits (Xiao et al., 2018). Currently, the main problem for the Shanghai's formal recycling system is the insufficient number of resource utilization facilities (recycling plants), the lack of enterprises that treat low and medium value wastes, and the informal recycling system presence (Beijing Evening News, 2016). A large number of high-value recyclable materials flow into the informal recycling system diverting recyclables from landfilling and incineration, but increasing environmental risks and safety risks (Wu et al., 2016). In the field of high-value recyclable materials, Baowu Group Environmental Resources Technology Co., Ltd., Weixiang Environmental Protection Technology Development Co., Ltd., Senlan environmental protection Co., Ltd. and other formal enterprises have emerged, and the resource utilization capacity has been developing. The main contradiction is focused on low and medium value recyclables (glass bottles, sheet metal, etc.) (SMPG, 2019). The facilities and enterprises involved in the recycling of low and medium value waste in Shanghai are insufficient. There is a group of recycling companies with strong technical and operational abilities who are optimistic about the low and medium value recycling market waste in Shanghai. Unfortunately, these enterprises are facing many difficulties, such as high employment cost, lack of land application, and difficulty in passing the environmental impact assessment (SMPG, 2019). In addition, due to the high population density and the scarcity of land in the central urban area, it is difficult to build or expand the waste transfer system, resource recovery facilities (recycling plants and transfer stations), and other facilities in the intermediate process under the influence of the *"neighborhood avoidance"* effect (*"not in my backyard"* syndrome). Many of the before mentioned facilities often operate at full load or even overload, which inevitably leads to the hidden danger of waste spillover pollution, and it is easy to cause the dissatisfaction of surrounding residents and social conflicts (SMPG, 2019).

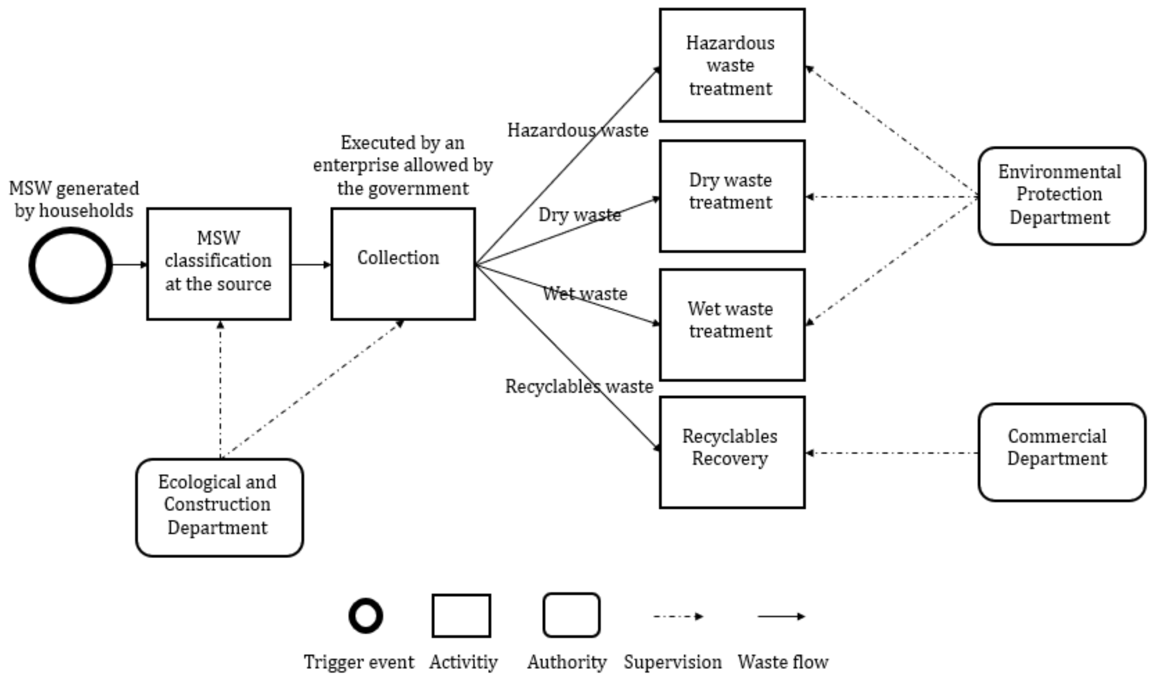

Figure 4.5: Formal recycling system.

4.3 Municipal Solid Waste new classification system

Since the end of the 20th century, in Shanghai, it has gradually emerged the awareness of the needing for garbage classification (Zhou et al., 2019). Shanghai is one of the most developed cities in China, and the municipal government and the people have strong abilities to accept foreign solutions. So, garbage classification has been encouraged by experts and academicians in Shanghai as a means of environmental protection (Zhou et al., 2019). Shanghai's experience with MSW classification had begun at the ending of the 1990s when it was selected as one of the first eight pilot cities for MSW classification. After more than 20 years of *"classification experience,"* Shanghai can take the leading role in incorporating the MSW classification into its legal framework. Several times central and local governments in China tried to promote MSW classification policy, but the effective implementation of MSW classification was not possible because of multiple factors, such as un-willingness of people, insufficient technology and infrastructure, poor coordination among different departments of the government, and tax laws and regulations (Vassanadumrongdee et al., 2018; Tang et al., 2001; Tai et al., 2011; Dai et al., 2016; Zhang et al., 2016). However, since when the first MSW classification was proposed, the Shanghai MSW classification has experienced many changes, as shown in Table 4.4. It can be seen that over the years, the MSW classification standards of Shanghai have changed many times, which has brought more difficulties to the build people's awareness and knowledge about MSW classification (Zhou et al.,. 2019).

Time	Relevant government document	Classification Method
2000	Formally put forward waste classification	Organic, inorganic, recyclable and hazardous waste
2002	Regulations of Shanghai Municipality on the administration of city appearance and environmental sanitation	Service area of incineration plant: incinerable, nonincinerable, waste glass, hazardous waste; Other areas: compostable, noncompostable, waste glass, hazardous waste
2007	Measures of Shanghai Municipality on the administration of collection, transportation, and disposal of municipal solid waste	Recyclable, kitchen waste, waste glass, hazardous waste
2010		Dry, wet, recyclable, hazardous waste
2011		Dry and wet foundation, 2 + X mode
2014	Measures of Shanghai Municipality on promoting the classification and reduction of domestic waste	Clear classification standard: dry, wet, recyclable and hazardous waste

Table 4.4: Classification method.

Recently, China changed its long term strategy from one focused on rapid development to another based on environmental protection. In 2017, some pilot cities were selected to implement the new MSW classification policy by the National Development and Reform Commission (NDRC) and the Ministry of Housing and Urban-rural Development (MHUD) of China. Shanghai was one of the first pilot cities selected to incorporate the classification into its legal framework (NDRC, 2019; MHUD, 2019). Various regulations have been released to be compliant with the new national development strategy by both municipal and district governments of Shanghai to promote the new MSW classification policy since 2017 (Shi, 2018; Fan, 2019). On July 1st, 2019, the Shanghai Municipal Solid Waste Management Regulation has come into force, including the MSW classification in the legal framework of Shanghai (as a consequence of the *"Operation National Sword"*). Figure 4.6 shows the connection among the 13th plan, the new MSW classification policy, and the Shanghai MSW management regulation.

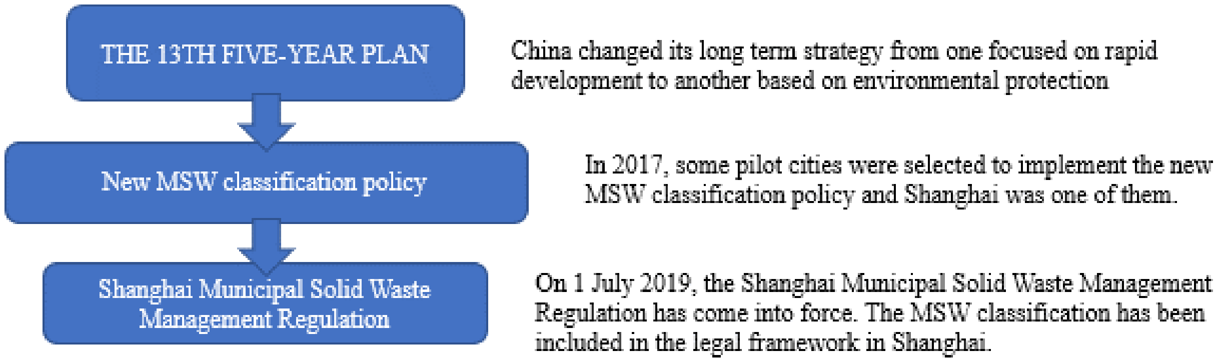

Figure 4.6: Genesis of the new MSW regulation.

The new Shanghai MSW classification system caught the attention not only from Shanghai residents but the whole of China. If the new classification system is successful, the Shanghai MSW classification policy can be taken as an example model, and it can be used as a benchmark to other cities (SMPG, 2018; Zhou et al., 2019).

