A Study of the Waste-To-Energy Industry in Beijing City

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Executive Summary

Beijing's population currently sits at approximately 22 million people, and these residents created over nine million tons of domestic garbage in 2017. Population growth and rapid economic development have resulted in a rapid increase in municipal solid waste (MSW) production in Beijing City. According to the National Municipal Bureau of Statistics, waste generation in Beijing increased from 4.5 million tons in 2005 to 9.2 million tons in 2017.[1] As a result of the "garbage siege" dilemma, the city government has realized that the disposal of garbage is a problem that must be urgently resolved.

The waste treatment procedures commonly used in Beijing include landfill, composting and waste-to-energy (WTE). In 2017, landfill, as the main waste treatment method in the city, accounted for 47% of total waste disposal; and waste-to-energy and composting comprised 35% and 17% respectively.[2] In recent years, with the growing pressures of land scarcity and rapid waste growth, the local government has focused on improving WTE technology and has provided significant financial support to the industry. Since 2008, ten waste-to-energy plants have been built and launched, with a total designed capacity of 13,650 tons/day.

This study focuses on the WTE industry in Beijing and discusses the MSW management and the development of the WTE industry in Beijing from the perspective of the circular economy. The quantity of waste-to-energy plants has increased significantly over the last ten years and will continue to grow in the near future; the gap between the current total designed capacity of waste disposal facilities and the actual MSW generation in Beijing could be abridged by the construction of additional waste-to-energy plants. Waste-to-energy has been given priority as a form of waste management and will play a more critical role than landfills in Beijing's MSW management over the next few years. Although the WTE industry offers a potential solution to the crisis, it also suffers from issues such as toxic pollutants, high social costs, and opposition from the public. The government needs to be more responsible for supervising the management and operation of waste-to-energy plants to counteract these issues. This paper suggests that waste reduction and utilization are expected to be the final strategies for waste management in Beijing, and that promoting effective waste sorting at source is an essential task for the city government.

[1] National Bureau of Statistics of China. (2018).
[2] Beijing Municipal Bureau of Statistics & Survey office of the National Bureau of Statistics in Beijing. (2018). Beijing Regional Statistical Yearbook.

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1. Introduction

The increasing amount of municipal solid waste (MSW) is a growing challenge across the world. Its management has become a significant problem for many cities. In 2017, the production volume of municipal solid waste in China was over 200 million tons, and it is still increasing at a rate of approximately 8% pa. This increasing amount of urban domestic garbage places considerable pressure on the public health and MSW management systems of cities. Traditional waste disposal methods, landfill and composting, do not have sufficient capacity to meet the daily waste treatment requirements.

In developed countries, especially Japan and Western Europe, waste-to-energy has become the mainstream technology for municipal solid waste disposal. After combustion, waste volume can reduce by 50 - 80% compared to the original, and the volume of garbage classified as combustible can be reduced by up to 90%.[3] Large-scale waste-to-energy devices can also effectively collect and use the heat generated during the process to produce electricity, thereby recycling the energy. The waste-to-energy technology effectively realizes waste reduction, harmlessness, and resource utilization. Compared with developed countries, China's waste treatment technology is immature, and the rate of the harmless disposal of waste is relatively low. In the 1980s, Shenzhen introduced a complete set of waste-to-energy treatment equipment from abroad and built China's first modern waste-to-energy plant.[4] In recent years, thanks to rapid economic development and China's governmental promotion of waste-to-energy technology, the waste-to-energy industry has developed rapidly in China. For China's first-tier cities and mega cities, represented by Beijing, waste waste-to-energy is currently the preferred solution to the "garbage siege" dilemma.

Several studies have provided an overview of the MSW management in Beijing City, but there have been few detailed studies of waste disposal in Beijing City, especially following the increased utilization of waste-to-energy technology. This paper presents an overview of current waste production and management in Beijing. The study investigates the development of waste-to-energy technology over the last few decades and the current operational status of waste-to-energy plants in Beijing. It points out the problems with the disposal of incinerated waste as well as management issues in the waste-to-power industry before suggesting improvements for that industry. It is the hope of this research that the city can improve the economic and environmental benefits of waste-to-energy plants, make full use of garbage resources, and gradually achieve circular development.

[3] Fang, J. (2004). Exploration of Development of Municipal Solid Waste Incineration in Beijing. *Urban Management Science & Technology,* 2004. No.1, Vol.6: 34-41

[4] Zhang, Y., Shang, X., Li, K., et al. (2011). Technologies status and management strategies of municipal solid waste disposal in China. *Ecology and Environmental Sciences*, 2011, 20(2): 389-396.

2. Waste in China

2.1. Waste Production in China

China has a large population and is a sizeable waste-producing country. With the acceleration of urbanization, "garbage siege" has become a common phenomenon in Chinese cities. By 2015, the accumulated municipal solid waste stock had reached 8 billion tons, covering an area of more than 800,000 acres, and the amount of waste generated was still growing at an annual rate of between 5% and 8%. It is estimated that Chinese people produce 0.8 kg to 1.3 kg of domestic waste per capita every day. The output of municipal waste is expected to reach approximately 323 million tons by 2020. Of the 668 cities in the country, two-thirds are surrounded by garbage and many cities are now finding that there is not enough space available in landfill sites.[5]

In 2018, 202 large and medium-sized cities across the country released information on the prevention and control of solid waste pollution in 2017. According to the statistics, in 2017, the amount of domestic waste produced in these 202 cities was 201.94 million tons, the disposal volume was nearly 200.84 million tons, and the disposal rate reached 99.5%. The table below lists the top 10 waste-producing cities; Beijing is the city with the largest amount of municipal solid waste, followed by Shanghai, Guangzhou, Shenzhen, and Chengdu. The total amount of MSW generated by the top 10 cities was nearly 57 million tons, accounting for 28% of the total amount of waste produced across the 202 cities.[6] The "garbage siege" in big cities like Beijing is becoming increasingly severe, and the resulting harm to the environment and public health is becoming increasingly prominent. The effective disposal of garbage has become an urgent problem for city governments.

Table 1: Top 10 cities of municipal solid waste generation in 2017[6]

	City	Province	Municipal solid waste production (1000 tons)
1	Beijing	-	9018
2	Shanghai	-	8995
3	Guangzhou	Guangdong	7377
4	Shenzhen	Guangdong	6040
5	Chengdu	Sichuan	5413
6	Xi’An	Shanxi	4225
7	Hangzhou	Zhejiang	4000
8	Wuhan	Hubei	3964
9	Dongguan	Guangdong	3926
10	Foshan	Guangdong	3900

[5] National Institute of Clean and Low-Carbon Energy. (2015).

[6] Ministry of Ecology and Environment. (2018). 2018 Annual report on pollution prevention and control of solid waste in Large and Medium-sized Municipal in China.

2.2. *Waste Disposal in China*

Waste disposal in China includes sanitary landfill, waste-to-energy, and composting. The majority of domestic waste goes to landfill. In the statistical annual report from the Ministry of Ecology and Environment, in the year of 2015, a total of 248 million tons of domestic waste was processed, of which 178 million tons were sent to landfill, 40 million tons were composted, and 66 million tons were incinerated.[7]

In recent years, due to the rapid growth of the amount of municipal solid waste produced, landfill sites and composting facilities have been unable to meet the needs of municipal solid waste treatment, and so a lot of effort has been put into developing waste-to-energy technology. Although landfill is still the most critical method of urban domestic waste disposal in China, due to the rapid growth of waste-to-energy treatment, the proportion of waste sent to landfill is declining. In relation to the treatment of cities' MSW, the proportion sent to landfill decreased from 85% to 57% from 2004 to 2017, a decrease of 22%, while the ratio of waste-to-energy treatment increased from 6% to 40% with an increase of 34%.[1]

Under the Law, of the People's Republic of China, on the Prevention and Control of Environment Pollution Caused by Solid Wastes, the Chinese government implemented the principles of "Reduction, Recycle, and Harmlessness" for MSW management. This requires the reduction of discharge and harm caused by solid waste, fully and rationally utilizing solid waste, and making it safe through treatment.[8] Since the waste-to-energy disposal method is most in line with these three principles, it is rapidly becoming the dominant direction for domestic waste treatment in China. The treatment of MSW in China has shown an increasing trend towards waste-to-energy generation and decreasing percentages of waste sent to landfill.

In recent years, waste-to-energy plants have become part of the basic facilities expected, especially in urban areas. At the end of 2018, waste power generation projects had spread throughout 30 provinces, municipalities and autonomous regions. There were 401 waste-to-energy projects throughout the country - 63 more than in 2017.[9] Most of the projects are concentrated in Eastern and Northern China and, due to its developed economy, Eastern China utilizes waste-to-energy technology on a much greater scale. The installed capacity of power generation plants in East China was approximately 56% of the total capacity of the whole country.[10]

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[7] Ministry of Ecological and Environment (n.d.). 2015 Environmental Statistics Annual Report.
[8] Standing Committee of the National People's Congress. (1996). Law of the People's Republic of China on the Prevention and Control of Environment Pollution Caused by Solid Wastes (2016 Revision).
[9] The Biomass Industry Branch of China Industrial Development Promotion Association (2019). 2019 China Biomass Power Generation Industry Report.
[10] The Biomass Industry Branch of China Industrial Development Promotion Association (2018). 2018 China Biomass Power Generation Industry Report.

By the end of 2018, the total installed capacity of waste-to-energy projects in China reached 9.16 million kWh, which was an increase of approximately 26% over the previous year. The annual power generation was 48.81 billion kWh, and the yearly electricity generation delivered to the power grid was 39.32 billion kWh. The volume of domestic waste disposed of via power generation grew from 100 million tons in 2017 to 130 million tons in 2018, which is an average annual increase of 30%.[6] With economic growth and the improvement of living standards, the amount of waste generated for disposal will continue to increase, and the waste-to-energy industry will need to maintain this rapid expansion. The Ministry of Ecology and Environment predicts that the installed capacity of waste-to-energy power plants will continue to develop at the current rate and exceed 11 million kilowatts by the end of the 2019.

