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Waste-to-Energy in China: Key Challenges and Opportunities

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Abstract: China—the largest developing country in the world—is experiencing both rapid economic maturation and large-scale urbanization. These situations have led to waste disposal problems, and the need to identify alternative energy sources. Waste-to-energy (WTE) conversion processes, a source of renewable energy, are expected to play an increasingly important role in China's sustainable management of municipal solid waste (MSW). The purpose of this research is to investigate the key problems and opportunities associated with WTE, to provide recommendations for the government. This paper begins by describing China's current MSW management situation and analyzing its waste disposal problems. The major challenges associated with China's WTE incineration are then discussed from economic, environmental and social points of view. These include the high costs associated with constructing necessary facilities, the susceptibility of facilities to corrosion, the lower heating value of China's MSW, air pollutant emissions and especially public opposition to WTE incineration. Since discarded waste can be used to produce energy for electricity and heat—thus reducing its volume and the production of greenhouse gas (GHG) emissions—with government policies and financial incentives, the use of WTE incineration as a renewable energy source and part of a sustainable waste management strategy will be of increasing importance in the future. The paper concludes by summarizing the management, economic and social benefits that could be derived from developing the country's domestic capacity for producing the needed incineration equipment, improving source separation capabilities, standardizing regulatory and legal responsibilities and undertaking more effective public consultation processes.

Keywords: waste-to-energy (WTE); incineration; renewable energy; municipal solid waste (MSW); sustainable waste management

1. Introduction

Minimizing the environmental impacts of waste management is key to sustainable use of the ecological environment. Recovery is one aspect of sustainable waste management that is based on the well-known hierarchy of "prevention" "reuse", "recycling", "recovery" and "disposal". Waste-to-energy (WTE) refers to the recovery of heat and power from waste, and in particular non-recyclable waste [1]. Traditionally, renewable energy has referred to resources that are replaceable or inexhaustible in nature, such as hydro, solar, and wind energy, as well as bioenergy. Municipal solid waste (MSW) designates the collection and disposal of urban waste, including most of that produced by households, businesses, and local authorities. MSW consists mainly of paper, food, wood, garden, cotton, and leather waste, as well some fossil fuel materials, such as plastics and fabrics. The United States Environmental Protection Agency has listed MSW as a renewable energy source [2]. WTE may be directly realized by combustion (such as by incineration, pyrolysis, and gasification), or by generating combustible components (such as in anaerobic digestion and mechanical biological treatments), thereby producing methane, hydrogen, and other synthetic fuels. Incineration and gasification are the key WTE technologies currently used in many countries. Many studies have focused on WTE in Western countries [3–6].

It is predicted that 77%–81% of China's population (about 1.1–1.2 billion people) will live in urban areas by 2050 [7]. Significant population growth and the improvement of living standards will lead to the rapid growth of MSW. Increasing MSW generation puts pressure on existing landfills, and also leads to environmental degradation. Thus, the government faces a huge challenge in disposing of this waste [8]. At the same time, China, the world's second largest energy consumer and largest oil-importing country, also requires an enormous quantity of energy to support its economic growth. With the global need to reduce carbon emissions, MSW can be used as a source of electricity [9]; thus, WTE technology is a good means for disposing of China's MSW. The WTE approach is growing rapidly in China, mainly because it can dramatically reduce the demand for landfills and their encroachment on land resources [10]; moreover, WTE can also lessen the country's dependence on fossil fuels, and reduce greenhouse gas (GHG) emissions [3–6]. WTE also has a significantly positive impact on economic growth [11].

A number of researchers have studied China's WTE processes. Most of them focus on technological developments and environmental influences [8,12–18], some focus on renewable energy policies in China [10,19–21], and some papers review the current and likely future practices of WTE in China [22,23]. However, little research has focused on the impacts of inefficient government management and public opposition on WTE development in China. Social factors such as public opposition are becoming serious obstacles to the construction of WTE facilities in China. The objective of this paper is to investigate the status of WTE incineration as part of China's sustainable waste management strategy, and to identify key problems and opportunities associated with this strategy. This paper summarizes China's current MSW management practices, and considers the further development of WTE in China. It discusses the main challenges facing the WTE industry, and the prospects for developing MSW as a source of renewable energy. The paper is organized into parts, each of which addresses one of the following four questions:

(a) What is the status of MSW management in China?
(b) What are the main challenges facing the WTE industry in China?
(c) What are the advantages of developing the WTE industry in China?
(d) How should the government respond to these challenges?