4.3.1 The main contents of the new regulation

According to the just-released Shanghai Municipal Solid Waste Management Regulation, the municipality of Shanghai classifies MSW into four categories, i.e., recyclable, hazardous, wet, and dry waste. The categories are defined as follow (Zhou et al., 2019):

- *Recyclable waste* includes the waste that is suitable for recycling, for instance, used paper, plastic, glass, metal, and fabric;
- *The hazardous waste* consists of the waste that might cause direct or potential harm to human health or natural environments, such as waste batteries, lamps, drugs, paints, and pesticides;
- *Wet waste* regards the perishable biomass waste such as leftovers, expired food, melon peel, fruit core, and dead flowers and plants;
- *Dry waste* includes any waste other than recyclable, hazardous, and wet waste.);

New MSW collection points have been diffused in almost every Shanghai corner (SMPG, 2018). Figure 4.7 shows some commons MSW collection points with four collection bins in Shanghai, and hazardous, recyclable, wet, and dry waste have to be thrown into red, blue, brown, and black bins, respectively (Zhou et al., 2019). Residents have to classify their wastes first in their home and then throw them into the right bins. Moreover, households have to throw the MSW in determined places and times. No waste collection outside of the prescribed time slots and places is permitted (SMPC, 2019).

Figure 4.7: MSW collection points (Zhou et al., 2019).

Then, the classified MSW will be collected by qualified companies and transported to different places for proper disposal (SMPC, 2019). Figure 4.8 highlights the MSW process for each waste stream.

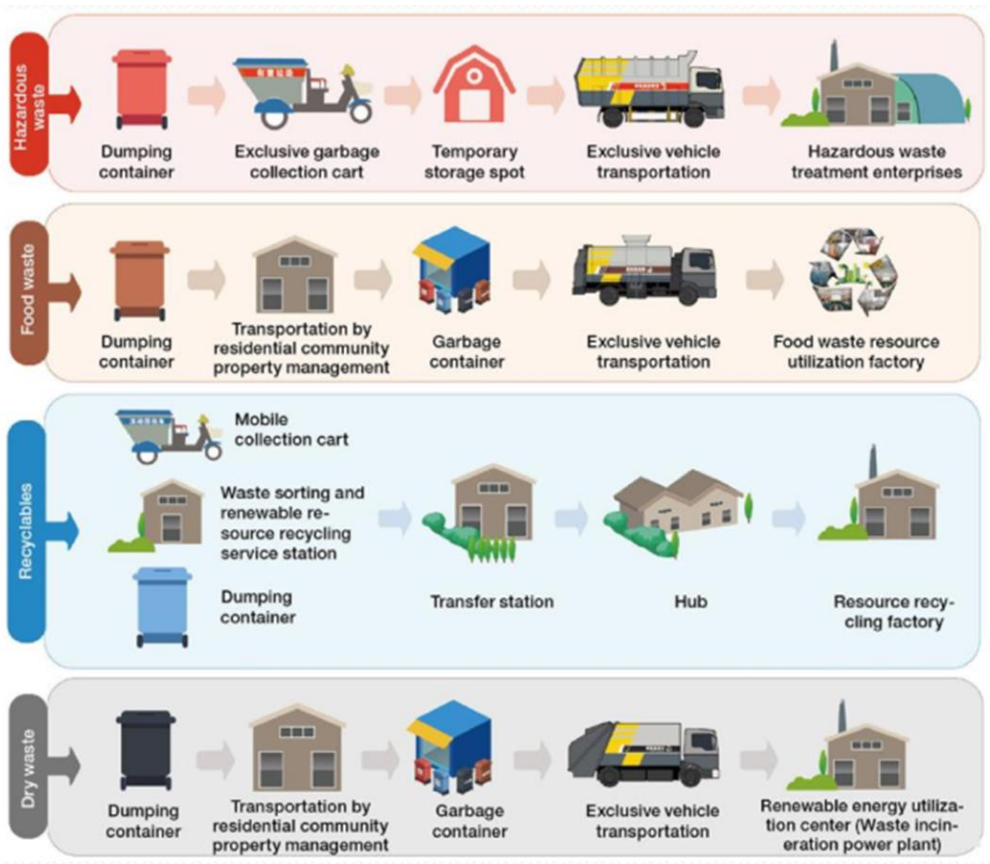

Figure 4.8: the MSW process for each waste stream (SMPC 2019).

Recyclable waste will be recycled by recycling companies for resource utilization. Hazardous waste enters into the hazardous waste treatment plant or the hazardous waste landfill for disposal (Zhou et al., 2019). The wet waste will be utilized as natural fertilizer after determined biological treatments or used to produce biogas (Anaerobic Digestion). After removing the impurities contained in wet wastes, such as plastic bags, they are sent to anaerobic tank for fermentation to produce biogas through crushing, cooking, oil extraction, and other steps. Each ton of wet garbage is able to produce about 80 cubic meters of biogas. Dry waste will be combusted in incineration plants to generate electricity or dumped in landfills (Zhou et al., 2019). Moreover, each category of MSW is collected and transported by a specific means of transport (SMPC, 2019), and thousands of MSW vehicles have been deployed to collect and transport waste in a proper manner (SMPG,2019; Lu, 2019). Figure 4.9 shows the main vehicles involved in each category (Zhou et al., 2019).

Figure 4.9: Vehicles employed for each different MSW stream (Zhou et al., 2019).

Many efforts are even made to decrease the MSW generation from the source. For example, disposable office supplies are discouraged, and recyclable papers are recommended to use. All the companies in Shanghai are encouraged to give priority to detachable, recyclable, and non-toxic materials and designs, and produce environment-friendly recyclable products (Zhou et al., 2019). Restaurants, shops, and hotels are not allowed to offer disposable items to customers on their own initiative (SMPC, 2019). Moreover, residents are encouraged to buy and consume recyclable and other environmental friendly products (Zhou et al., 2019). To effectively implement the new classification policy, the government has adopted some particular measures (Zhou et al., 2019):

- *MSW classification publicity*: The promotion through publicity of MSW classification started in 2017. Slogans, videos, posters on MSW classification were everywhere, such as in newspapers, magazines, televisions, and the internet. In the recent two years, in Shanghai, a lot of promotional activities have been held, and brochures have been sent to residents (Shi, 2018; Lu et al., 2019; People's Daily, 2019). Figure 4.10 shows respectively: a) brochures, b) poster, c) television video, d) scenario of promotional activities (Zhou et al., 2019);

Figure 4.10: a) brochures, b) poster, c) television video, d) promotional activities (Zhou et al., 2019).

- *School education*: In schools, teachers are required to teach to students how MSW classification works, and the children are required to explain what they learned to their parents (SMPG, 2019; Kankanews, 2019). Figure 4.11 shows a teacher who is teaching to her students the main principles of the MSW classification system (Zhou et al., 2019);

- *Specialist guidance*: Volunteers, temporarily hired people or retirees, are trained to guide citizens to classify MSW and assigned to some MSW collection points (Shi, 2018; Lu et al., 2019; Shanghai Municipal People's Congress, 2019). Figure 4.11 shows a volunteer helping citizens to classify MSW (Zhou et al., 2019);

- *Incentive methods*: the Green Account works as an incentive mechanism for residents, and they are widely distributed to residents (Shi, 2018; Lu et al., 2019; Wu et al., 2016; People's Daily Online, 2019). The Green Account, associated with a smartphone, can record for each resident every right classification of MSW and will then give them credits, which could be exchanged for goods. In other words, by means of points for gifts and other means, residents are encouraged consciously classify garbage in their daily life, and then put it into classification (this is an attempt to compensate the informal recycling convenience for the households). By the end of 2017, the total number of Green Account has exceeded 1200 machine (Zhou et al., 2019). Unfortunately, still now, the participation rate of green accounts is low, the popularity is low, and the management of green accounts in many communities is missing in Shanghai. It can be considered as a Human-Machine interaction collection system, therefore an intelligent collection method. Figure 4.11 shows a Green Account credit card and a credit-good exchange machine (Zhou et al., 2019);

- *Penalties*: According to the Shanghai Municipal Solid Waste Management Regulation, those who fail to classify MSW fined CNY 50 to CNY 200, and the transportation companies that mix the MSW can be fined CNY 5000 to CNY 50000 (Figure 4.11) (SMPC, 2019; Zhou et al., 2019).

Figure 4.11: a) MSW classification lesson, b) voluntary activities, c) Green Account credit card and a credit-good exchange machine, d) Penalties (Zhou et al., 2019).