2.3. Future of Waste-to-Energy Industry in China

The waste-to-energy (WTE) industry has good prospects in China. Firstly, the increase in the volume of domestic garbage removal and transportation will create an ample market for the WTE industry. It is estimated that by 2025, the amount of MSW disposed of in cities and counties in China will be 440 million tons. The proportion of this waste sent for power generation will exceed 60%. The average daily waste-to-energy treatment capacity can reach about 720,000 tons.[11] Secondly, in areas with a developed economy and high living standards, the organic matter content and calorific value of domestic waste are also high. Economic development and the improvement of living standards will increase the heat value of waste, effectively increasing the efficiency and revenue of waste combustion for power generation. Another important factor is the support provided by the national government; waste-to-energy is a nationally promoted waste treatment method, and the electricity generated from WTE plants is an essential component of the country's renewable energy.

Under China’s 13th Five-Year Plan (2016-2020), the state government proposed that economically developed areas and cities with a shortage of land resources and a large population should give priority to the use of waste-to-energy technology to reduce the amount of landfill. In addition, when constructing waste-to-energy plants, cities should also build supporting facilities for the disposal of waste combustion residues and fly ash. Sanitary landfill will become the last choice for domestic waste disposal, as a safeguard for garbage treatment. It will predominantly be used for incineration residue, fly ash, and emergencies.

For municipalities directly under the Central Government (Beijing, Shanghai, Tianjin, Chongqing), planned cities and provincial capital cities, the national government has set higher requirements for waste treatment and waste-to-energy techonology. By the end of 2020 these key cities need to: establish a waste recycling system and a complete supervision system for garbage treatment,

[11] Yu, X. (2018). Analysis and Prospect of Municipal Solid Waste Incineration in China. *China Power Enterprise Management.*

effectively classify domestic garbage, raise the recycling rate to above 35%, send no unsorted waste to landfill, achieve a 100% harmless waste disposal rate, and increase waste-to-energy plants' capacity to more than 50% of the total capacity of harmless treatment.[12]

3. Waste in Beijing City

3.1. Waste Production and Waste Material Flow in Beijing

Beijing is the political, cultural, and economic center of China. In 2018, Beijing had a permanent population of about 21.54 million people. With the continuous expansion of the city and sustained economic growth, the living standards of residents have also steadily improved. On a daily basis, the city's municipal solid waste changes in both volume and composition. The data of recent years shows that the overall generation of garbage in Beijing has been increasing in line with the increase in population and GDP. The population of the city was 15 million in 2004 and nearly 22 million in 2017, while the economic development index, GDP, has increased more quickly and achieved a more than a four-fold increase from 600 billion yuan in 2004 to 2802 billion yuan in 2017. The total MSW generated in Beijing decreased slightly in 2010 and 2012, due to an increased emphasis on environmental issues, but then rose again. In 2017, the total amount of waste generated in Beijing reached 9.24 million tons, with a daily output of about 25,000 tons. [13]

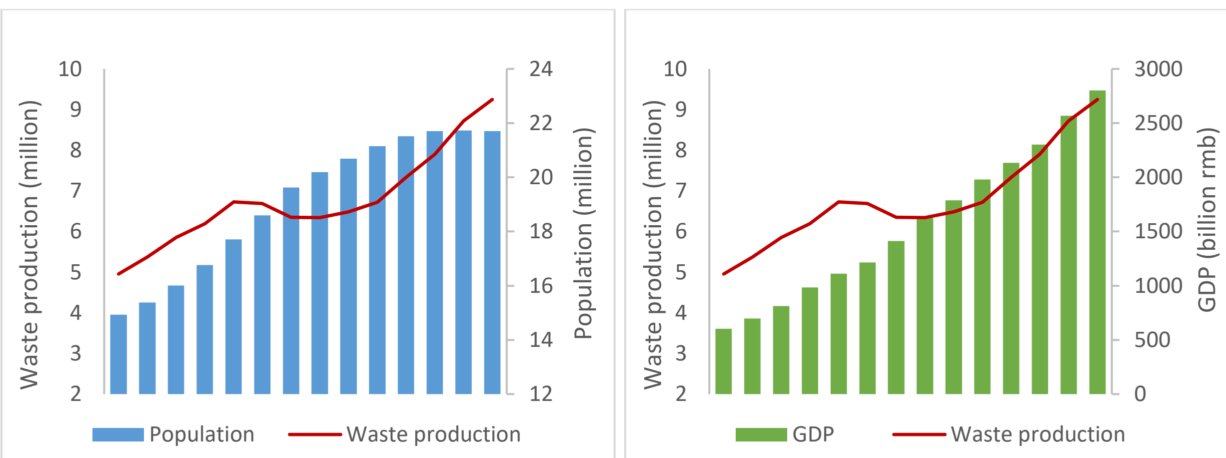

Figure 1: Trends in Population, GDP, and Output of Domestic Waste in Beijing, 2004 – 2017

Beijing divides MSW into four categories: recyclables, kitchen waste, hazardous waste, and other waste.[14] Recyclables mainly refers to articles that can be processed into raw materials or articles that can be reused after recycling, such as paper, plastics, metals, and glass. Kitchen waste mainly includes leftovers, root vegetables, and other residues, which contain a large amount of organic

[12] National Development and Reform Commission & Ministry of Housing and Urban-Rural Development (2016). The National 13th Five-year Plan for the Construction of Urban Domestic Waste Treatment Facilities.
[13] Beijing Municipal Bureau of Statistics. (Various years).
[14] Beijing Municipal Commission of Urban Management. (n.d.). Classification of Domestic Waste.

substances suitable for composting. Hazardous waste refers to waste that causes direct harm or poses a potential risk to the human body or the environment, such as used batteries, and requires special safety treatment. Other waste includes waste food bags, waste paper towels, lime butts, and other trash.

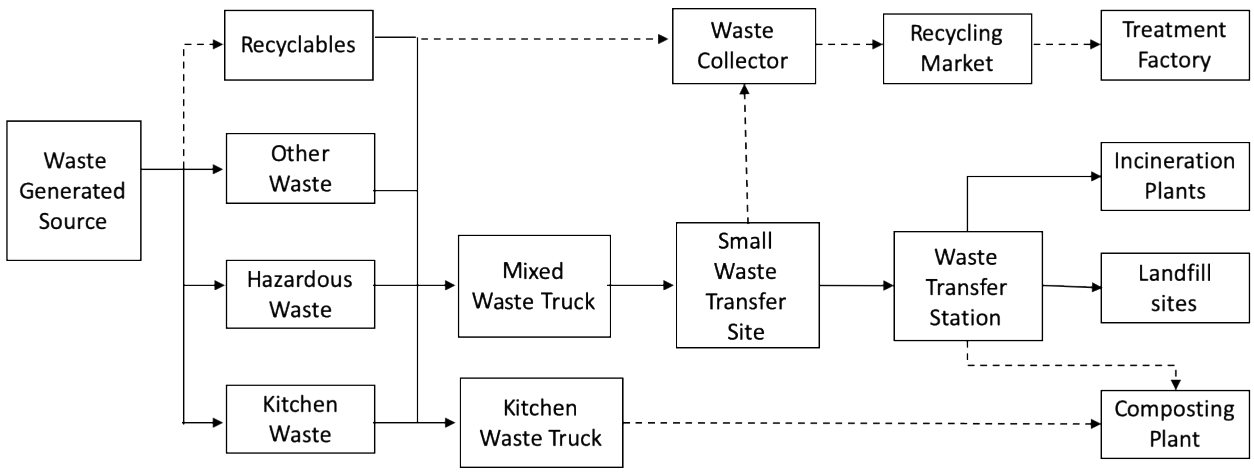

Figure 2: Waste Material Flow in Beijing

The typical trend of Beijing's waste material flow is shown in the above figure.[15] Sanitation teams are responsible for regularly cleaning trash bins and transferring the waste by small tricycle or truck. Sanitation workers collect recyclables, kitchen waste, hazardous waste and other waste together and send the mixed garbage to small transfer stations for packing and storage. These stations are usually located near settlements. Large garbage trucks then transport the waste from small transfer stations to the large closed sanitation transfer stations for waste sorting. The sorted waste is then transported to waste treatment plants to be incinerated, biochemically treated, or to go to landfill. In addition to this mixed waste collection, recyclables have an additional process path. Waste producers can sell recyclables to waste collectors, or recyclers can retrieve recyclable material from trash bins in the community or from the mixed waste at small transfer sites. Recyclables then enter the recycling market through resale and eventually go into the resource recovery and processing facilities.

At present, Beijing's population has a weak awareness of garbage classification, and waste sorting is therefore inadequate. The waste classification work carried out in waste transfer stations has made up for these shortcomings and improved the resource utilization rate of solid waste. In Beijing, there are also dedicated garbage trucks for the collection and transportation of certain classifications of waste.[16] For example, specific kitchen waste trucks collect kitchen waste, which

[15] Qi, L. (2014). Analysis of the status of municipal waste disposal in Beijing. *China Resources Comprehensive Utilization*, 2014, Vol.33, No.4: 38-41.
[16] Yang, X. (2019).

is then sent directly to the treatment plant. However, due to inadequate waste classification at source, the use of this method is limited.

3.2. Waste Disposal in Beijing

The amount of MSW generated in Beijing is increasing. To meet the demand for treatment, garbage removal and harmless disposal have also increased year on year. In 2018, in Beijing's sanitation system, the volume of domestic waste collected and transported to treatment plants reached 9.756 million tons - it was 2.956 million tons in 2000. The amount of garbage harmlessly disposed of was 9.751 million in 2018 – it was 1.667 million tons in 2000. The harmless treatment rate of the waste removed in 2018 was 99.94%, a 43.94% increase from the rate of 56% in 2000.[17]