The data used for this study was taken from annual Chinese statistical yearbooks on the environment, and official documents published by the Chinese Government.

2. China's Urbanization and Management of Municipal Solid Waste

2.1. China's Urbanization and the Generation of Municipal Solid Waste

One characteristic of urbanization is the flocking of rural populations to cities. Figure 1 shows China's urbanization trend over the past two decades. The data reveals that China's urban population reached 731.1 million in 2013, and that the urbanization rate was 53.73%, which is close to that of a middle-income country [24].

Due to rapid urbanization, China's MSW has also been markedly augmented, and it now ranks high in the world in terms of quantity. In 2013, China's MSW totaled 172.39 million tons, and it has been increasing at an annual rate of 8%–10% [17]. It is estimated that it will total 323 million tons by 2020, and 480 million tons by 2030 [25]. At present, the per capita production of MSW is 1.12 kg in China's cities [20], but it may be more in large cities such as Beijing, Shanghai, and Guangzhou.

More than 400 large and medium cities, some of which have no suitable places for landfills, are confronting the problem of waste siege, which has led to the serious pollution of surface and underground water, soil contamination, and environmental destruction [26]. Since the management of MSW impacts the environment and public health, the Chinese government has devoted increasing attention to this issue.

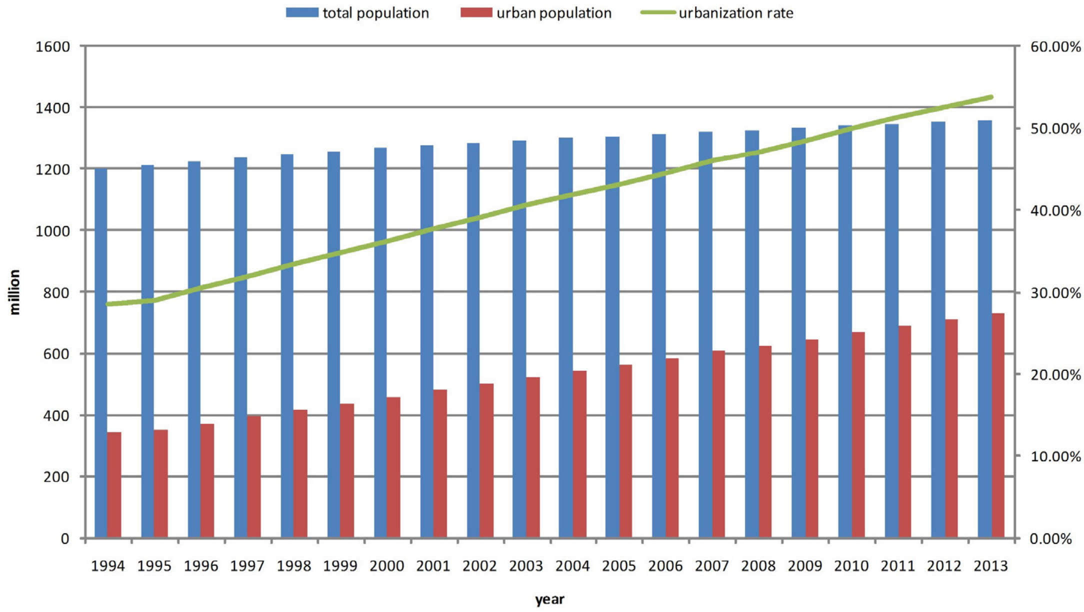

Figure 1. The urbanization trend of China over the past two decades [24].

The management of MSW involves systematic engineering, including the collection, transportation, recycling, treatment, and disposal of waste. Figure 2 shows the trends of MSW management in China from 1980 to 2013. It can be observed that MSW management developed rapidly in previous decades. The management of MSW began in the 1980s, when waste management was dominated by open dumping; the waste disposal rate, which was less than 2% before 1990, gradually increased in the 1990s, and reached 49.1% in 1998, and 89.3% in 2013.