4.3.2 Consideration of MSW management regulation

China has started to explore MSW classification later than the developed countries, and it can take time to well implementing a proper MSW classification in China and Shanghai. Zhou et al., (2019), proposed a SWOT analysis (Strengths, Weaknesses, Opportunities, and Threats) on the new MSW classification policy showed in Table 4.5. Several studies show that leadership and financial support from the government are crucial to MSW management and the Environmental Impact Assessment, particularly to the first implementation stage (Alzate-Arias et al., 2018; Lamoureux, 2019). Nowadays, most of the MSW collection, transportation, and disposal companies are owned by governments in Shanghai. Also, the costs of human resources, management, and publicity are supported by the government. The leading and promotional role of the government is strongly encouraged to continue in the initial stage of the classification policy (Zhou et al., 2019). Consequently, the burden on government finance and management has increased because of the just-above explained high expenditure. Taiwan and US cases show that Waste Collection Fees System, private capital, and private companies can significantly decrease the expenditure for the government (Skumatz, 2008; Lu et al., 2006). In the next decades, Waste Collection Fees System, private capitals, and companies should be incorporated into MSW classification to implement a sustainable and marketized classification industry in Shanghai and overall China. In 2019, Shanghai has been the first city of China to promulgate a mandatory local regulation on MSW classification (SMPC, 2019). The MSW classification legal system should be refined and optimized for implementation and nationwide promotion. The government should continue its rigorous inspection and continuous supervision, and those who break the rules should be fined (Zhou et al., 2019). MSW classification effectiveness is mostly influenced by people's willingness to classify, knowledge, and habits (Vassanadumrongdee, 2018). Currently, most of the waste is correctly classified in Shanghai, but it is based on a high number of human resources and material input. MSW classification is not still a habit and a moral principle among Shanghai citizens. To obtain a proper awareness of the significance of classification, and decrease the human and material input, there are needed further publicity and school education. Zhou et al., (2019), suggested to include the knowledge about MSW classification in scholar textbooks shortly. Further, more promotional advertisement, videos, and brochures are useful options,

Classification	Description
Strengths	1. Strong willingness of the government.
Weaknesses	1. Private capital has not been generally introduced. 2. Laws and regulations need to be further improved. 3. Poor coordination among different departments of the government.
Opportunities	1. Willingness of citizens is increasing.
Threats	1. People's insufficient knowledge of MSW classifications. 2. Habit has not yet been formed.
Recommendations	1. A leading role and good coordination among different departments of the government are needed. 2. A marketized industry should be established. 3. Laws and regulations should be further improved. 4. More publicity and education are necessary.

Table 4.5: Strengths, weaknesses, opportunities, and threats (SWOT) analysis of the present MSW classification policy in Shanghai (Zhou et al., 2019).

To implement a well functioning MSW classification system in Shanghai and the whole of China will require a long period. Following, there are the main learned points of the initial MSW classification regulation experience in Shanghai (Zhou et al., 2019). First, the leading role of the government in the initial stage of the system implementation and proper coordination among its departments is considered crucial, and it is encouraged to ensure proper MSW classification development. Second, waste collection fees system and private capital and private companies should be involved to promote a sustainable and marketized MSW-relevant industry in the future. Third, laws and regulations should be refined and optimized, and continue enforcement of them is needed. Fourth, more publicity and school education on the MSW classification system are helpful in making the MSW classification part of the habits and moral principles of Shanghai's citizens.

4.3.3 Consequences of the new MSW regulation in the first month

According to the Shanghai data about the first month of the MSW classification implementation (July 2019), from the previous month (June 2019), the average collection daily rate of wet waste is increased by 14.8%, the recyclable materials are increased by 9.68%, and the dry garbage decreased by 11.65% (SMPG, 2019). The hazardous waste has not changed significantly, and the July average amount was 291 kg. In contrast to the not changing in hazardous waste, there is a significantly increasing in wet waste. In Shanghai, the capacity of the dry waste incinerator has reached 12'700 tons/ day, and wet waste capacity has reached 1720 tons/per day at the beginning of 2019 (they are projected to be improved to 19'300 tons/day and 5500 tons/day respectively). In August, the average daily amount of wet waste was 8157 tons/day, and it means an increase of 1.28 times compared with the average daily amount in August 2017 (MHUD, 2019). Therefore, in August, an average wet waste of around 6000 tons/day was disposed of improperly through landfills and/or incineration (NDRC, 2019). Indeed, the amount of wet waste disposed of by incineration and landfilling has increased, causing low energy recovery and the landfilling problem related to co-disposal (odor, leachate, and GHG emissions). On the other hand, since the releasing of the MSW regulation the content of moisture in dry waste has decreased, resulting in improved combustion stability. Moreover, the wet wastes collected through the new classification have less content of wastewater, and it means a reduction of the discharge of leachate, an acceleration of the natural fermentation of garbage, and an increasing of the power generation efficiency. Concluding, during the first month after the implementation of the new MSW classification regulation, the quality of the collected dry and wet waste is improved, resulting in better energy recovery and landfilling property. However, there was a shift of the waste amount from the dry waste to the wet waste, indeed, the average daily dry waste collected is decreased and the average daily wet waste is increased. If the shifting will continue, it could bring to an overcapacity of the dry treatment plants (particularly incineration plants) in Shanghai. Moreover, given the amount of wet waste disposed of improperly, the Shanghai's municipality should undertake more new wet treatment plan projects (also the projected capacity of 5500 tons/day by the end of 2020 will be not enough). In any case, only data of one month is not enough to draw out reliability conclusion on the long period.

4.4 The informal recycling system

In Shanghai, the informal ecosystem has a crucial role in diverting recyclables from landfills and incineration plants and reintroduce them into the economy. The informal recycling system can be described as a system well-connected, hierarchical, and at scale. The main informal actors are pickers who collect materials on tricycles (WMs), informal companies that buy, sort, and store materials (MMs) and then sell them to the larger informal resource recovery plant inside the system (informal recycling plants). It is possible to classify the system as a self-reliant and efficient sector, with private collectors using their storefronts, large collection centers, and tricycles to collect, separate, and transport material. Figure 4.12 shows a waste picker on a tricycle collecting wood (Morrison & Schonberg, 2017).

Figure 4.12: Informal waste picker on a tricycle (Morrison & Schonberg, 2017).

From the first collection to the final recycling, informal workers play an essential role in each step of the process. Individual informal waste pickers (WPs) sell to small sorting centers, the small centers sell to larger centers (both considered as MM), and the larger centers sell to reprocessing plants that reintroduce recyclable materials on the market (informal recycling plants). In Shanghai, the informal workers are hundreds of thousands, who are encouraged by the price and availability of the different materials**.** Informal workers are interested in maximizing profit (Morrison & Schonberg, 2017). Therefore, collectors' activity intensity is influenced by international commodity prices and macroeconomic variables that are able to influence prices. Other influencing factors can be the rising of e-commerce, higher construction activity, or new government regulations. Following, there are summarized the main categories of informal workers having a crucial role in the functioning of Shanghai's informal recycling system (Morrison & Schonberg, 2017).

- *Swapping points* (TPs) are areas where full-time pickers or opportunistic collectors (residents, WPs, MM) meeting up to gather, buy and sell material to other informal pickers. These points can be managed by a single informal recycler (often handling just one recyclable material) or multiple informal recyclers companies, and each of them handles different materials (for example, plastic, cardboard, and wood together). Many of these swapping points are non-licensed sites, and collectors who work there should be careful to attract official attention;
- *Small Collection Centers* (MM) are sites where full-time collectors and opportunistic collectors are paid for the MSW collected by waste type and weight. It is possible to consider these areas as consolidation centers for the MSW picked all over the city. These centers sort materials by type before preparing them for transportation to processing centers. If the amount of MSW is not enough to fully load a single truck, small centers can decide to sell recyclable materials to large consolidation centers;
- *Large Consolidation Centers* (MM) have a similar function to small collection centers. They are larger than small collection centers and process high-volume of a broader range of recyclable materials every day. Many of them are licensed so that they can remain in the same place for an extended period;
- *Processing centers* (informal recycling plants) are the last points in the material lifetime, and they are mainly in nearby provinces of Jiangsu and Zhejiang. Trucks arrive in processing centers, and they sell material for processing. Through these centers, materials are reintroduced into the economy (selling them to manufacturing companies). Unfortunately, this is the less transparent side of the informal recycling system, and the quality of treatment has not been clearly identified, causing many environmental and health burdens and risks.

Figure 4.13 shows how informal recycler players interact with each other (Morrison & Schonberg, 2017).

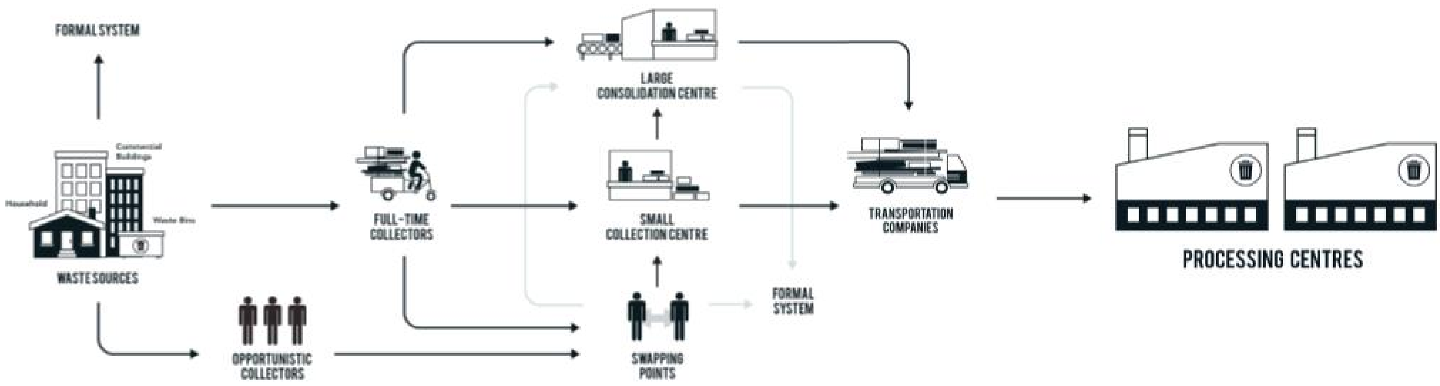

Figure 4.13: Informal recycling system in Shanghai (Morrison & Schonberg, 2017).