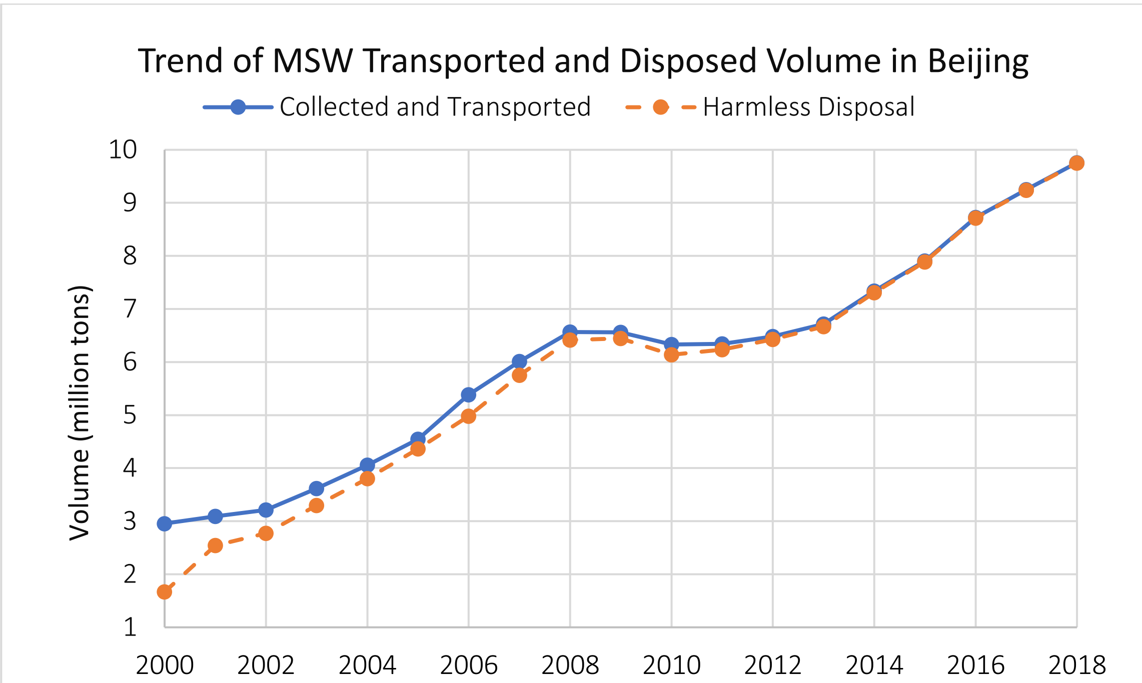

Figure 3: Amount of Municipal Solid Waste Removed and Disposed of in Beijing (2000 – 2018)

At present, Beijing uses three methods of harmless waste disposal: waste-to-energy, composting and sanitary landfill. After years of development, these three waste treatment methods are industrialized.

- The purpose of waste-to-energy is to minimize the volume of municipal solid waste and use the heat generated by the combustion to generate electricity. However, this method can reduce the utilization rate of garbage, and may cause secondary pollution.
- Landfills bury solid waste at a suitable site and add covering materials to allow it to reach a balance after a long period of physical, chemical, and biological effects. The method is simple

[17] Beijing Macroeconomic and Social Development Database. (Various Year).

and easy to implement but landfill sites usually cover large areas, and the garbage frequently produces toxic liquids that erode the soil, pollute water sources, and affect the health of residents.

- Composting involves mixing the organic matter in the garbage with a certain proportion of inorganic matter. Under controlled conditions, the organic waste can be degraded and transformed into stable humus by microorganisms and can then be used to fertilize farmland. The advantage of this method of disposal is the partial realization of resources, but this is offset by the long processing cycle and potential secondary pollution.

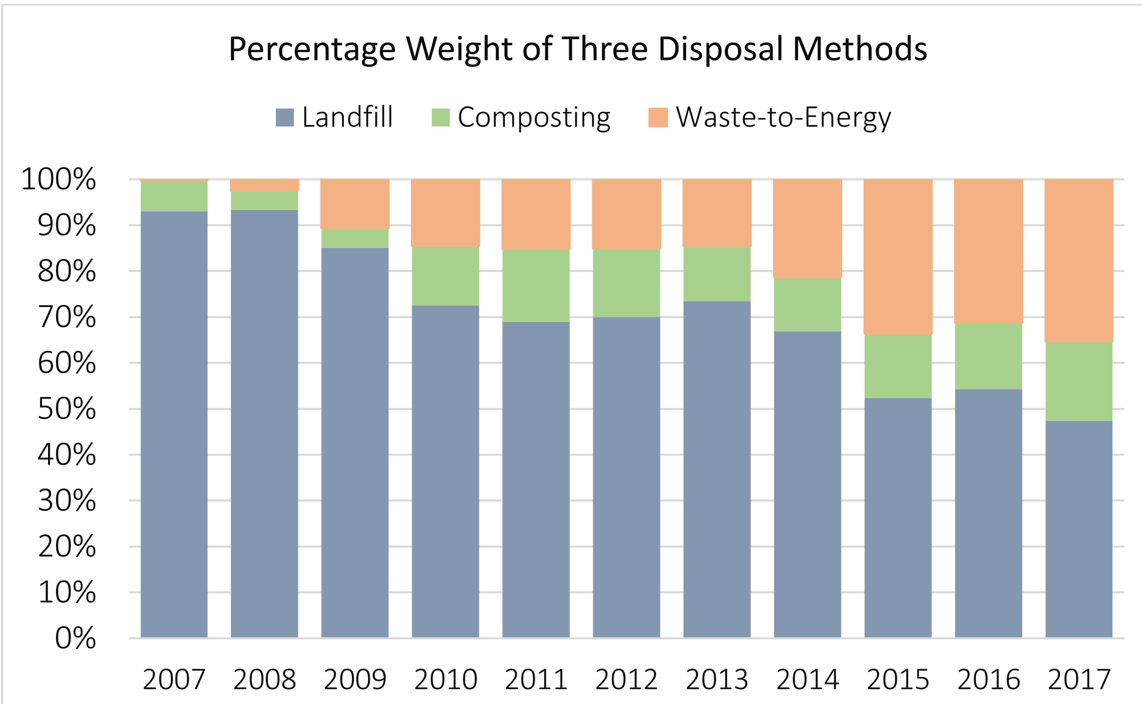

Figure 4: Percentage Weight of Three Disposal Methods in Beijing (2007-2017)

Although landfill is currently still the primary waste disposal method in Beijing city, waste-to-energy and composting have been catching up in recent years. In 2008, sanitary landfill accounted for over 90% of MSW disposal, while waste-to-energy and composting only comprised 2% and 4% respectively. However, after waste-to-energy method was prioritized by the government, the percentage of waste-to-energy disposal soared quickly. In 2017, only 47 percent of domestic waste was placed into landfill sites. Waste-to-energy accounted for 35% of the total capacity of waste disposal, which is a 33% increase from 2% 10 years before.[17]

3.3. Urban Functional Areas and Waste Treatment Factories

In different administrative divisions within Beijing, the production volume of domestic waste is different. The waste generation per capita decreases radially from Beijing's urban center towards surrounding suburban areas. Influenced by population, production status, economic level, future tasks, and other factors, different districts in Beijing play different roles in the city's development plan including waste treatment. This can be seen from the distribution of waste treatment plants and the waste disposal amounts in different areas.

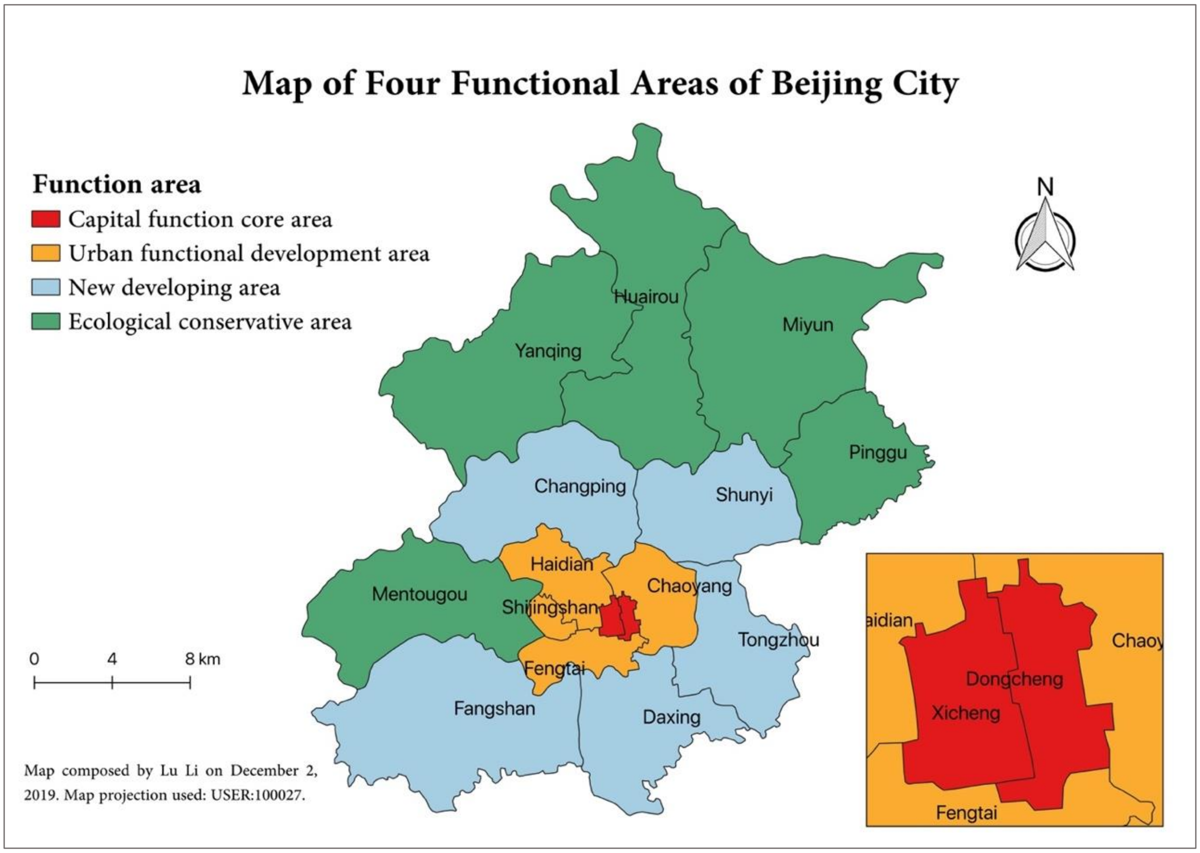

Figure 5: Map of Four Urban Functional Areas of Beijing City

Beijing consists of 16 administrative county-level subdivisions. In the city's 11th Five-Year Plan, the municipal government proposed four distinct urban functional areas: capital function core area, urban functional development area, new developing area, and the ecological conservative area.[18]

- The capital function core area reflects Beijing's characteristics as a national political and cultural center. Its main task is to strengthen urban management and protect the historical and cultural heritage of this ancient capital.
- The urban functional development area reflects Beijing's modern economic and international communication functions. The development goals of this region are to expand economic services, promote technological innovation, and develop high-tech industries in order to enhance the city's competitiveness.

[18] Beijing Municipal Commission of Development and Reform. (2006). Development planning of functional areas in Beijing during the "11th Five-Year Plan" period.