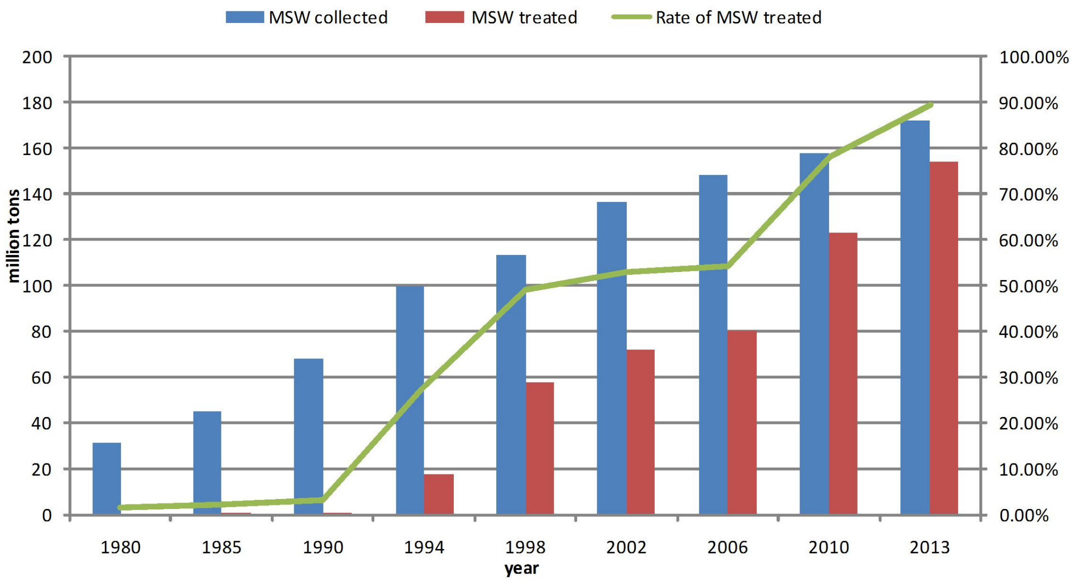

Figure 2. Municipal solid waste (MSW) management in China from 1980 to 2013 [24].

2.2. Municipal Solid Waste Management in China

In China, most recycling tasks are completed by informal collectors who specialize in different kinds of refuse—rubber, aluminum, tin, plastic, and paper—who either collect these materials by going house to house or by sorting through the garbage [27]. Precise data on MSW recycling in China remain elusive. Xu [28] estimated that recyclable wastes accounted for 37.3% and 42.7% of the total amount of MSW generated in Guangzhou and Beijing, respectively. After being recycled and collected by the environmental sanitation department, some of the MSW is treated by the residents or communities, and the remaining MSW is neither treated nor collected. By the end of 2013, China had the largest waste output in the world, producing more than seven billion tons of untreated MSW, which occupied over three billion square meters of land, and many cities were struggling with garbage disposal problems. Of 668 cities in China, two-thirds are surrounded by garbage [29]. In one-fourth of these cities, garbage has to be transported to nearby rural areas; the grim situation of "waste siege" has already caused serious pollution in surface and underground water, and in the soil, thus destroying the environment [26].

In China, household waste is mainly deposited in landfills or incinerated. Table 1 summarizes the amount of waste processed using different technologies, from 2003 to 2013. Landfills are the main means of MSW disposal in China; at the end of 2013, almost 70% of household waste was being deposited in landfills. The landfill approach not only consumes extensive tracts of land, but also results in secondary pollution. Various state departments' investigations of waste disposal in 47 key cities in China revealed that national landfills are commonly subjected to leakage, and their operating conditions and secondary emissions do not meet national standards [30].

Table 1. The status of MSW disposal in China from 2003 to 2013 [24].