Because of the large-scale of the Shanghai informal collection, sites and centers are deployed all over the city. It can be possible to individuate several small collection sites and only one or two large collection centers for each district. The informal system effectiveness can be found in the interaction of the small and larger sites and individual stakeholders deployed all over the city. Figure 4.14 maps MSW informal collection sites in the central districts of Shanghai (Morrison & Schonberg, 2017).

Figure 4.14: Shanghai informal collection network (Morrison & Schonberg, 2017).

People employed in the informal system ranging from 3.3 to 5.6 million, and nevertheless their dirty work, many informal collectors are satisfied with their industry choice (Linzner and Salhofer, 2014). They are mostly workers from Jiangsu and Anhui provinces. Some collectors are part-time workers, while others consider as their main occupation the collection and separation of materials for resale them or manage a collection center. The informal industry has significant earning potential, even for the collectors at the bottom of the chain. A typical collector can earn around 100 RMB for each cart of cardboard (the most frequently collected material), and on average, collectors send two carts per day to collection points. In other words, a collector can earn 200 RMB per day and around 67’200 RMB per year (Morrison & Schonberg, 2017).

4.4.1 The informal recycling pricing system

In Shanghai, the informal sector divides recyclables MSW into a few essential categories, with different subcategories, prices, and end-of-life treatments. The basic price setting is made by the processing factories (that reintroduce recycled materials into the economy). Once the price is fixed by factories, the intermediate informal actors make price adjustments (Morrison & Schonberg, 2017). Consequently, the price adjustments influence all the informal chain until the informal collector pickers. Anyway, at each stage prices are influenced by the size, capacity, and profit-making goals of informal key actors within the system. Pricing variation of the informal prices can influence the demand for recycled materials, and informal collector activities (Morrison & Schonberg, 2017). Pricing variation can be related to several factors, including seasonal manufacturing activity, scarcity of virgin materials, and international and domestic commodity prices. For example, during the recession period of 2008, the activities intensity of collectors was significantly impacted. Material prices decreased to the point that informal collection was not profitable anymore. Even though this is a rare occurrence within the informal recycling market, it is proof of the influence that the global and domestic commodity market has on “on-street” activities. Collectors often develop preferences about materials related to their price and market demand, and these prices have a direct influence on their activities (Morrison & Schonberg, 2017). For instance, in Shanghai, informal pickers will ask payment to pick glass bottles or sheet metal from residents, but they will pay them for paper and cardboard. One of the most reasons for the high value of paper and cardboard recyclables is the increasing packaging demand due to e-commerce growth (Morrison & Schonberg, 2017).

4.4.2 The case of paper & cardboard

Over the past decade, China has experienced high economic and urbanization growth as well as consumption growth. A great demand for paper and cardboard has risen, and the demand for recycled cardboard has increased too. The main reason has been attributed to the presence of e-commerce companies and the shipping of billions of packages per year (Morrison & Schonberg, 2017). The leading e-commerce players present in Shanghai are Alibaba, Taobao, and Kuaidi. The fundamental pillar of their business model has been the fast shipping, but due to the growing Chinese customer base, their necessity for raw packaging materials has hugely increased. Therefore, they needed a high and steady supply of raw and recycled materials. The increasing demand for paper & cardboard has had a significant impact on the related recycling market, encouraging a faster reintroduction process of the cardboards into the economy (Morrison & Schonberg, 2017). Further, it has caused both short and long-term price spikes for local recycled cardboard. In addition to the risen of the e-commerce companies, other factors have impacted on the cardboard pricing, including Environmental Impact Assessment and new regulations. The following case study (Morrison & Schonberg, 2017) explains the most critical variables and their influences on the pricing of recycled cardboard in a period of two weeks in 2016 (Figure 4.15) (Morrison & Schonberg, 2017).

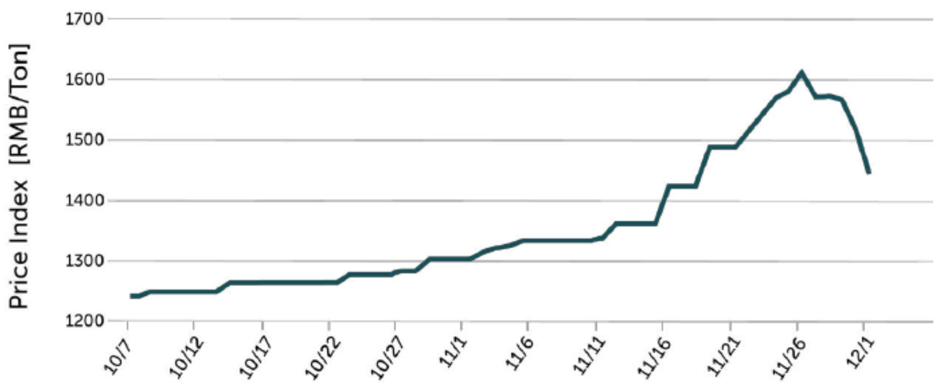

Figure 4.15: The Price of Cardboard (Morrison & Schonberg, 2017).

On October 20th, 2016, China's Ministry of Environmental Protection heightened enforcement in 20 Chinese provinces. Many paper processing factories (recycling plants) were not able to pass the Environmental Impact Assessment, and they were forced to shut down because they failed to pass it. The consequence was a further drop in the domestic offer of recycled paper and cardboard, resulting in higher prices. Moreover, during the period 2011-2015, China imported 27 to 30 billion kilograms of foreign waste paper per year (before the waste ban) (Morrison & Schonberg, 2017). This massive import of paper caused the increasing offer of paper and cardboard, generating a downward pressure to the price. Near to the end of 2016, there was the Chinese ban (*"Operation National Sword"*) on the import of foreign waste, and it caused upward pressure on waste paper prices. In a period of two weeks, the waste paper increased from 1210 RMB per ton to 1610 RMB per ton *(Figure x)*. Some extensive recycling facilities, to avoid the initial price volatility, began to stockpiling cardboard, hoping to earn better profits as soon as the price reached its peak. Therefore, paper and cardboard offer further decreased, and the prices increased yet (Morrison & Schonberg, 2017). The last significant factor influencing waste paper price was China's Singles' Day on November 11th. It is likely the primary cause of companies' packaging waste. During the following weeks of the Singles' Day, the National Post Office delivered 350 million packages. Therefore, the high demand for raw packaging materials generated by the 11th of November, was another factor influencing the price trend, generating a considerable spike in demand for paper and cardboard (Beijing Evening News, 2016).

4.4.3 The Jurney of the recyclable materials

In a recent study (Morrison & Schonberg, 2017), there were sent eight shipments of cardboard into the informal recycling system to better understand the paper and cardboard recycling process. Figure 4.16 shows the common path undertaken by most of the shipments. The collectors collected paper & cardboard materials nearly to Jing'an temple (Morrison & Schonberg, 2017). Within three hours, they arrived at a large collection center and loaded the recyclable materials into a large truck. Then, the trucks drove to a cardboard and paper manufacturing company (recycling plant). The company was specialized in providing packaging material, and paper. Once the trucks reached the recycling plant, wastes were discharged and loaded in a yard full of paper and cardboard waiting to be processed. From this point to the end of the recycling process took around five days, then the materials were able to return to circulation as packaging or similar. It means that the entire process, from the collection to the reintroduction into the economy, occurred in less than a week. It can be considered as another evidence of the informal recycling system efficiency (especially if compared to the formal recycling system) (Morrison & Schonberg, 2017). The experiment was repeated for the other recyclable materials (plastic, metal, wood, cardboard, and styrofoam), and more than 50 shipments were sent and followed.

Figure 4.16: Start and Endpoint of Collected Cardboard (Morrison & Schonberg, 2017).

Figure 4.17 shows the common route followed by informal workers for plastic, metal, and wood materials (Morrison & Schonberg, 2017). Through the experiment, it became clear that a well-established net of informal buyers exists within the Shanghai city boundaries, and within 24 hours, most materials reached a resource recovery factories (recycling plants) where the recyclable materials would be reprocessed and reintroduced into the economy. In the case of cardboard, plastic, and metals, these results are particularly true. Many of the collected materials were reintroduced into the market as new goods within 7-15 days. It can be seen as proof of the excellent efficiency of the overall informal process (Morrison & Schonberg, 2017).