- The new developing area focuses on the development of manufacturing and modern agriculture in Beijing. It is also an important settlement area for the population and industries migrating from urban centers.
- The ecological conservation zone, which is predominantly mountainous, provides the ecological barrier and water source for the city. To ensure the sustainable development of Beijing, the region is working on promoting environmental protection, developing eco-friendly industries, and building the ideal entertainment space for the public.

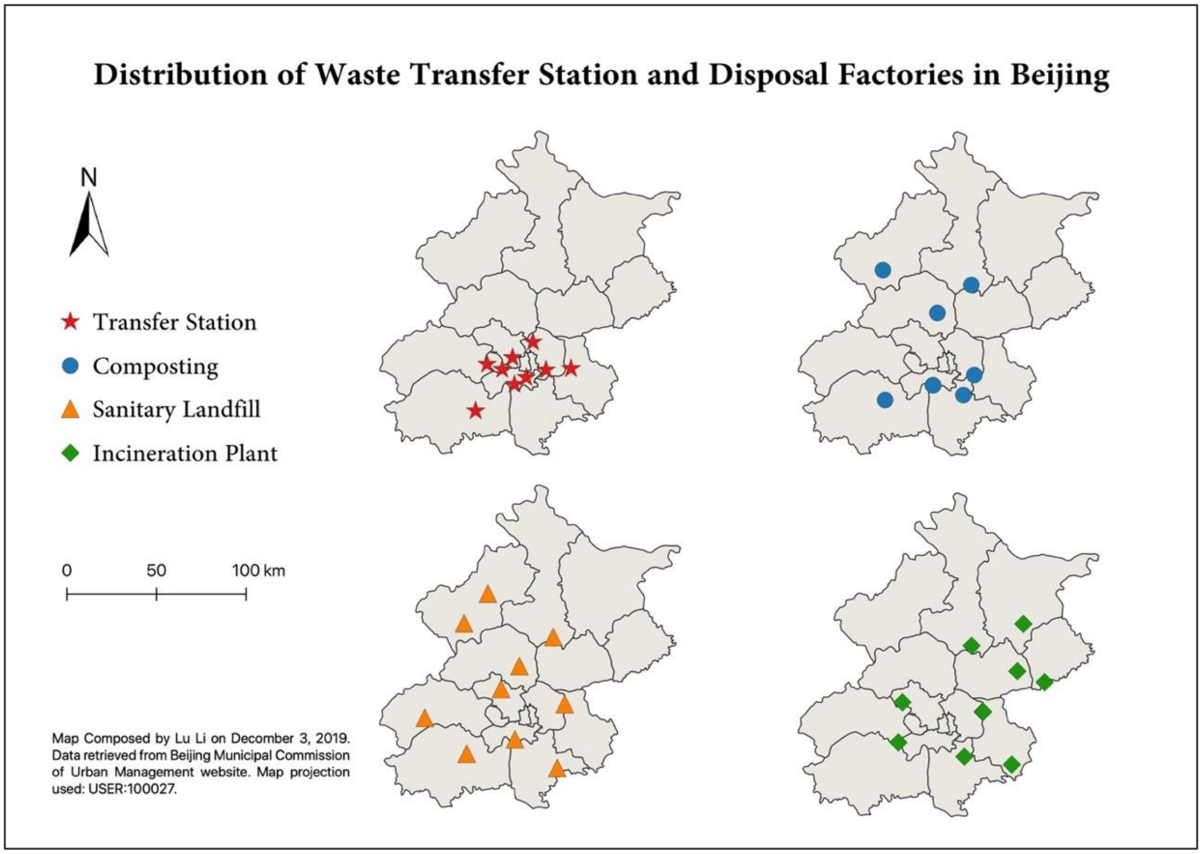

Figure 6: Map of Waste Transfer Stations and Disposal Factories in Beijing

The city now has 9 large-scale waste transfer stations and 29 officially operating waste treatment plants, including 8 composting facilities, 10 waste-to-energy plants, and 11 landfill sites.[19] The nine garbage transfer stations are concentrated in the city center and other developed areas. These areas are densely populated, economically developed, and have high levels of consumption, so they are priority sources for waste production. Establishing transfer stations in these areas can reduce the time and costs of waste collection and transportation. Sanitary landfill, composting,

[19] Beijing Municipal Commission of Urban Management. (2019). Beijing Domestic Waste Treatment Facility Summary Table.

and waste-to-energy plants are relatively scattered in the new developing and environmental protection zones, where there are more land resources and lower population density.

In order to promote the treatment of domestic garbage and to avoid over-construction of waste treatment facilities, in 2010, Beijing implemented penalties for the cross-regional treatment of waste. The policies stipulate that each district must pay financial compensation to the district that receives and deals with their garbage, at a price of 150 yuan per ton. The municipal government also established a standardized platform to collect the fees from districts that produce waste and distribute it to the districts processing the waste. For example, in 2012, Dongcheng and Xicheng districts paid 70 million and 88 million yuan to the platform, respectively. On the other side, Changping received 179 million yuan, Daxing received 168 million yuan, and Tongzhou received 45 million yuan for the treatment of transferred waste.[20]

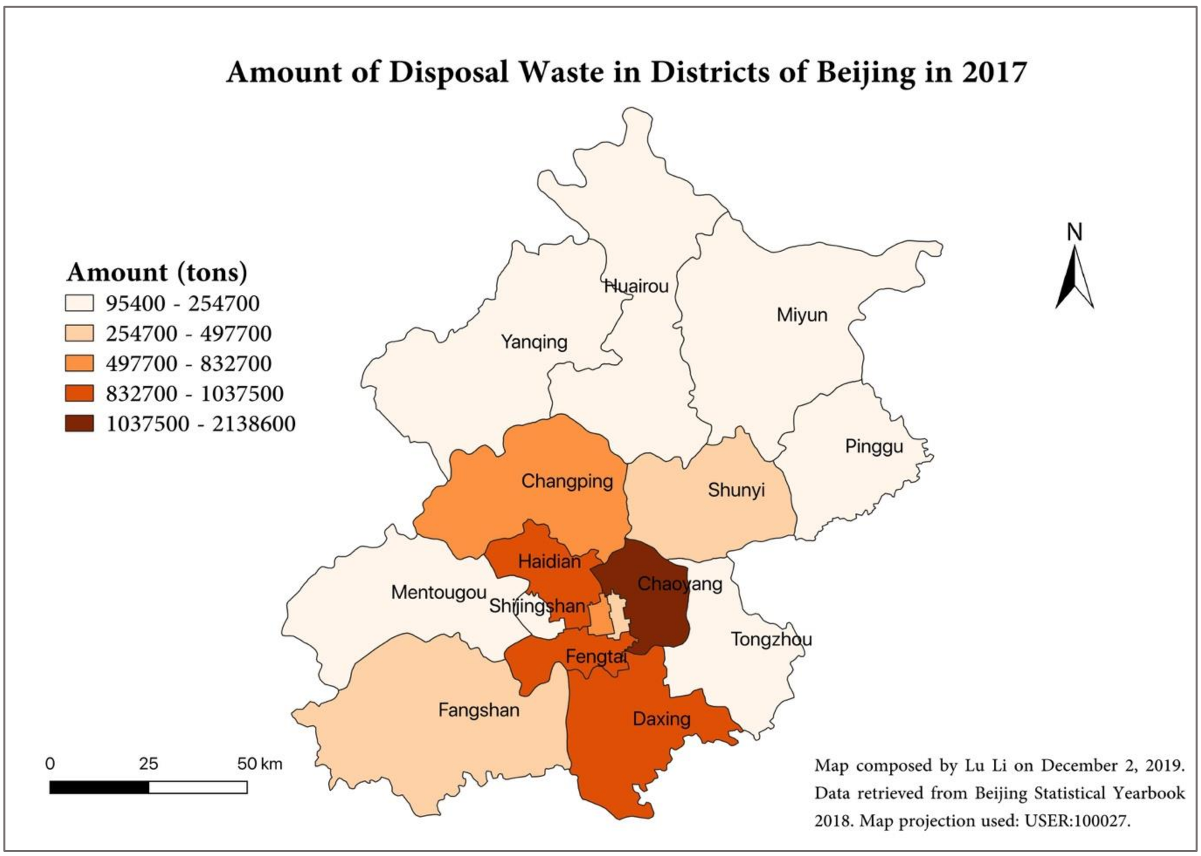

Figure 7: Map of Waste Disposal in the 16 districts of Beijing (2017)

The interregional transfer of waste helps districts in capital functional and ecological conservative areas reduce the pressure of waste treatment, and protects the urban and rural environments. At the same time, the policies promote the effective use of waste disposal facilities in developing

[20] The people's Government of Beijing Municipality (2013). The implementation of economic compensation policies for domestic garbage off-site treatment has a significant effect.

regions. These effects are reflected in the above map depicting the amount of waste harmlessly disposed of in each of the districts. The urban functional development area and new developing zone undertook most of the garbage disposal work. Among them, Chaoyang District has the strongest waste disposal capacity and its disposal volume was over two million tons in 2017.[21] In contrast, the amount of garbage disposed of in the other two functional areas is much lower.

The introduction of a compensation system and the centralized management of funds has achieved good results. The city government is now focusing on promoting waste reduction in waste generation zones and helping waste-disposal districts to upgrade disposal technology and to improve the environment surrounding treatment facilities.

4. Waste-to-Energy Industry in Beijing

4.1. Development of Waste-to-Energy

The development of the waste disposal industry in Beijing started late. Before the 1980s, household waste in Beijing was transported to farmland in the suburbs as fertilizer. After the 1980s, more non-degradable substances such as metals, plastics, and glass began to appear in domestic garbage and so the waste was no longer suitable for farmland composting. At this point, the city government had neither waste processing facilities nor relevant regulations. Littering and dumping became serious problems, and a large amount of urban garbage was stacked or landfilled in suburban areas.

In the mid-1990s, Beijing began the construction of a small number of sanitary landfill sites, but these landfill plants have deficiencies in terms of site selection, anti-seepage systems, leachate treatments, and monitoring systems. Leachate pollution under landfill sites caused groundwater pollution and led to increasing incidences of diseases in surrounding communities. As the landfills began to fill, and in light of the shortage of land for new sites, the difficulty and costs of using landfills has risen sharply. With the surge in waste production and the unsustainability of landfills, waste-to-energy, as an internationally recognized waste technology, has begun to receive more and more attention from the city government.