Year	Landfill			Composting			Incineration		
	Number of Plants	Treatment Capacity (million tons/year)	Ratio * (%)	Number of Plants	Treatment Capacity (million tons/year)	Ratio * (%)	Number of Plants	Treatment Capacity (million tons/year)	Ratio * (%)
2003	457	64.04	85.49	70	7.17	9.57	47	3.70	4.94
2004	444	68.89	85.39	61	7.30	5.57	54	4.49	9.05
2005	356	68.57	85.79	46	3.45	4.32	67	7.91	9.90
2006	324	64.08	81.80	20	2.88	3.68	69	11.38	14.53
2007	366	76.33	81.92	17	2.50	2.68	66	14.35	15.40
2008	407	84.24	82.85	14	1.74	1.71	74	15.70	15.44
2009	447	88.99	80.17	16	1.79	1.61	93	20.22	18.22
2010	498	95.98	79.35	11	1.81	1.50	104	23.17	19.16
2011	547	100.64	76.88	-	-	3.26 **	109	25.99	19.85
2012	540	105.13	72.55	-	-	2.71 **	138	35.84	24.73
2013	580	104.93	68.16	-	-	1.74 **	166	46.34	30.10

* Ratio = capacity of a specific waste treatment type/capacity of all waste treatment types. ** Since 2012, the term "other treatment" has been used in the China Statistical Yearbook [24] instead of the term "composting treatment".

Waste incineration technology was introduced in China in the late 1980s, and it developed rapidly in the 1990s. More than 30 large and medium-sized cities operate, or are building, waste incineration plants [31]. Over the past decade, the number of incineration plants has risen markedly. In 2003, there were only 47 incineration plants, with a total capacity of 3.7 million tons a year in the whole country; ten years later, in 2013, there were 166 plants, with a total capacity of 46.3 million tons a year [32].

MSW incineration has many advantages over using landfills, such as effecting significant volume reductions (approximately 90%), complete disinfection, and energy recovery [15]. It is becoming an important means of waste disposal in big cities, where space for landfills may be limited. Studies have been conducted of the current MSW incineration status of China's cities [12,13,33]. In most of these cities, it is still difficult to fully incinerate waste and control secondary pollutants, because of the waste's high moisture content, high inorganic composition, high degree of heterogeneity, and the low heat value of household waste; therefore, improving the quality of the waste that is fed into furnaces is crucial to achieving safe incineration.

3. Challenges Facing the Waste-to-Energy Industry in China

China's WTE industry is largely based on power generation by waste incineration, which relies on a technology that is, comparatively speaking, more mature and simpler than other alternatives. WTE incineration of MSW is in the initial stages of renewable energy production in China. In 2014, power generation by WTE incineration was 18.7 billion KWh, accounting for 1.2% of total "new and renewable" energy production [34]. Driven by national policy and its low-carbon objectives, China's household waste incineration industry has developed quickly. In 1988, China established the first incineration plant; more such facilities followed, and the processing capacity of each grew. Table 2 lists China's significant incineration power plants. In the coming years, generating power through waste incineration will also be China's main means of waste disposal. Since problems associated with waste incineration involve not only the technology, but also environmental, social, public health, and many other aspects, China is now facing many problems with regard to the construction of WTE incineration facilities.

Table 2. Significant MSW incineration power plants in China [20].

Year Constructed	Name	Incineration Capacity (tons/day)	Generating Capacity (million kWh)	Investment (million USD)
1988	Shenzhen Qingshui river MSW incineration plant	300	-	-
2002	Shanghai Pudong MSW incineration plant	1000	100	110
2005	Shanghai Jiangqiao waste incineration power plant	1500	180	144
2011	Shandong Jinan second MSW incineration plant	2000	270	147
2013	Guangzhou Likeng second MSW incineration plant	2250	290	152
2013	Beijing Lujiashan MSW incineration plant	3000	310	329

3.1. Facilities' High Cost and Susceptibility to Corrosion

Compared with other MSW treatment technologies, WTE involves a large capital investment and high operating costs. As the core of the WTE incineration facilities, the incinerator accounts for approximately 50% of the cost of investing in a WTE plant [20]. Imported incineration equipment is very expensive. For example, as shown in Table 2, the Shanghai Pudong Waste Incineration Power Plant, which utilizes Alstom equipment and technology, cost nearly 110 million USD, and the Shanghai Jiangqiao Waste Incineration Power Plant, which employs Seeger equipment, required an investment of 144 million USD [35]. These costs are not sustainable for most Chinese cities, so the majority of WTE plants in China are located in the most economically developed urban centers [20]. Although private capital investment is increasing, local governments are still the main funding sources.