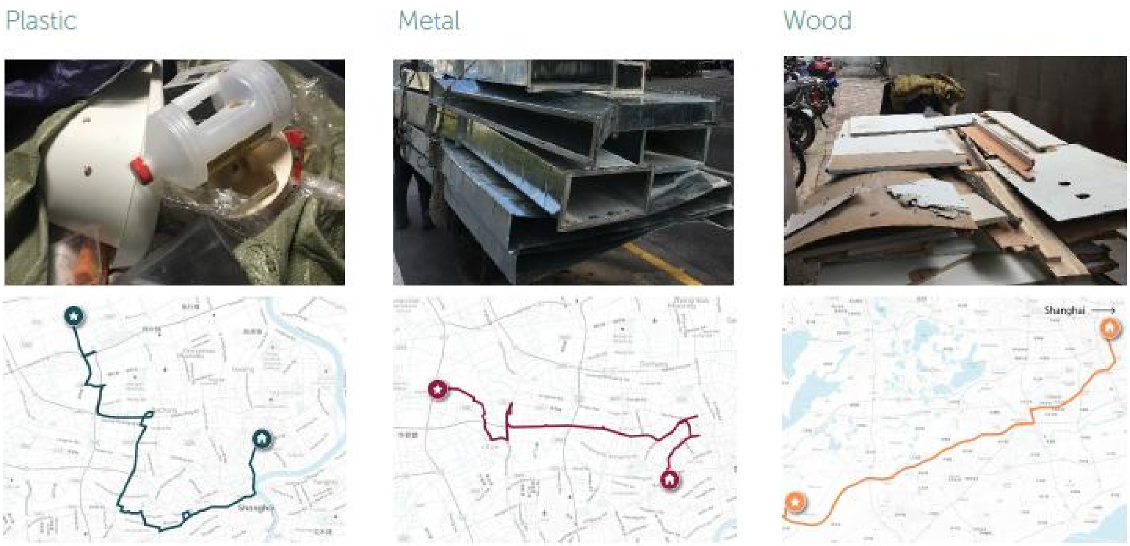

Figure 4.17: Routes for Specific Materials Collected in the Informal Sector (Morrison & Schonberg, 2017).

4.4.4 Shanghai's informal recycling system - Challenges & Solutions

The informal recycling system is characterized by a significant efficiency, especially if it is compared to the current formal recycling system state. On the other hand, the informal sector has several social and environmental problems. The household attitudes toward informal sector workers are a growing problem, especially in Shanghai's areas where housing prices and living standards are high (Morrison & Schonberg, 2017). Even if most informal collection centers handle non-hazardous material, their work tends to be dirty and unsightly. Many residents in different districts are pushing back against the informal sector, and the public opinion is forcing to close the informal collection centers in areas where there is still an operational need. Even though the informal recycling collection process does not add any environmental risks, and rather it is seen as a positive contribution to divert MSW from the landfill, the processing step of the recyclable materials is seen as a subject of environmental concern. After the illegal dumping scandals in 2017, it became clear that the current recycling system does not have the proper control all over the waste transport and logistics. Moreover, several recycling plants around Shanghai have no environmental certification (from an Environmental Impact Assessment), so the Chinese government targets these factories to close because of the environmental costs (Morrison & Schonberg, 2017). Related to the environmental issues, there is a lack of transparency in the informal recycling system, and it is seen as a grey area of Shanghai's economy. Informal workers are self-employed workers and are not required to report collection routes, sorting locations, or final treatment sites to anyone. Along the formalization process, the government has to control better and monitor every step of the informal recycling system. Better control of each step will allow for superior accountability throughout the informal recycling value chain and will create a precise method to identify and punish actors for environmental or social issues. In late 2016, the government interrupted paper production at factories outside Shanghai because they failed to be compliant with environmental standards. Moreover, many large collection centers and swapping points have closed in recent years. In Shanghai's Huangpu District, at least four informal collection centers have shut down over the past ten years. Leaving only small storefronts, individual collectors, and swapping points, and most of them currently deliver waste to points outside the city (Morrison & Schonberg, 2017). What happened in Huangpu district is not limited to just that area, very few long-term, large-scale informal collection centers can be found inside the Shanghai's city center. Moreover, they are subjected to stricter regulations, and remaining centers are under threat. Centers struggled to overcome the Environmental Impact Assessment, and they will close if they do not modernize their plants. The government asked to large centers to invest in upgrading existing facilities with new equipment, and better on-site conditions that reduce air, odor, and sound pollution. Private companies can help these centers in the investment process. After updating the collection centers, private companies can help them applying for an environmental impact assessment evaluation and getting an official license and enable them to operate within Shanghai's formal recycling collection system. Shanghai's formal recycling system needs to develop recycling facilities, and at the same time, the municipal government has to Figure out how to incorporate the informal sector system into the formal sector (Morrison & Schonberg, 2017). Moreover, it is crucial keeping the same informal worker's incentives to maintain their everyday efficiency, or there can be the risk of a massive build-up of MSW on the street. The informal sector has to be taken into consideration in the future, because it includes thousands of street-level collectors and hundreds of sorting facilities, diverting MSW from landfill. The formal sector, compared to the informal sector, has fewer sorting incentives, a limited presence on the streets, and less experience with recycling and reuse. If the municipality wants to have proper control of the MSW management system, it will need to integrate the informal workers sorting and collection efficiency (Morrison & Schonberg, 2017). Moreover, the government has to try to replicate the same relationship between local collectors, large collection centers, and recycling facilities. To ensure the right transition process into a cleaner formal system, private solution providers are encouraged to offer their expertise, investment, and recycling infrastructure (Morrison & Schonberg, 2017).Concluding, Shanghai's MSW management has reached a point of significant transition, landfills reach capacity, and the generation of waste has been increasing steadily. For many years, the informal recycling system has helped to divert recyclables materials from landfilling and incineration. If the informal sector were simply cut off, there could be thousands of recyclable materials lost in landfills, illegal dumping, and waste accumulation around sidewalks (Morrison & Schonberg, 2017). Moreover, hundreds of thousands of informal workers would remain without a job. Therefore, it is a crucial issue for the government to understand how to formalize the informal recycling system. The government has recognized the benefits of the informal recycling system – efficient collection and free recycling. Nevertheless, Shanghai residents have begun to perceive the overall informal sector as dirty and polluted, associating them with air and water pollution, odor, and lower property values. Consequently, the pressure to modernize the informal system has grown further. This condition put the government in a challenging position (Morrison & Schonberg, 2017). The MSW management system needs informal pickers to recycle and divert MSW from landfills, but on the other hand, the government wants to make Shanghai an example of a developed, green, clean, and modern city. The fundamental success factor for Shanghai's municipality is to replicate the efficiency of the informal recycling system based on price mechanisms and the relationships net among the informal actors within the system (Morrison & Schonberg, 2017). The challenge also represents a crucial opportunity for firms. As soon as Shanghai formalizes the recycling system, innovative companies can provide solutions and helping the formalization transition. Shanghai could become a testing city for new investment, as Shanghai municipality try to formalize the informal recycling system, build new recycling plants, and bring the waste collection up To Environmental Impact Assessment standards. With a drive for investment, the government in these cities will be more willing to sponsor, approve, and partner with companies that have established strong reputations in MSW management to bring the system through a cleaner, more efficient future.

4.5 Treatment & Recovery

The collected MSW in Shanghai needs to be harmlessly treated. The MSW incineration has been encouraged by the Chinese Central Government as an efficient way to divert waste from landfill. Indeed, the 12th and 13th Five-Year Plans stated that Shanghai must decrease its waste to landfill in favor of Waste-to-Energy. Rather than build new landfills, Shanghai's municipality has begun to promote incineration plant projects (Shanghai Municipal Government, 2015). Figure 4.18 shows how the MSW incineration method has been gradually replacing the landfilling (Morrison & Schonberg, 2017). At the current state, there are three main methods of MSW harmless disposal methods: landfill, incineration, and composting. The current annual MSW treatment capacity is around 9 million tons, making the capacity suitable with the present annual MSW generation (i.e., 9 million tons/year). At the beginning of 2019, the total treatment scale was about 27'000 tons/day, and there were 15 main disposal facilities, including three landfill sites, eight incineration plants, two composting plants, and two kitchen waste disposal plants (Kankanews, 2019). Table 4.6 shows in detail each disposal facility along with the related capacity, as of the beginning of 2019. Moreover, ten new MSW treatment plants are currently under construction in Shanghai (SMPG, 2019). When the ongoing projects will be completed, the total daily disposal capacity should increase to 32’800 tons by the end of 2020 (SMPG, 2019). Already since the end of 2019, the MSW incineration treatment capacity is expected to be 19’300 tons per day, and MSW organic treatment capacity 5,500 tons per day (SMPC, 2019). In 2017, the harmless treatment reached 100% of the collected MSW, of which disposal rate in sanitary landfills accounted for 41.1%, incineration treatment accounted for 40.1%, and the resources recovery accounted for was 18.8% (Chen, 2019) (Figure 4.18), and in the same year the Shanghai’s municipality announced that the city would build new recycling facilities . In Shanghai, at the beginning of 2019, landfilling is still the most common method for MSW management (China National Bureau of Statistics, 2016), but considering the current undergoing project, since the end of 2019, the most common treatment will be MSW incineration. If the landfills are not properly maintained, they can degrade, cause unnoticed leachate, and contaminate the surrounding soil and groundwater. Besides, in the case of the co-disposal landfill (non-biodegradable matter with biodegradable matter), the degradation of organic material can result in a buildup of methane. If the landfill is properly managed, it can be possible to isolate the gas and use it for renewable energy production. In terms of daily capacity, the Laogang Landfill is the largest Chinese landfill (SMPC, 2019).