In 2004, as a key project of the Beijing 2008 Olympic Games and the first waste-to-energy plant in Beijing, construction began on the Gao'antun waste incineration plant. At the end of 2008, the incinerator began disposing of domestic waste. Over the past decade, the construction of Beijing's waste treatment facilities has reached the fastest speed in history. In China's 12th Five-Year Plan period (2011-2015), Beijing started the construction and renovation of 42 waste treatment facilities, including waste-to-energy, biochemical, and leachate treatment projects. There were four waste-to-energy plants completed and put into trial operation - Chaoyang Waste Incineration

[21] Beijing Municipal Bureau of Statistics (2018). Beijing Regional Statistical Yearbook.

Center, Haidian District Renewable Energy Power Plant, Lujiashan Waste Incineration Plant, and Nangong Domestic Waste Incineration Plant. These Four newly built waste-to-energy plants, with a total capacity of 7600 tons/day, increased the city's waste-to-energy treatment capacity by almost 400%.[22] What is more, Lujiashan Waste Incineration Plant is currently the largest waste-to-energy plant in Asia.[23] Chaoyang Waste Incineration Center is the second waste-to-energy plant in the Chaoyang District, after Gao'antun Waste Incineration Power Plant.

4.2. Waste-to-Energy Plants in Beijing

Beijing now has ten operational waste-to-energy plants located in nine districts; they are mostly located on the fringe of districts. In order to extend the service life of existing landfill sites, most waste-to-energy facilities have been built close to these existing landfill sites. In addition to these ten plants, there are also other waste-to-energy projects currently in the process of being constructed or planned. Except for the capital function-core area, each urban functional area has at least one site identified for the construction of a waste-to-energy plant in the city government's plan. Over the next few years, Beijing's waste-to-energy industry will continue to grow due to the construction of new waste-to-energy plants and expansion of existing plants.

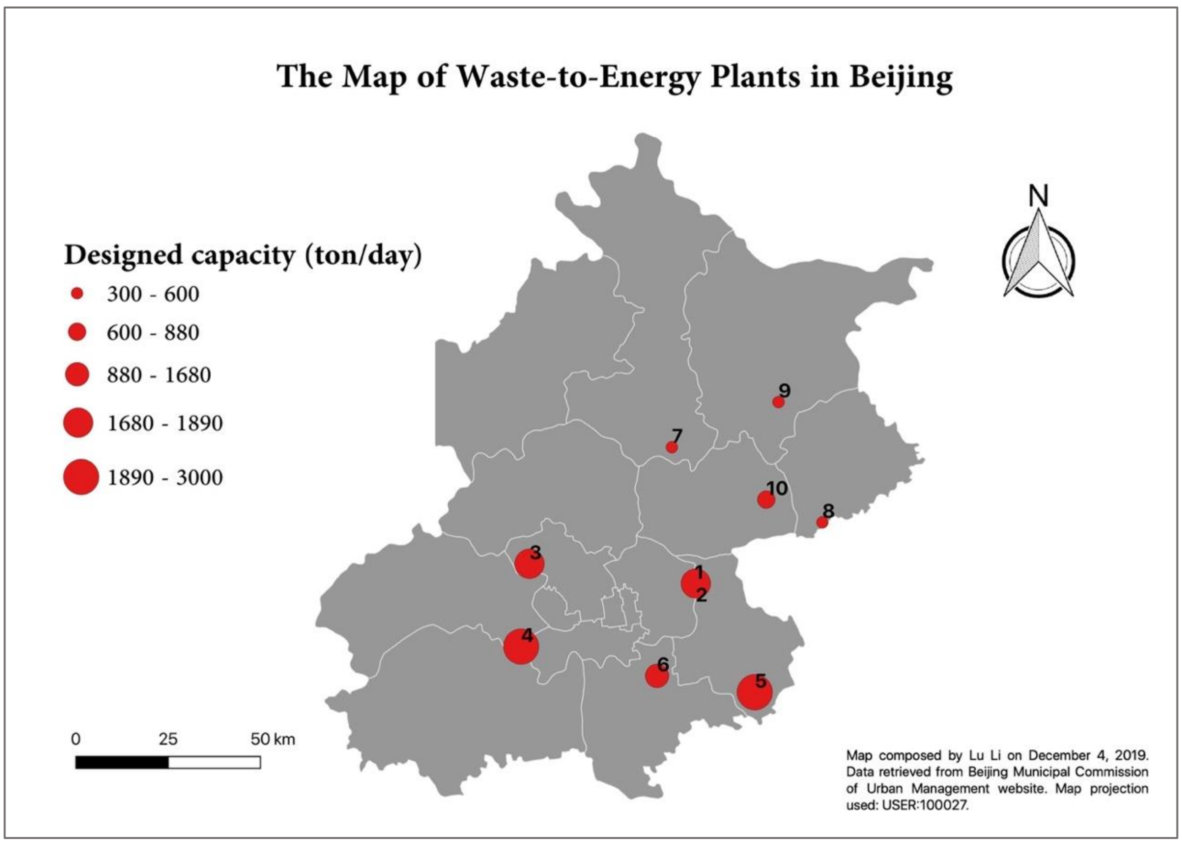

Figure 8. Waste-To-Energy Plants in Beijing

[22] Beijing Municipal Commission of Urban Management. (2018). Beijing Environmental Sanitation Development Plan.
[23] Jiang, W. & Lin, Z. (2017). Waste treatment, from extensive industry to circular economy. *Beijing Business Today.*

Table 2: List of Waste-to-Energy Plants in Beijing

	Facilities	Year of formal operation	Designed capacity (ton/day)	Estimated Annual Treatment Capacity (1000 tons)	Estimated Annual Electricity Generation (million kWh)
1	Gao'antun Waste Incineration Power Plant	2009	1,600	700	220
2	Chaoyang Waste Incineration Center	2016	1,800	657	226
3	Haidian District Renewable Energy Power Plant	2017	1,800	/	280
4	Lujiashan Waste Incineration Plant	2013	3,000	1000	420
5	Tongzhou District Renewable Energy Power Plant	2018	2,250	750	200
6	Nangong Domestic Waste Incineration Plant	2017	1,000	310	130
7	Huairou Domestic Waste-to-Energy Plant	2018	600	/	/
8	Pinggu Waste Comprehensive Treatment Plant	2018	300	210	60
9	Miyun Waste Treatment Center	2018	600	200	56
10	Shunyi Waste Treatment Center -Incineration Plant	2018	700	/	80

Every day, these WTE plants receive a tremendous amount of waste in Beijing city. The total designed treatment capacity of the ten operating plants is 13,650 tons per day. They can generate more than 1600 million kWh of electricity a year from approximately four million tons of waste. Take the Lujiashan waste incineration plant as an example. Lujiashan waste incineration plant was constructed by the Beijing Municipal Government in partnership with Shougang Group, with a total investment of 2.16 billion yuan. The project was officially launched in 2010 and was put into production at the end of 2013. This waste-to-power plant has a daily processing capacity of 3,000 tons and is the largest waste-to-power plant in Beijing. As of 2016, the waste-to-energy plant had received a total of 2.18 million tons of garbage, and 1.7 million tons of garbage had been incinerated to produce 627 million kWh, of which 475 million kWh went into the electricity grid.[24]

Although the city's consumption of WTE electricity has increased, due to the increase of waste-to-energy plants and the nation's move towards renewable resources, compared to natural gas and

[24] Gao, F. (2016). Revealing Beijing's largest waste treatment plant - Lujiashan Waste Incineration Plant. *WORLD ENVIRONMENT*, 2016. No.4: 80-81

other renewable energies, WTE electricity is still only a minor part of the urban power supply. In 2018, Beijing's power consumption reached 1144.2 billion kWh, which was an increase of 7.1% over the previous year. The amount of electricity consumed during production was 88.6 billion kilowatt-hours, and residents' electricity consumption was 25.6 billion kilowatt-hours.[25] While the estimated total annual power generation of the ten existing waste-to-energy plants was less than 2 billion kWh. Excluding self-consumed electricity, the WTE generated electricity flowing into the power grid is insignificant in comparison to Beijing’s overall electricity consumption. Therefore, the electricity generated by waste-to-energy is not a sufficient stand-alone reason to promote this disposal method. The main function of Beijing's waste-to-energy industry, at this time, is to reduce the volume of waste and increase the city’s capacity for treating waste.

4.3. Waste-to-Energy Technology

In the Policy for Municipal Solid Waste Treatment and Pollution Prevention Technology, released in 2000, the national departments made the following provisions for waste-to-energy treatment technology[26]:

- Waste-to-energy plant is encouraged in areas where the average heating value of the waste is higher than 5000kJ/kg, sanitary landfill sites are scarce, and the economy is well developed.
- Waste-to-energy facilities should adopt mature technologies such as grate incinerators and only cautiously use other furnace types. It is forbidden to use incinerators that do not meet control standards.
- The waste should be fully burned in the incinerator, and the flue gas should stay in the post-combustion chamber at a temperature of not less than 850 ℃ for not less than 2 seconds.
- The thermal energy generated by waste combustion should be recycled as much as possible.
- Waste-to-energy plants should strictly control and deal with flue gas, sewage, slag, fly ash, odor, and noise in accordance with the relevant standards to prevent environmental pollution.
- Advanced and reliable technology and equipment should be adopted to control the emission of flue gas from waste combustion. It is preferred to use the semi-dry method and bag filter dust removal techniques for flue gas treatment.
- The leachate in the garbage storage pit and the wastewater from the production process should be pretreated and treated separately and discharged after reaching the standard.
- The slag generated from the waste combustion, if not classified as a hazardous waste, can be recycled or directly landfilled. Fly ash and slag classified as hazardous waste must be disposed of as hazardous waste.

[25] Beijing municipal Bureau of Statistics (2019). Beijing Economic and Social Development Statistics 2018.
[26] State Environmental Protection Administration (2000). Policy for Municipal Solid Waste Treatment and Pollution Prevention Technology.