Corrosion problems are often associated with WTE incineration [36]. The combustion gases that contain various impurities (especially HCl and chloride salts) result in much higher corrosion rates of boiler tubes [37]. Chlorine and sulfur have been considered key elements in the corrosion process [38,39]. Because of China's poor performance with regard to waste classification, the high moisture content of waste and its tendency to generate HCl and SO_2 and other acid gases after oxidation may erode WTE facilities [40].

3.2. The Low Heat of Municipal Solid Waste

While recycling is a standard practice in the West, China's MSW management is still mired in the stage of waste separation, which is poorly executed [41]. In comparison with developed countries that have sophisticated approaches to the classification of waste, China's MSW classification system is less well developed. Its MSW has a lower heat value because of its relatively higher organic composition and moisture content, so it achieves lower energy efficiencies when incinerated [42]. The average heat value of MSW in China's waste incineration plants is 3–6.7 MJ/kg, which is far lower than the 8.4–17 MJ/kg in developed countries [43,44]. Table 3 summarizes the composition of the MSW of some of China's cities. Because this waste contains many organic substances and nutrients, the renewable resources it contains may be destroyed in the incineration process; it is difficult to recycle the heat generated in the incineration process; about 30% of the generated heat may be lost as smoke, which itself requires purification.

Table 3. The composition of MSW in some of Chinas' cities [31].

City	Organic Matter (%)	Inorganic Matter (%)	Paper (%)	Fiber (%)	Plastic (%)	Glass (%)	Metal (%)	Moisture (%)	Heating Value (kJ/kg)
Changzhou	44.4	34.6	3.6	3.2	8.0	3.5	1.0	48.5	2998
Hangzhou	58.2	24.0	3.68	2.23	6.6	2.1	1.0	53.6	4439
Wenzhou	44.7	17.9	7.7	1.7	23.9	1.3	1.0	52.0	6710
Guangzhou	60.2	17.1	5.4	3.4	9.0	3.4	0.5	50.1	4399
Shenzhen	40.0	15.0	17.0	5.0	13.0	5.0	3.0	45	5639

3.3. Air Pollutant Emissions and Fly Ash Management

In environmental impact reports, many Chinese WTE operators have declared that they employ advanced technologies, yet, of these, a large number refrain from providing detailed data to substantiate their claims.

Substandard incineration facilities and flue gas purification systems trigger a series of environmental pollution problems, and pollutants are generated in the process of incineration; in particular, emitted dioxins cause serious air pollution. Ni *et al.* [16] measured dioxin emissions in 19 WTE incineration plants in China, and found a value of between 0.042 ng TEQ $N \cdot m^{-3}$and 2.461 ng TEQ $N \cdot m^{-3}$; the average level was 0.423 ng TEQ $N \cdot m^{-3}$; 16% of the incineration plants do not meet national standards (1.0 ng TEQ $N \cdot m^{-3}$), and 78% do not meet EU standards (0.1 ng TEQ $N \cdot m^{-3}$). The problem of dioxin emissions is one of the main reasons there is public opposition to the construction of waste incineration plants in the vicinity of residences. Therefore, WTE enterprises must improve the standards and practices of their incineration facilities and flue gas purification systems, to reduce the discharge of various pollutants, and so to protect public health.

Management of the fly ash generated during waste incineration—that leads to secondary pollution—has not been addressed in China. Although the volume of waste decreases rapidly during incineration, some residues remain, such as bottom and fly ash. After a stabilization treatment, bottom ash is used as a building material. In contrast, fly ash is a hazardous waste that contains dioxin and has heavy metal content; therefore, it must be specially treated [45]. As a requirement, the fly ash should first be stabilized by cement solidification or other pretreatment technologies, and then be disposed of in a special landfill. However, few cities possess special venues for dealing with the fly ash, and instead it has often been reported that it is being deposited in open dumps (see Figure 3).

(**a**)

(**b**)

Figure 3. (**a**) Fly ash in the open area of a waste-to-energy (WTE) incineration plant and (**b**) Fly ash dumps open without curing. (Photos source: [13,46]).