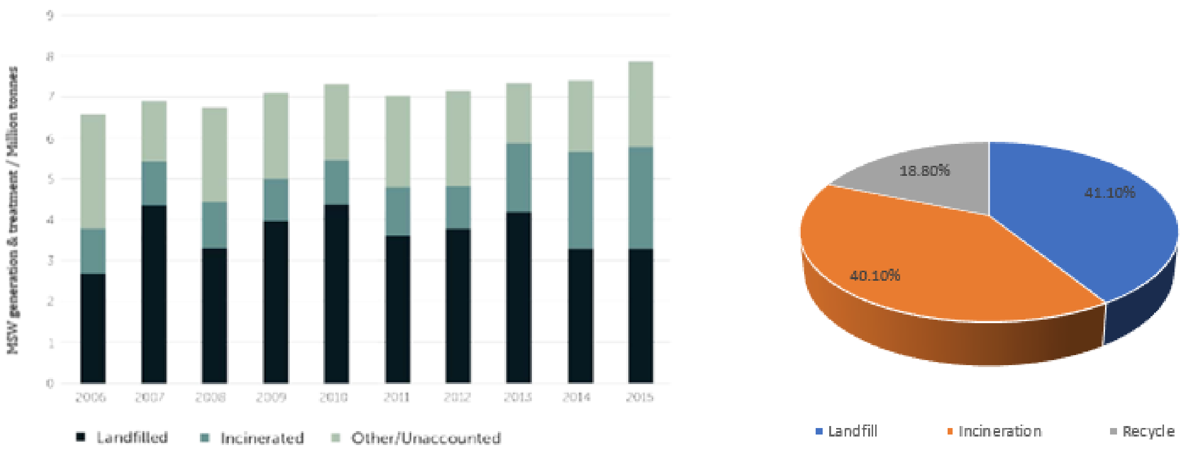

Figure 4.18: Shanghai’s Waste Production and Treatment (Morrison & Schonberg, 2017).

	Main disposal facilities	Management unit	Disposal Method	Disposal capacity(t/d)
1	Jiangqiao waste incineration plant	Shanghai Huancheng renewable energy Co., Ltd	Incineration disposal	1000
2	Jinshan permanent domestic waste comprehensive treatment plant	Shanghai Jinshan baimars Green Energy Co., Ltd	Incineration disposal	800
3	Shanghai Fengxian municipal solid waste terminal disposal center project	Shanghai dongshitang renewable energy Co., Ltd	Incineration disposal	1000
4	Shanghai Tianma municipal solid waste terminal disposal and Comprehensive Utilization Center	Shanghai Tianma renewable energy Co., Ltd	Incineration disposal	1000
5	Yuqiao incineration plant	Shanghai Pucheng Thermal Power Co., Ltd	Incineration disposal	1000
6	Chongming incineration plant	Shanghai Chengtou Yingzhou domestic waste disposal Co., Ltd	Incineration disposal	400
7	Laogang incineration plant	Shanghai Laogang waste disposal Co., Ltd	Incineration disposal	6000
8	Liming incineration plant	Shanghai Pudong Environmental Protection Development Co., Ltd	Incineration disposal	1500

9	Laogang Landfill	Shanghai Laogang waste disposal Co., Ltd	Landfill disposal	9900
10	Chongming landfill	Shanghai Chengtou Yingzhou domestic waste disposal Co., Ltd	Landfill disposal	1300
11	Songjiang landfill	JMW solid waste disposal Co., Ltd	Landfill disposal	1500
12	Pudong biochemical plant	Shanghai Pudong Meishang biological high tech environmental protection Co., Ltd	Composting Disposal	1000
13	Qingpu comprehensive treatment plant	Shanghai Guoqing Biotechnology Co., Ltd	Composting Disposal	500
14	Minhang kitchen waste treatment plant	Shanghai Kitchen Waste Treatment Technology Co., Ltd	Food waste AD	200
15	Chongming kitchen waste treatment plant	Chongming County Government	Food waste AD	20

Table 4.6: Shanghai's treatment capacity (SMPG, 2019; SMPC, 2019; Chen, 2019).

4.5.1 Laogang landfill - Turning waste into a green energy source

The traditional landfill has long been a standard solution to manage the MSW from growing cities, but pioneering new technology can transform traditional landfills into sustainable and green assets, generating new resources for the cities and reducing greenhouse gas emissions. In Shanghai, it was done extraordinary work with the Laogang gas-to-energy landfill, using biogas technologies to help to build a path towards a truly circular economy (Qiongfang, 2016; Asia communications, 2017) (Figure 4.19). Established in 2005 Shanghai Laogang phase IV landfill is one of the largest landfills in China in terms of daily capacity (9900 tons per day). Shanghai Laogang Landfill IV is situated in Pudong New Area, precisely in Laogang, on reclaimed land extending into the East China Sea, and it is one of the largest landfills in the world. The landfill is 4.2 km in length, a width of 800 meters, and a total area of 361 hectares (3,61 km^2). It accepts and treats MSW from downtown and surrounding districts, and is able to take residues from MSW incineration or other treatment plants (Qiongfang, 2016; Asia communications, 2017). The MSW is delivered to the site, weighed and checked, and taken to the designated waterproof site of the landfill. The MSW is then spread out and compacted. Over 2.1 million tonnes of waste treated in 2014. The leachate is a by-product of the process formed as the MSW decomposes. The leachate must be collected and treated to rigid standards before discharge. Another important by-product of landfill decomposition is biogas (Asia communications, 2017). Biogas is formed by the anaerobic digestion of organic MSW inside the airtight landfill cell; it is abundant in methane, and the biogas could be a valuable resource. In the Laogang landfill, it has been implemented an advanced solution that allows to collect biogas and using it to generate significant electrical power. The Laogang Phase 4 landfill can generate biogas on-site and accumulate approximately 10’000 MWhour in electric power every year (Asia communications, 2017). The project is the largest landfill gas-to-energy project in Asia and has avoided substantial greenhouse gas emissions since its launch in 2012. It has reduced 25’800 tonnes of methane emissions in 2014 and avoided 542’000 tonnes of CO2 equivalent (Asia communications, 2017).

Figure 4.19: Laogang landfill (Asia communications, 2017).

4.5.2 Shanghai's Laogang Renewable Resource Recycling plant– World's biggest MSW incineration plant

Currently, in Shanghai, there are eight official MSW incinerators plants, with a combined daily capacity of 12'700 tons. It has been planned to improve the MSW incineration daily capacity to 19'300 tons by the end of 2019. Four days before the new MSW classification guidelines (it will be discussed in the next paragraphs), the second phase of the Shanghai's Laogang Renewable Resource Recycling Center started operation on June 28th, adding eight more incinerators to the plant (Figure 4.20). The construction of the plant was announced in 2010, and the expansion was announced in 2015 (Mingning & Qiuyu, 2019). With the completion of the second phase, the updated waste-to-energy plant has improved its MSW daily capacity from 3000 tons to 6000 tons, raising the total annual plant's capacity to 2 million tons. Wu Yuefeng, the chief engineer of the plant, said: *"If you dump all of the garbage generated by the residents of Shanghai in one day into the Hongkou Football Stadium, it will pile up to a 21-meter-high hill. Nevertheless, after treatment, we can reduce this to only 2% of its original weight and 1% of its volume."* The huge MSW incineration plant is located 10 km from the Shanghai Pudong International Airport and is part of the Laogang solid waste complex (since 1989, the complex has processed 75 million MSW tonnes) (Mingning & Qiuyu, 2019). The municipality has the official goal to increase the number of MSW incinerators in Shanghai and ameliorate the rate of "dry waste." Tang Jiafu, deputy director of the Shanghai Landscaping and City Appearance Administrative Bureau, said that 80% of the total Shanghai's MSW, will be incinerated by 2020 (Mingning & Qiuyu, 2019). Moreover, Wu Yuefeng declares that the updated incineration plant will be able to burn around one-third of the MSW generated in Shanghai and to generate 1.5 billion kWh. In addition, the slags generated by the plant as a by-product (i.e., bottom ash) can be recycled and utilized as building materials. The new MSW classification system should play an important role in reaching the incineration rate goal settled, though it remains unclear which kind of effects it will have on the incineration rate (Mingning & Qiuyu, 2019).