At present, Beijing's waste-to-energy industry predominantly utilizes incinerator equipment and related treatment technologies from developed countries. All of Beijing's waste-to-energy plants, both those already built and those under construction, have installed the mechanical grate incinerators widely used abroad.[27] The mechanical grate incinerator's advantages are a large processing capacity, short treatment cycle, significant waste volume reduction, and recoverable combustion waste heat. It is suitable for large-scale treatment of unsorted high-calorie municipal solid waste.[28] Take the Gao'antun waste incineration plant as an example. Gao'antun waste incineration plant adopts SN type grate incinerator from the Japan TAKUMA Co., Ltd., and uses Alstom's Novel Integrated Desulphurization (NID) technology for flue gas purification and the Selective non-catalytic reduction (SNCR) method to reduce nitrogen oxide (NOx) emissions.[29]

The processing system of Gao'antun waste incineration plant includes a garbage receiving and feeding system, waste incineration, waste heat boiler system, steam turbine system, flue gas purification system, ash and slag processing system, automatic control system, and electric power transmission system.[30] After the garbage truck is weighed, it enters the garbage unloading station and discharges the waste into the storage pool. Following a certain period of dehydration and fermentation, the waste in the pool is mixed and sent to the furnace. The leachate generated from the dehydration of garbage enters the collection pond and is transported to the leachate treatment facility. During the combustion process, the mixed waste moves into the drying section where heated air is sent from the bottom of the grate to dry the trash quickly. Then, the waste enters the combustion section and is burned at a high temperature above 850℃, so that the combustible and harmful components can be completely decomposed. Finally, in the ashes section, the garbage is in the process of cooling down and is completely burned into ash. The remaining slag in the incinerator is cooled and transported to the belt. After the magnetic separator magnetically selects any waste iron, the remaining slag is stored in the slag pool and then loaded for transportation. The flue gas purification system performs desulfurization, denitrification, dust removal, and dioxin removal; and the dust generated is sent to the ash warehouse for loading and transportation. The waste heat boiler uses the heat generated by the combustion to generate steam and produce electricity. After meeting the energy needs of the equipment in the plant, the remaining electricity is transmitted to the power grid.

The future development of waste-to-energy technology in Beijing will focus on the reduction of pollution and energy utilization. The most important area of focus is the exhaust gas purification technology of waste-to-energy plants, since the elimination of pollutants such as dioxins has received increasing attention. The utilization technology of the waste heat from waste-to-energy

[27] Fu, Y. (2014). Investigation of Beijing Municipal Solid Waste Incineration Project. *China Newsweek*, No. 685.
[28] Zhao, X., Li, Z., Li, X. (2017). Research on Technology of Mechanical Grate Waste Incinerators. *China Resources Comprehensive Utilization,* Vol.35, No.9: 135-138
[29] Beijing Gao'antun Waste-To-Energy Corporation. http://bjgat.com.cn/about.asp
[30] Beijing Gao'antun Waste-To-Energy Corporation. (2017). http://bjgat.com.cn/xinxi.asp?classid=6&id=232

plants also needs to be further improved. To meet increasingly stringent environmental protection requirements, waste-to-energy facilities in Beijing are moving towards the integration of equipment units for flue gas purification, residue and wastewater treatment, and waste heat recovery.

4.4. Circular Economy Industrial Park

Considering the increasing waste production amount and the composition of domestic garbage, developing a circular economy is an essential strategy for future waste treatment in Beijing city. Beijing city government pointed out that, to accompany the accelerated construction of waste-to-energy plants, it is necessary to build sanitary landfill sites for incineration residues and other related treatment facilities. To meet the needs of sustainable development, the city government has proposed a Circular Economy Industrial Park model to achieve the comprehensive utilization of domestic waste.[31]

The circular economy is a generic term for the “reducing, reusing, and recycling” activities conducted in the process of production, circulation, and consumption. The circular economy industrial park is a park-type environmental protection complex. The park received all or some kinds of urban solid waste, such as domestic garbage, feces, kitchen waste, construction waste, and medical waste. In a large-scale park, there are various types of waste treatment facilities, and different kinds of garbage can be disposed of via different technologies such as waste-to-energy, biological treatment, and sanitary landfill. The parks also serve as a research and development base for environmental technology, and they are open to visitors for environmental protection education.

The most representative example is the Chaoyang Circular Economy Industrial Park constructed in 2002, which is the first industrialized waste treatment park in Beijing. The park consists of the Gao'antun Sanitary Landfill, Construction Waste Recycling Center, Waste Material Recycling Center, Restaurant Kitchen Waste Treatment Plant, the Medical Waste Treatment Plant, and two waste-to-energy plants - Gao'antun Waste Incineration Power Plant and Chaoyang Waste Incineration Center.[32] With the aim of comprehensively utilizing resources, water, and energy and saving materials, the park has established internal and external circulation chains with low energy consumption and low emissions. For instance, electricity generated by the waste-to-energy plants is used to meet the needs of the other plants before any remaining power is sent to the national electricity grid. The waste-to-energy plants, the vehicle charging station in the park, and electric sanitation vehicles also constitute a small circulation system, realizing the reuse of garbage waste and the reduction of vehicle emissions. In addition, the slag produced by incineration goes to the

[31] Beijing Municipal Government & CPC Beijing Municipal Committee (2009). Opinions on comprehensively promoting domestic garbage disposal. *Beijing Daily.*

[32] Exploration and Enlightenment of Beijing Chaoyang Circular Economy Industrial Park Development Model. (2016).

construction waste treatment plant to make construction materials, and the unusable slag will be sent to the Sanitary Landfill Site.

The concept of the circular economy has made municipal solid waste a resource, and the circular economy industrial park is one of the effective carriers for developing the circular economy. In addition to Chaoyang district, other districts in Beijing such as Fengtai, Miyun, Haidian, Fangshan, and Shunyi, are also either constructing or operating circular economy parks.

5. Challenge

Compared to other disposal methods, waste-to-energy has the advantage of reducing the physical volume of waste and is considered relatively harmless. Therefore, the proportion of waste disposed of via WTE plants is increasing in Beijing where land resources are tight. But at the same time, the development of waste-to-energy in Beijing also faces many problems:

- In recent years, with the large-scale construction of waste-to-energy plants, the public has become more attuned to the secondary pollution of heavy metals and flue gas, especially dioxin pollution.
- The domestic production of incinerators is relatively low, and the acquisition of new waste-to-energy equipment mainly depends on imports. The investment required to establish a waste-to-energy plant is significant and to some extent this offsets some of its benefits and governmental promotion of waste-to-energy.
- The calorific value of domestic waste is lower than that of western cities, which influences the performance of heat utilization methods, including waste-to-energy power generation. From the perspective of sustainable development, without comprehensive waste classification systems, over-reliance on waste-to-energy treatment may waste material resources.

5.1. Toxic Pollutants and WTE Regulation

Waste-to-energy disposal can eliminate physical waste volume, manage the environmental impacts better than landfills, and utilize the waste for electricity production. In reality, waste-to-energy methods are complicated; to be efficient it requires pre-sorting waste to remove organic and non-flammable materials. Ineffective pre-sorting reduces the efficiency of all waste-to-energy technology. When the waste entering the furnace contains many organic and other non-flammable materials, the waste-to-energy plant cannot reach the high temperatures necessary to produce electricity and avoid toxic emissions and by-products.[33] What is more, waste-to-energy plants create fly ash that needs to be disposed of safely. Among the various pollutants generated

[33] Liu, J., Lei, T., Yang, S. Li, Z., He, X. (2012). Garbage-fired Power Generation in China Today and Development Trends. *SINO-GLOBAL ENERGY*, 2012, No.6, Vol.17: 29-34.

from waste combustion, the handling of fly ash is the most difficult, and the fly ash contains many harmful heavy metal substances such as Cd, Pb, Zn, Cr, and the toxic pollutant - dioxin.[34]

Compared with other cities in developed countries, Beijing's domestic waste contains a high proportion of kitchen waste, more water content and impurities, which increases the difficulty of combustion. Due to the insufficient waste classification and sorting, and because of the complex composition of impurities, harmful substances are often produced during the combustion process.[35] In 2014, China promulgated the new national standard to control pollution from municipal solid waste combustion. These new standards lower the limits for pollutant discharges and narrow the gap between Chinese and European standards. However, the new standard does have limitations in meeting public expectations. Due to the lack of published information about leachate, waste gas, and odorous pollutants, it is difficult to determine the actual harmlessness of the incinerator plants. In practice, some WTE plants may not strictly enforce emission standards.

Research on dioxin pollution from Chinese waste-to-energy plants states that the monitoring data disclosed by operators are most frequently the results achieved in optimal conditions.[36] In conventional short-term dioxin sampling, the time scale of flue gas detection only accounts for 0.1% to 0.2% of the incinerating time. Studies show that dioxin emissions at the beginning, end, and abnormal operating stages of waste combustion account for 40% to 60% of total emissions.[37] Therefore, short-term monitoring cannot reflect the actual dioxin emissions. In contrast, European countries have developed continuous flue gas sampling devices to perform long-term sampling of flue gas for several days to one month, which can reflect dioxin emission in a cycle. Besides, in China's Standard for the Control of Pollution from Municipal Solid Waste Incineration (GB 18485-2014), there is no explicit requirement for the disclosure of monitoring information. Some waste-to-energy companies only disclose the data of dioxin concentration during monitoring. It is not possible to calculate the total dioxin emissions without relevant emission parameters such as flue gas flow rate and temperature.

Weak regulation and the absence of public emissions data make waste-to-energy a toxic industry for city residents. Almost all of Beijing's waste-to-energy plant projects have experienced public opposition to a certain extent. The common points of contention are site selection and low public participation in the Environmental Impact Assessment (EIA) process for waste-to-energy plants. One example is that construction of the planned Liulitun incineration project in Haidian District

[34] Bi, C. (2018). Status of Municipal Solid Waste Incineration and Its Pollution Control in Beijing. *Environmental Sanitation Engineering*, April 2018, Vol. 26, No. 2: 33-35

[35] Mao, G., Zhang, Y., Wen, W., He, D. (2010). Analysis of Municipal Solid Waste Treatment Status and the Feasibility of Incineration in China. *Urban Development Studies*, No.9, Vol.17:12-16

[36] Zhao, S., Song, W., Liu, J., Pu, Z. (2011). Pollution Status and Suggestions for Emission Reduction of Dioxin from Incineration of Municipal Solid Waste in China. *Environmental Engineering.* 2011. Vol.29. No.1: 86-88

[37] Ni, Y., Qi, Y., Song, X., et al. (2015). Stack Source of Dioxin Continuous Sampling Technique and Operation Demonstration. *The Administration and Technique of Environmental Monitoring.* 2015. No.5

was paused in 2007 and finally abandoned because of "Not-in-my-backyard" protest movements by residents in surrounding communities. In 2010, the original plans were relocated to Dagong Village in Haidian, which has a sparse population, and construction was restarted

5.2. Public-Private Partnership (PPP) Model

After nearly ten years of policy supplementation and market exploration, the commercial value of Beijing's waste treatment industry is growing. In Beijing, the city's waste-to-energy industry has already attracted social capital investment and the city government is now promoting Public-Private Partnerships (PPP) to encourage private enterprises and private capital to invest in the waste-to-energy industry. PPP is a project model where government and social capital cooperate in the production of public infrastructure. Under the PPP model, a private entity receives a concession from the public sector to finance, build, own, and operate the government-planned waste-to-energy project. At the same time, the government provides such enterprises with a waste disposal fee. Two common PPP models in Beijing waste-to-energy plants are BOT (build, operate, transfer) and BOO (build, own, operate). In a BOT project, the waste-to-energy facility will be transferred to the public administration at the end of the concession agreement; in a BOO project, the ownership of the project will remain with the project company.