3.4. Public Opposition to Waste-to-Energy Incineration

With growing awareness of the need for environmental protection, public opposition has become the main obstacle to China's WTE incineration program. This public opposition has three main causes. First is the *Not In My Back Yard* (NIMBY) phenomenon that has spread between cities. Inappropriate site selections for MSW incineration plants are the main reason for NIMBY sentiments. MSW incineration plants have been constructed too close to residential areas (Figure 4) and even schools, and a few plants have been built near lakes or rivers that provide drinking water sources for residents. In addition, some mainstream media report that MSW incineration power plants are potential sources of air pollution linked to cancer, and imply that security cannot be guaranteed, even though these plants supposedly meet EU standards. Due to the negative publicity of mainstream media and other factors, public opposition to the construction of MSW incineration plants has occurred in cities including Guangdong, Zhejiang, and Shandong [47–49]. Village demonstrations, student strikes, and other protests affect social stability (Figure 5). These disturbances cause panic among members of the public.

Figure 4. A WTE incineration plant near residential buildings (photos source: [50]).

Figure 5. Protests against WTE incineration in China (photos source: [49]).

The second reason for opposition to the WTE incineration program is the lack of public participation. Sheery [51] concluded that public participation could be divided into eight levels (Figure 6). There was no public participation when the WTE incineration plants were first developed in China. As citizens' environmental consciousness is being awakened, there is growing concern about the construction of WTE incineration plants. Since 2010, there have been some demonstrations against the construction of WTE incineration plants that have attracted the attention of the government. Consequently, some public consultations have been conducted prior to initiating construction of WTE facilities, but the public participation processes are regarded as tokenism, which is far removed from involvement at the level of citizen power.

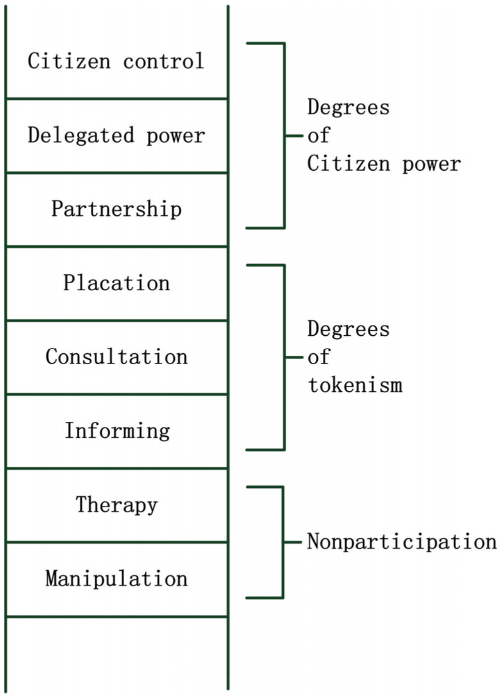

Figure 6. The eight rungs of the Ladder of citizen participation [51].

A credibility gap developing between the government and the public was the third reason for public opposition to the WTE incineration program. Many large and medium cities, especially coastal cities, already have WTE incineration plants. However, because of the large capital investments needed for waste incineration facilities, and the small economic gains that result from them, private capital shuns involvement in them unless subsidies are offered by the state. Thus, Chinese WTE incineration plants take the form of public-private partnerships, which tend to lead to fraudulent conduct, since government construction contracts, franchises, and operating subsidies are easily obtained through bribery. This is the main reason that some WTE incineration plants do not meet national emission standards, and do not disclose environmental monitoring information [16]. A survey conducted by two environmental nongovernment organizations (NGOs) in 2014 shows that it is difficult to get access to information from the government. Researchers approached 160 WTE operating incineration plants with the request that they disclose their pollution emission data, and only 65 of them responded, often with incomplete monitoring information, and only rarely including key data on dioxins and fly ash [52]. The implementation and monitoring of public utilities requires genuine transparency, but when governments are both investors and regulators, the general public finds it hard to obtain lucid information from state agencies, which in turn deepens public distrust.

4. Prospects for the Waste-to-Energy Industry in China

4.1. Policy Support

Reliable and effective policy is regarded as the solid foundation of MSW conversion to energy. China's government has given special support to the development of renewable energy.