Figure 4.20: Shanghai's Laogang Renewable Resource Recycling (Mingning & Qiuyu, 2019).

4.5.3 Laogang solid waste base

The Laogang landfill and the Laogang Renewable Resource Recycling are part of a larger center called Laogang Solid Waste Base. It is considered the largest solid waste treatment in Asia. The construction of the center started in 1985, and the operation was started in 1989. Since then, the center has handled 77 million tons of MSW. Currently, its daily capacity amount to 15’900 tons, a significant percentage of the total MSW generated each day in Shanghai (around 25’000 tons per day) (Mingning & Qiuyu, 2019). In other words, more than half of the daily MSW generated is disposed of and treated by the Laogang Solid Waste Base. Zhang Jun, the operation manager of the Laogang Waste Treatment and Operation Co., said: *“The new MSW classification rules will reduce the pressure on terminal treatment and decrease the amount of trash produced.*” Moreover, a proper separation of dry and wet MSW will reduce the odor and the leachate of MSW in the Laogang landfill and increase the energy recovery in the Laogang incinerators (Mingning & Qiuyu, 2019; Asia Communications, 2017).

4.5.4 Hazardous waste

Currently, there are ten hazardous waste disposal units in Shanghai, including three hazardous waste landfills and seven centralized incineration disposal units of hazardous waste (excluding medical waste). It is fundamental to recognize that hazardous wastes from MSW stream is treated along with industrial hazardous wastes. The current hazardous treatment capacity is around 316’000 tons per year. Among them, the total hazardous waste landfill capacity is around 137’000 tons per year, and the total hazardous waste incineration capacity is around 178’000 tons per year. Table 4.7 shows the capacity treatment details in 2018 (Kankanews, 2019).

The hazardous waste disposal unit	Facility type	Hazardous disposal capacity (tons/year)
Shanghai solid waste disposal Co., Ltd	Landfill site	27’402
Shanghai Chengtou Yingzhou domestic waste disposal Co., Ltd.	Landfill site	5486
Shanghai Environment Industry Co., Ltd	Landfill site	104’358
Shanghai Chemical Industry Park Shengda Waste disposal Co., Ltd	Incinerator	106’123
Shanghai Tianhan Environmental Resources Co., Ltd	Incinerator	20’822
Shanghai Changying Environmental Protection Service Co., Ltd	Incinerator	209
Shanghai JuLang environmental protection Co., Ltd	Incinerator	7757
Shanghai Xingyue Environmental Protection Service Co., Ltd.	Incinerator	4969
Shanghai lvzou Environmental Protection Engineering Co., Ltd	Incinerator	32’748
Shanghai Xingji industrial waste treatment Co., Ltd	Incinerator	5791

Table 4.7: Shanghai's hazardous treatment capacity (Kankanews, 2019).

4.6 Conclusion on the Municipal Solid Waste Management of Shanghai

Shanghai is considered one of the most important megacities all over the world and the *"showpiece"* of the enormous Chinese economic growth. Because of its enormous economic development and urbanization growth, the MSW generation has increased, too, posing a great challenge on Shanghai's Municipality and Shanghai's MSW management system. The collection rate and harmless treatment have reached 100% (in contrast with overall China). The most common treatment method is still landfilling in Shanghai, but The MSW incineration has been encouraged by the Chinese Central Government as an efficient way to divert waste from landfill. Indeed, the 12th and 13th Five-Year Plans stated that Shanghai must decrease its waste to landfill in favor of Waste-to-Energy (ideally, reaching the objective of *"zero landfills"*). At the beginning of 2019, the MSW dry and wet treatment capacity were around 27'000 tons/day (enough to treat the 9 million MSW generated in 2018). In addition, in 2017, the recycling rate was around 18.80% (lower than other megacities), even if it could be greater because of the presence of the informal sector. Shanghai's municipality projected to increase the daily capacity to 32'800 tons/day by the end of 2020, according to the annual increase in MSW generation. Moreover, since the end of the 20th century, in Shanghai, it has gradually emerged the awareness of the needing for garbage classification. Shanghai's experience with MSW classification had begun at the ending of the 1990s when it was selected as one of the first eight pilot cities for MSW classification. After more than 20 years of *"classification experience,"* Shanghai can take the leading role in incorporating the MSW classification into its legal framework. On July 1st, 2019, the Shanghai Municipal Solid Waste Management Regulation has come into force, including the MSW classification in the legal framework of Shanghai (as a consequence of the *"Operation National Sword"*). The leading role of the government in the initial stage of the MSW classification and proper coordination among its departments is considered crucial, and it is encouraged to ensure proper MSW classification development. Moreover, laws and regulations should be refined and optimized, and continue enforcement of them is needed. Finally, more publicity and school education on the MSW classification system are helpful in making the MSW classification part of the habits and moral principles of Shanghai's citizens. During the first month after the implementation of the new MSW classification regulation, the quality of the collected dry and wet waste is improved, resulting in better energy recovery and landfilling property. However, there was a shift in the waste amount from the dry waste to the wet waste; indeed, the average daily dry waste collected is decreased, and the average daily wet waste is increased. If the shifting continues, it could bring to an overcapacity of the dry treatment plants (particularly incineration plants) in Shanghai. Moreover, given the amount of wet waste disposed of improperly, the Shanghai's municipality should undertake more new wet treatment plan projects (also the projected capacity of 5500 tons/day by the end of 2020 will be not enough). In any case, only data of one month is not enough to draw out reliability conclusion in the long period. Moreover, according to the waste hierarchy, many efforts are made to decrease the MSW generation from the source. For example, disposable office supplies are discouraged, and recyclable papers are recommended to use. All the companies in Shanghai are encouraged to give priority to detachable, recyclable, and non-toxic materials and designs, and produce environment-friendly recyclable products. Restaurants, shops, and hotels are not allowed to offer disposable items to customers on their own initiative. In addition, residents are encouraged to buy and consume recyclable and other environmental friendly products (Zhou et al., 2019). The main barrier to establishing a soundness formal recycling system can be considered similar to those explained for the whole of China, such as the presence of the informal sector, the absence of a stable recycling market, and the needing for improving the people's knowledge of MSW classifications. Integration through innovative collection technologies, financial innovation as Public-Private Partnership and tax exemption for recycling industries, and ameliorating the accessibility to resource recovery facilities and authorities support to ensure people awareness (respectively), have been proposed as solutions to improve the current situation of the formal recycling system and remove the previously cited barriers. Moreover, regarding the integration issue, the fundamental success factor for Shanghai's municipality integration process is to replicate the efficiency of the informal recycling system based on price mechanisms and the relationships net among the informal actors within the system, and it could be facilitated by adopting intelligent collection tools. The challenge also represents a crucial opportunity for firms; innovative companies can provide solutions and helping the formalization transition, and Shanghai could become a testing city for new investment. Concluding, Shanghai is one of the Chinese cities with the longest experience in MSW classification and MSW management practices, and Shanghai's people are the willingness to experimented with new foreigner solutions. These can be considered as the reasons behind the choice to make Shanghai the first Chinese cities to incorporate the MSW classification in its regulations. If the MSW classification will succeed, and the main barriers removed (especially the one related to the integration of the informal recycling system), it could be a great success case for the whole China, and Shanghai could be taken as an example model, as a benchmark.

5 Conclusion

The MSW management of China and Shanghai has been successfully reviewed in this thesis work, and in the following are presented the main conclusions. The MSW management system in China has made much progress in the last decades. It has been able to decrease significantly the open dumping rate, increasing the harmless treatment exploiting the WTE industries, encouraged by effective policies and regulations. However, it is still far from the MSW management of developed countries, and its rate of recycling is still too low. Moreover, it should be pursued the waste hierarchy by a national point of view, and the percentage of MSW disposed of by landfills should be decreased. However, inside the country, there are deeply differences by regions; the most main and advanced MSW treatment facilities are deployed in the Eastern Regions, leaving the Western regions with a lacking of MSW treatment capacity. The principal findings of the current thesis are the importance of the informal recycling system, one of the most achievement for the Chinese Central Governments should be to incorporate, exploiting an integrative approach, the informal sector. The formal recycling system has to be improved to increase the recycling rate and the effectiveness of the recycling facilities, following the main target to get a sustainable MSW management system. The main recommendations of this thesis work are to ameliorate it through private participation and integrating the informal recycling system exploiting Intelligent Collection companies and practices. The Chinese exploring of the MSW classification started in the 2000s with the pilot project that is later than the other leading countries in recycling. One of the eight pilot cities was Shanghai, and it was one of the few cities that achieved a good result from the pilot program, along with Beijing. This is one of the most important reasons that explain why the Central Governments have chosen Shanghai as the first city to incorporate the MSW classification in its legal framework. Shanghai is considered by China, the *"showpiece"* of the enormous Chinese economic growth, and if the program will succeed Shanghai will be an excellent example for all the Chinese cities and megacities. Therefore it is important to understand the current status of the implementation of the new MSW regulation. Following, there are the main learned points of the initial MSW classification regulation experience in Shanghai. First, the leading role of the government in the initial stage of the system implementation and proper coordination among its departments is considered crucial, and it is encouraged to ensure proper MSW classification development. Second, waste collection fees system and private capital and private companies should be involved to promote a sustainable and marketized MSW-relevant industry in the future. Third, laws and regulations should be refined and optimized, and continue enforcement of them is needed. Fourth, more publicity and school education on the MSW classification system are helpful in making the MSW classification part of the habits and moral principles of Shanghai's citizens. Moreover, the municipality of Shanghai is undergoing several projects to improve its treatment capacity, according to the steady MSW increasing. The WTE industry in Shanghai is strongly encouraged by the municipality to replace landfilling, and it is compatible with the waste hierarchy. Finally, it should be precise that Shanghai is one of the most economically developed cities in the whole of China. If the MSW classification were a success it would be challenging to implement these practices in the less fortune Western regions. Even though this is out of the scope of this thesis, the most important achievement to reach sustainable MSW management in overall China should be supported by a commitment by the Central Government and local governments to reduce the economic and social inequalities among regions.