Waste-to-energy disposal has high environmental benefits but low economic benefits. Without waste disposal fees and other subsidies, the company cannot recover investment and obtain reasonable profits. The assessment of the social costs of Beijing's waste-to-energy plant showed that the social cost of waste-to-energy is huge, not only the health loss caused by the emission of hazardous air pollutants, but also the high financial subsidies. According to one report, the social cost per ton of waste combustion in Beijing is 1088.49 yuan, of which 763.99 yuan is health loss and 324.5 yuan is the subsidy for waste-to-energy plants.[38] This subsidy includes waste disposal fees, electricity price subsidies, leachate treatment subsidies, fly ash and bottom ash treatment subsidies.

The effects of these subsidies are dramatic. According to state regulations, for waste-to-energy projects using domestic waste as raw materials, the on-grid electricity price is converted based on the amount of waste entering the plant. Under the current standard, the on-grid electricity of one ton of domestic garbage is 280 kWh, and the national uniform electricity price is 0.65 yuan/ kWh within 280 kWh (including tax). For electricity that is contributed to the grid in excess of the 280 kWh, the price is the same as for the local coal-fired generating units,[39] which is 0.3924 yuan/ kWh in Beijing. As the electricity subsidy is calculated based on the weight of the waste entering the

[38] National Academy of Development and Strategy, RUC. (2017). Evaluation Report on the Social Cost of Beijing Municipal Solid Waste Incineration.
[39] National Development and Reform Commission (2012). Notice on Improving the Price Policy of Waste Incineration.

plant, it reduces the motivation of waste-to-energy plants to reduce the moisture content and increase the heat value of the waste. It does not help to promote accurate waste classification. The subsidy also encourages WTE plants to generate profits by adding auxiliary fuel or other high-calorie industrial waste to generate electricity, making the waste-to-energy plant a new source of pollution. With the electricity price subsidy and other treatment subsidies, the waste-to-energy plant can achieve rapid cost recovery and profits through the income generated within 280 kWh. Some companies use electricity price subsidies as their main source of income and were awarded the contracts for waste-to-energy projects by asking for low waste disposal fees.

Although the environmental sanitation service industry in the capital is moving towards marketization and industrialization, waste disposal is still a public service in Beijing. The public need incinerator plants that operate harmlessly but relying on electricity subsidies and requesting low waste disposal fees lays the groundwork for irregular operations. The trend of increasingly lower waste disposal fees has made the principle of "bad money drives out good" increasingly apparent in the industry. It will deepen public resistance to waste-to-energy and make the "NIMBY" more intense.

5.3. Waste Classification

The best way of disposing of waste is through comprehensive treatment: recycling of recyclables, composting of biodegradable organics, waste-to-energy of combustibles, and finally, utilizing landfill for garbage that cannot be processed elsewhere.[40] This comprehensive utilization of waste is the ultimate goal of Beijing municipal waste disposal and the basis of its waste classification system. According to the social cost assessment of Beijing waste-to-energy industry, if accurate waste classification is strictly implemented from collection through to waste-to-energy, with the separate handling of kitchen waste and recycling of recyclables, the social cost of MSW management in the city can be reduced from 4.22 billion yuan in 2015 to 1.53 billion yuan.

The inadequacy of waste classification and separation is a major problem in Beijing. As living standards have improved, residents have demonstrated lower levels of interest in the value of waste products; those with higher incomes no longer consider selling recyclable waste. This is exacerbated by the inconvenience of recycling, as there is a lack of collection channels in residential communities. This makes it hard for the public to develop the habit of sorting their waste. Throughout the waste collection and transfer process, the focus is on economic efficiency instead of environmental benefits and this affects the effectiveness and scope of recycling. Even if residents separate their waste, the collection vehicles may mix the waste to save time and costs. This undermines the source classification initiative and increases the pressure on the disposal process. Due to the insufficient classification, the garbage sent to the waste-to-energy plant is

[40] Chen, X. & Du, B. (2009). "The current situation and development trend of municipal living garbage treatment technology." *Inner Mongolia Environmental Sciences.* 2009(21): 64-67.

simply screened by the transfer station. The mixed waste components are complex and makes it difficult to control the emissions. Rather than relying on end-of-life disposal methods, the city government should start from the source and improve waste classification.

The establishment of the waste classification system in China sped up four years ago. Under national policies, 46 of China's key cities begin to promote waste classification and will build basic classification and treatment systems by the end of 2020. Cities at the prefectural-level and above need to construct a garbage classification and treatment system by the end of 2025.[41] From July 1, 2019, Shanghai has officially implemented stringent compulsory waste classification regulations to promote the fixed-point sorting system.[42] The garbage is divided into four categories: dry garbage, wet garbage, recyclables, and hazardous waste. Individuals and companies who do not properly sort their waste and do not make corrections will receive a ticket. Individuals can be fined up to 200 yuan ($28), and companies and institutions may face fines of up to 50,000 yuan ($7080). In addition, transport operators can refuse to collect any incorrectly sorted garbage.

In Beijing, the mandatory waste classification is currently carried out in government agencies and public institutions. The representative of Beijing Municipal Administration Committee recently revealed that the revision of Beijing city's policies on waste management is included in the legislative plan, and that the newly revised regulations intend to clarify the individual's responsibility for garbage classification. It can be expected that Beijing will implement the mandatory waste classification mechanism following Shanghai's example.

In addition to tough penalties, some communities are also trying to encourage people to sort waste by providing incentives. In 2019, a pilot residential community in Xicheng district begin to use facial recognition to help residents sort garbage. Waste in the community is divided into eight categories: kitchen waste, other waste, plastics, paper, metal, textiles, toxic and harmful garbage, and battery and electronic garbage. Each trash bin is installed with a small screen and camera that can recognize people' face and automatically open for residents. Residents can earn points for successfully sorting the garbage and the points can be exchanged for daily necessities like eggs and hair shampoo. At present, there are more than 2,100 residents in the community, and the waste classification participation rate has reached more than 50%.[43]

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[41] China starts domestic waste classification in cities at the prefectural-level and above since 2019. (2019). *Xinhua News Agency*.
[42] The era of compulsory garbage sorting begins. (2019). *CHINA DAILY*.
[43] Beijing community launches "face recognition" trash can. (2019). *The Beijing News.*

Figure 9: The Waste Sorting Bins in a Pilot Community in Xicheng district[44]

6. Conclusion and Recommendations

Rapid economic development and high population density are the internal factors increasing waste production in Beijing. With the continuous growth in municipal solid waste production, the phenomenon of "garbage siege" has become increasingly serious. At the beginning of the 21st century, more than 90% of Beijing's garbage was sent to landfill resulting in pollution to the surrounding environment and groundwater systems. Considering tight land resources, dense population, and insufficient advancement of waste classification, the disposal method of waste-to-energy has become the number one choice for Beijing's waste reduction, recycling and harmless treatment. Although landfill is still the predominant method of waste disposal, the waste-to-energy industry has developed rapidly in Beijing. In the last ten years, the percentage of waste sent to landfill has decreased from 93% in 2007 to 47% in 2017. On the other side, since the city government's promotion of waste-to-energy and emphasis on waste-to-energy conversion, WTE had increased to 35% of total waste treatment by 2017.

In general, the harmless treatment of waste-to-energy is more thorough. After high temperature combustion, most of the toxic and harmful components in the garbage are decomposed. The effect of waste volume reduction is obvious, the speed of garbage disposal is accelerated, and the resource utilization of garbage is realized. However, there is a certain gap between China's waste-

[44] Wang, H. (2019). *Beijing Daily Online*.

to-energy industry and that of developed countries. China's waste-to-energy industry still has much room for improvement. In view of the current status of Beijing's waste treatment system and waste-to-energy industry, here are some suggestions:

- To promote the efficiency of waste-to-energy and maximum use of waste resources, the city government needs to promote the classification of municipal solid waste at source and implement separate collections and transportation for the classified waste. Recycling plastic products and reducing kitchen waste can reduce the chlorine content and increase the calorific value of the waste entering the furnace. It contributes to the stable operation of the waste-to-energy system and reduces the generation and discharge of hazardous air pollutants such as dioxins. For Beijing's waste treatment system, the urgent task is to implement classification regulations to manage the waste-sorting behavior of waste producers and change the current model of mixed loading and transportation.
- The second is to maintain the construction and development of the circular economy industrial park based on the existing waste-to-energy plant. In comparison to decentralized waste treatment plants, the industrial park realizes the connection of garbage classification, resource utilization, and waste treatment. It can reduce the difficulty of site selection and construction investment, help to improve the land resource conservation, protect the ecological environment, and reduce the "neighborhood" effect. Moreover, the circular park can help to achieve the goals of the waste treatment network, infrastructure sharing, centralized processing, and standardized operation and management.
- The city government needs to formulate standards for the public–private partnership model for the waste-to-energy industry and raise the entry barrier for the waste-to-energy market. With the rapid development of the sector, waste-to-energy companies have begun to face multiple pressures such as stricter emission standards, price competition, and rising operation costs. Under such circumstances, the government needs to improve the market access system, design a reasonable payment mechanism, and raise the standard to reduce the possibility of unfair competition and environmental pollution risks.
- Finally, at the national level, China needs to regulate the price policy for waste-to-energy industry and implement a carbon emissions trading system. The main benefits of the waste-to-energy industry in China are the on-grid electricity prices, garbage disposal fees, and government subsidies. Since more and more companies participate in the industry, the growing competition within the industry has led to a reduction in waste disposal fees and high pressure on government subsidies. Opening the carbon emissions trading market could be a new opportunity for waste-to-energy enterprises. China's greenhouse gas emissions are a problem; the establishment of a national carbon emissions trading market will ease this situation, and also create profit possibilities for industries like waste-to-energy. In the future, if China forms a domestic trading market, the scale of the market will be enough to support waste-to-energy companies obtaining a benefit from carbon emissions trading.