According to the "Twelfth Five-Year Plan" of the national MSW harmless disposal facilities, the investment in WTE incineration is about 12.3 billion dollars, which accounts for 56% of the total investment. Stimulated by the national plan of waste management, WTE incineration projects are planned in more provinces [10].

In terms of its funding policy for large environmental protection projects, the state generally requires that investors contribute 30% of the capital investment required for a project, the remainder of which can be raised by national subsidies or commercial bank loans. Further, according to the Ministry of Finance and State Administration of Taxation, WTE incineration plants are exempted from 5% of the income tax. The power supply authority will sign a grid-connection agreement with a WTE incineration plant that meets grid-connection conditions, and the authority will give priority to purchasing approved, on-grid energy, from the plant. According to the Development and Reform Commission, the purchase price can be offset by the feed-in tariff of 0.04 USD/kWh. In addition, local governments will subsidize WTE incineration, with subsidy standards from 9.3 dollars/ton to 14.3 dollars/ton [10]. WTE incineration plants that rely on tariff revenue can basically break even. Waste disposal fee subsidies granted by the local government become the corporate profits.

MSW incineration is a technology intensive industry, which also demands advanced technologies. Technology policies for China's WTE incineration industry are mainly focused on technical specifications and technical support [10]. MSW incineration plants constructed using advanced environmental technologies can effectively protect the environment and achieve the comprehensive utilization of resources. They have great significance for the economic development of cities and, consequently, are supported by national industrial policy, which provides an important guarantee for the further rapid development of waste incineration projects in the future [21].

4.2. Great Market Potential

In many Chinese cities, given their high population densities and shortage of land resources, it is extremely difficult to select suitable landfill sites. Incineration can reduce the volume of garbage by 90%. A WTE incineration plant with the capacity to incinerate 1000 tons per day only requires an area of 16.5 acres. As WTE incineration can lead to the substantial conservation of land resources, it will become the main disposal mode in China's future MSW management. If waste can be converted into energy, the nation's shortage of energy will be somewhat alleviated. At this time, the output of global household waste is increasing at an annual rate of 8.42%, and that of China by over 10%. Currently, the amount of global household waste produced annually is nearly 490 million tons, of which more than 30% is created in China. At present, China's WTE incineration rate is just 30%, which means that 2800 megawatts of electricity are wasted each year, and that the discarded "renewable waste" is worth up to 3.9 billion USD [53].

The collected MSW of China in 2013 was about 172 million tons. It had increased by 11.2%, compared to 2004, and untreated MSW accumulated in the past year was more than seven billion tons. A large historical inventory and the continued increase in waste generation together provide a solid material foundation for the development of a waste disposal industry. The government will invest 41.3 billion USD on WTE incineration facilities during the "Thirteenth Five-Year Plan" (2006–2020). From a market perspective, WTE enterprises have a promising future [54].

4.3. Waste-to-Energy Incineration to Reduce Greenhouse Gas Emissions

On one hand, WTE incineration can replace fossil fuel generation, and achieve a reduction in the GHG emissions that were formerly created by the energy sources replaced; on the other hand, it can also avoid the discharge of landfill gases from waste in landfills, and therefore, it has dual reduction effects (Table 4). As a result of the high food waste content in China's MSW, WTE incineration plants were a main source of the country's GHGs. Reducing the food waste content in MSW by half will significantly reduce the nation's GHG emissions, and such a reduction will convert WTE incineration plants in some cities from GHG sources to GHG sinks. In other words, enhancing the separation of wastes at the source will improve the combustion efficiency of MSW, and, consequently, WTE incineration in China has a huge potential for reducing GHG emissions.

Table 4. Carbon reductions of each MSW treatment method in China [55].