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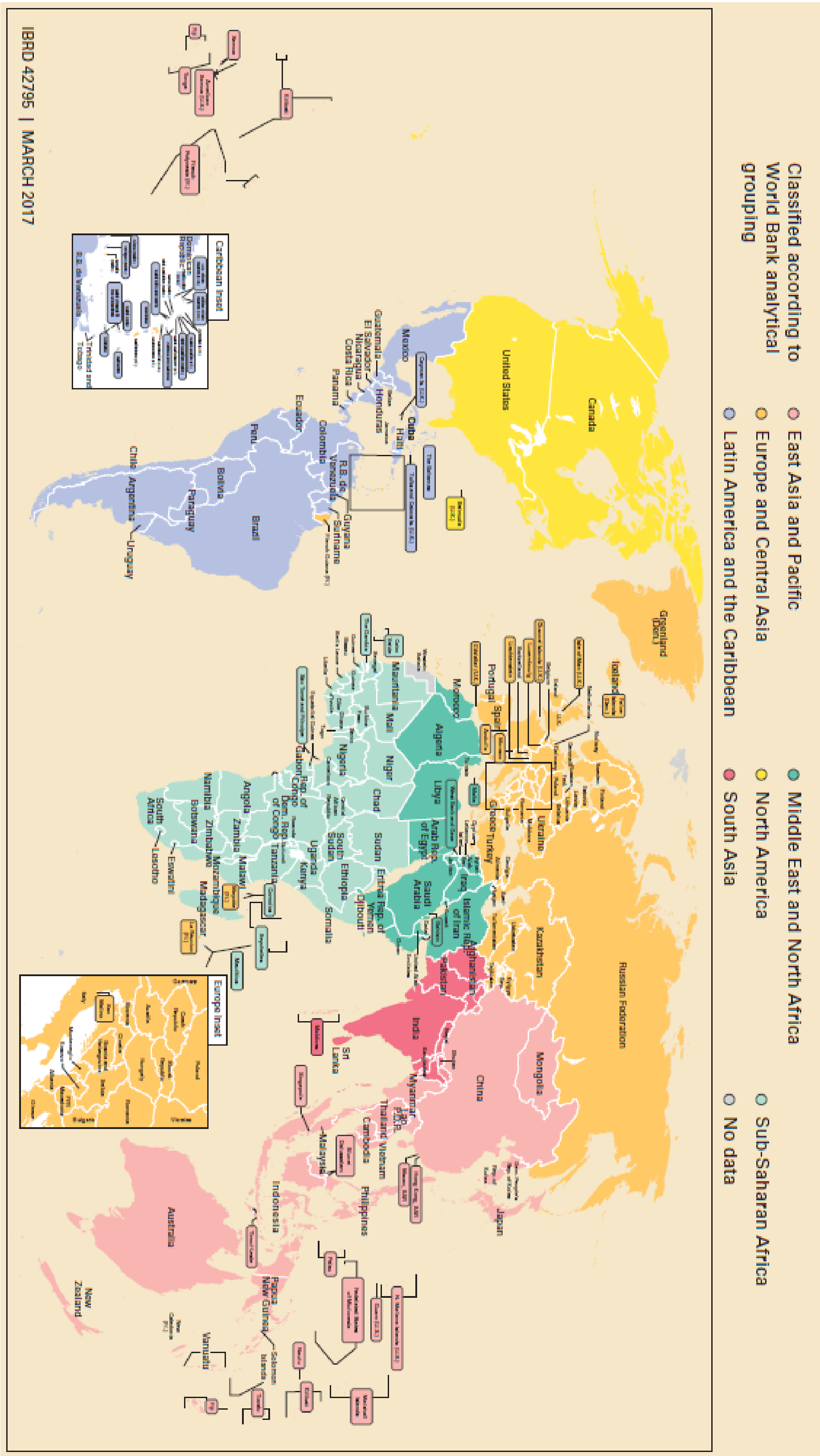
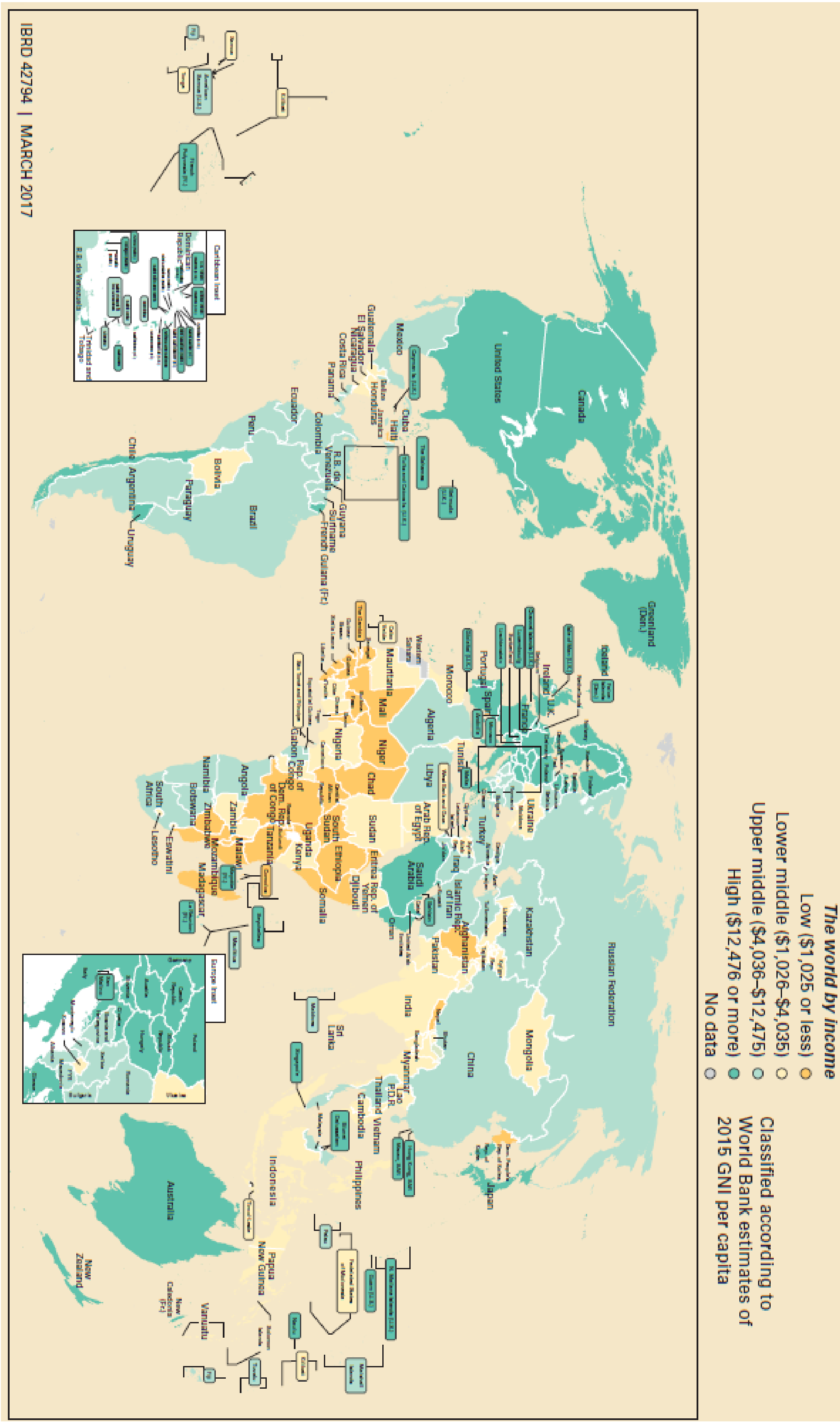
ANNEX 1 (Kaza et al., 2018);



ANNEX 2 (Kaza et al., 2018);



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