Appendix

Table 1: Population, GDP, Output of Domestic Waste in Beijing, 2000-2017

Year	Population (million)	GDP (billion yuan)	Output of Domestic Waste (1000 tons)
2000	13.64	316.2	-
2001	13.85	370.8	-
2002	14.23	431.5	-
2003	14.56	500.7	-
2004	14.93	603	4,955
2005	15.38	697	5,369
2006	16.01	811.8	5,851
2007	16.76	984.7	6,195
2008	17.71	1111.5	6,728
2009	18.6	1215.3	6,691
2010	19.62	1411.4	6,349
2011	20.19	1625.2	6,344
2012	20.69	1787.9	6,483
2013	21.15	1980.1	6,717
2014	21.52	2133.1	7,338
2015	21.71	2301.5	7,903
2016	21.73	2566.9	8,726
2017	21.71	2801.5	9,248

∗Note: Currency Equivalents (the average value in 2017): $1.00 (US) = 6.7518 yuan (CNY)

Source:
Beijing Municipal Bureau of Statistics & Survey office of the National Bureau of Statistics in Beijing. (Various years). Beijing Statistical Yearbook. http://tjj.beijing.gov.cn/English/AD/
Beijing Macroeconomic and Social Development Database. http://43.254.24.2/ww/MenuItemAction!queryMenu

Table 2: Domestic Waste Produced, Transported and Disposal Amount in Beijing City, 2000-2017

Year	Disposal Treatment Capacity (ton/day)	Volume of Domestic Waste Removed and Transported (1000 tons)	Volume of Harmless Disposal of Domestic Waste (1000 tons)	Rate of Harmless Disposal
2000	6550	2,956	1,667	56.40%
2001	6750	3,093	2,541	82.15%
2002	8750	3,214	2,775	86.36%
2003	9400	3,614	3,299	91.31%
2004	10,050	4059	3,806	76.82%
2005	10,350	4546	4,362	81.25%
2006	10,350	5383	4,977	85.06%
2007	10,350	6009	5,751	92.83%
2008	12,148	6566	6,416	95.36%
2009	13,680	6561	6,444	96.31%
2010	16,680	6330	6,137	96.66%
2011	16,930	6,344	6,232	98.24%
2012	17,530	6,483	6,426	99.12%
2013	21,971	6,717	6,670	99.30%
2014	21,371	7,338	7,308	99.59%
2015	27,321	7,903	7,887	99.80%
2016	24,341	8,726	8,712	99.84%
2017	24,341	9,248	9,237	99.90%

∗Note: Rate of Harmless Disposal = Volume of Harmless Disposal of Domestic Waste/ Volume of Domestic Waste Removed and Transported

Source: Beijing Macroeconomic and Social Development Database. (Various Year). http://43.254.24.2/ww/MenuItemAction!queryMenu

Table 3: Population, Area, Population Density, and GDP of Different Districts of Beijing, 2017

	District	Population (Thousands)	Area (km2)	Population Density (1000/km2)	GDP (billion $)
1	Doncheng	851	42	20.26	33.28
2	Xicheng	1,220	51	23.92	58.07
3	Chaoyang	3,739	471	7.94	83.47
4	Haidian	3,480	426	8.17	88.02
5	Fengtai	2,186	304	7.19	21.14
6	Shijingshan	612	90	6.82	7.93
7	Changping	2,063	1,430	1.44	12.44
8	Fangshan	1,154	1,867	0.62	10.10
9	Shunyi	1,128	980	1.15	25.41
10	Tongzhou	1,509	870	1.73	11.23
11	Daxing	1,761	1,012	1.74	9.55
12	Huairou	405	2,557	0.16	4.23
13	Mentougou	323	1,331	0.24	2.58
14	Yanqing	340	1,980	0.17	2.02
15	Miyun	490	2,336	0.21	4.12
16	Pinggu	448	1,075	0.42	3.46

∗Note: Currency Equivalents (use the average value in 2017): $1.00 (US) = 6.7518 yuan (CNY)

Source: Beijing Municipal Bureau of Statistics & Survey office of the National Bureau of Statistics in Beijing. 2018. *Beijing Regional Statistical Yearbook (in Chinese).* http://tjj.beijing.gov.cn/nj/qxnj/2018/zk/indexch.htm

Table 4: Summary of the Quantity of Waste Disposal Facilities and Treatment of Waste in Different Districts of Beijing, 2017

	District	Amount of Waste Harmless Disposal Facilities	Amount of Waste Transfer Station	Volume of Harmless Disposal of Domestic Waste (1000 tons)	Rate of Harmless Disposal of Domestic Waste
1	Doncheng	0	0	497.70	100%
2	Xicheng	0	0	652.60	100%
3	Chaoyang	3	2	2,138.60	100%
4	Haidian	1	2	996.50	100%
5	Fengtai	0	1	199.60	100%
6	Shijingshan	2	1	1,031.70	100%
7	Changping	2	1	99.10	100%
8	Fangshan	2	1	432.30	100%
9	Shunyi	1	1	254.70	98.95%
10	Tongzhou	1	0	416.40	99.64%
11	Daxing	2	0	832.70	100%
12	Huairou	3	0	1,037.50	99.94%
13	Mentougou	2	0	174.90	97.06%
14	Yanqing	1	0	170.30	100%
15	Miyun	1	0	207.00	100%
16	Pinggu	3	0	95.40	99.38%

∗Note: Rate of Harmless Disposal of Domestic Waste = Amount of Harmless Disposal of Domestic Waste / Amount of Collecting and Transferring Domestic Waste

Source: Beijing Municipal Bureau of Statistics & Survey office of the National Bureau of Statistics in Beijing. (2018). Beijing Regional Statistical Yearbook. http://tjj.beijing.gov.cn/nj/qxnj/2018/zk/indexch.htm

Table 5: List of Operating Domestic Waste Treatment Facilities in Beijing

Treatment	Facilities	Designed Treatment capacity (ton/day)	District
Composting	Fengtai Composting Plant	600	Fengtai
	Fengtai Restaurant Food Waste Treatment Plant	300	Fengtai
	Yanshan Waste Comprehensive Treatment Plant	250	Fangshan
	Dongcun Garbage Comprehensive Treatment Plant	300	Tongzhou
	Asuwei Waste Comprehensive Treatment Plant	1600	Changping
	Nangong Waste Composting Plant	2000	Daxing
	Wolvjie Garbage Comprehensive Treatment Plant	200	Huairou
	Yanqing Garbage Comprehensive Treatment Plant	300	Yanqing
Waste-to-Energy	Gao'antun Waste Incineration Power Plant	1600	Chaoyang
	Chaoyang Waste Incineration Center	1800	Chaoyang
	Haidian District Renewable Energy Power Plant	1800	Haidian
	Lujiashan Waste Incineration Plant	3000	Mentougou
	Tongzhou District Renewable Energy Power Plant	2250	Tongzhou
	Nangong Domestic Waste Incineration Plant	1000	Daxing
	Huairou Domestic Waste-to-Energy Plant	600	Huairou
	Pinggu Waste Comprehensive Treatment Plant	300	Pinggu
	Miyun Waste Treatment Center	600	Miyun
	Shunyi Waste Treatment Center Incineration Plant	1140	Shunyi
Sanitary Landfill	Gao'antun Waste Sanitary Landfill Site	1000	Chaoyang
	Liulitun Waste Sanitary Landfill Site	1500	Haidian
	Fengtai Residue Landfill Site	2000	Fengtai
	Zhaitang Waste Landfill Site	41	Mentougou
	Dongnanzhao Waste Sanitary Landfill Site	1000	Fangshan
	Asuwei Waste Sanitary Landfill Site	2000	Changping
	Anding Waste Sanitary Landfill Site	1400	Daxing
	Huairou Waste Sanitary Landfill Site	300	Huairou
	Xiaozhangjiakou Waste Sanitary Landfill Site	150	Yanqing
	Yongning Waste Sanitary Landfill Site	100	Yanqing
	Shunyi Waste Treatment Center	440	Shunyi

continued on next page

Table *continued*

Treatment	Facilities	Designed Treatment capacity (ton/day)	District
Transfer	Xiaowuji Waste Transfer Station	2000	Chaoyang
	Datun Waste Transfer Station	1800	Chaoyang
	Wuluju Waste Transfer Station	1500	Haidian
	Fengtai Pretreatment Screening Plant	2000	Fengtai
	Majialou Waste Transfer Station	2000	Fengtai
	Yamenkou Waste Transfer Station	500	Shijingshan
	Putaozui Waste Transfer Station	400	Mentougou
	Chengguan Waste Transfer Station	200	Fangshan
	Tongzhou Waste Transfer Station	800	Tongzhou

Source: Beijing Municipal Commission of Urban Management. 2019. Beijing Domestic Waste Treatment Facility Summary Table.
http://csglw.beijing.gov.cn/sy/sycxfw/xxcx/shljxxcx/201706/t20170621_40844.html

Table 6: Limit for Pollutants Emitted from Municipal Solid Waste Incineration

	Type of Pollutants	Daily Average Limit (mg/m3)	Hour Average Limit (mg/m3)
1	Particulate Matter	20	30
2	Nitrogen oxides （NOx）	250	300
3	Sulfur dioxide （SO2）	80	100
4	Hydrogen chloride （HCl）	50	60
5	Carbon monoxide （CO）	80	100
6	Hg (mg/m3)	0.05	Average Value
7	Cd + Tl (mg/m3)	0.1	Average Value
8	SB + As + Pb + Cr + Co + Cu + Mn + Ni (mg/m3)	1.0	Average Value
9	Dioxins and furans (ng TEQ/m3)	0.1	Average Value

∗Note: Average Value: the average test values of at least three samples at equal time intervals. (The time interval is a minimum of 30 minutes and a maximum of 8 hours; The sampling interval for dioxins is a minimum of 6 hours and a maximum of 8 hours.)

Source: Ministry of Ecology and Environment of the People's Republic of China. (2014). Standard for pollution control on the municipal solid waste incineration (GB18485-2014). http://kjs.mee.gov.cn/hjbhbz/bzwb/gthw/gtfwwrkzbz/201405/W020140530531389708182.pdf

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