Disposal Methods	Composting	Incineration	Landfill
Quantity of MSW (million tons)	181	2317	9598
Carbon reduction (million tons)	9	102	−4340
CO_2 reduction (million tons)	33	374	−15,913
Carbon reduction factor (t/t)	0.051	0.044	−0.45

4.4. Waste-to-Energy Incineration for Environmental Protection and Economic Benefits

WTE incineration greatly reduces the harmful components of MSW. After the process of high temperature (850–1100 °C) incineration, in addition to the heavy metals, the harmful components of MSW are fully decomposed, and a large number of bacteria and other pathogens can be completely eliminated. This process results in a less hazardous amount of waste. The gas and residue that incineration produces, such as slag and ash, is odorless. Most of the foul gases are decomposed at high temperatures, so incineration is the most effective way of dealing with combustible carcinogens, viral pollutants, and highly toxic organic compounds. WTE incineration has the positive potential for improving a city's health environment. Waste incineration technology can effectively prevent the pollution of underground water and air by landfills. In addition, it can reduce the consumption of land resources. WTE incineration can also effectively decrease the pollution caused by coal-fired power generation. Thus, it can create a high-quality energy supply, realize energy diversification, and ensure energy security, while yielding good economic benefits.

Psomopoulos *et al.* [11] examined the contribution of WTE implementation to economic growth in Greece. He found that WTE incineration can reduce the need for oil, electrical, and other types of energy imports, and that energy recovery from MSW can produce good economic returns. It can also reduce GHG emissions, and lessen the economic investment that would otherwise be required for purposes of environmental protection. Moreover, WTE has a smaller footprint, in relation to the extent of valuable land required for this process, and, consequently, additional land resources that become available can be used to produce greater economic benefits. Furthermore, the services required to operate WTE facilities promote local employment.

5. Conclusions and Recommendations

With a large population, accelerated urbanization, and economic development, China's living standard is gradually improving. Its growing capacity for MSW reflects these changes. China's MSW is currently being achieved using landfills; however, this approach is unsustainable, so the adoption of WTE technology is crucial to effect sustainable MSW management. WTE incineration, which also brings with it certain problems, is in a marked ascent. The following recommendations are offered to government as guidelines for future decision-making.

5.1. Product Equipment: Combine Foreign Advanced Technologies and Domestic Technologies

On the one hand, foreign equipment is very expensive. The required capital investment coupled with the costs of operating and maintaining domestic WTE equipment are equivalent to about one-third to one-half the cost of imported technologies [8]. An imported 600 ton/day WTE facility costs 70.6–78.5 million USD. In contrast, a comparable domestic facility with equipment designed by Tsinghua University costs only 28.2–31.4 million USD, and the costs of operating and maintaining domestic equipment ranges from 11 USD/ton to 12.6 USD/ton, which is much lower than the costs associated with imported ones that range from 48.6 USD/ton to 53.4 USD/ton [56]. On the other hand, MSW in China shows high moisture levels and low heat contents, and foreign advanced equipment cannot provide the best performance. A good example comes from the first modernized WTE plant (Shenzhen, Guangdong) in Guangdong province. The incinerators were imported from Japan in the late 1980s. To adequately incinerate the local MSW, they were operated with prolonged drying and incineration times, and suffered from problems, such as grate blockages. The need to add supplementary fuel also substantially increased the operating costs, and the power output was limited. In 1996, another incinerator, which had been built with over 80% parts manufactured domestically and the modification of imported incinerators, generated approximately 200 kWh electricity with each ton of local MSW [23].

China must recognize that current domestic WTE technology is not competitive with foreign technologies, because it is based on lower environmental standards. The average level of dioxin emissions was about 0.2 ng TEQ Nm^{-3} in Tsinghua WTE plants in 2007. This met China's standards at that time (1 ng TEQ Nm^{-3}). In 2014, China's standards were raised to allow emissions of only 0.1 ng TEQ Nm^{-3}, which was consistent with international standards. However, it is unacceptable by today's standards, and technical improvements are needed to meet the more stringent foreign standards for emissions. China should acquire sufficient knowledge of foreign advanced technologies to be able to design and invest in the research and development of incineration technologies and equipment domestically—and especially of large-capacity incinerators—thereby making WTE incineration more affordable for municipalities across the country.

5.2. Enhancing Source Separation and Pretreatment to Increase Waste-to-Energy Efficiency

Waste separation is a precondition of WTE incineration. Due to poor waste classification, China's MSW has a high organic waste composition and moisture content, which results in lower heat values, low incineration efficiency, and the production of secondary pollution, such as dioxins. Therefore, waste classification must be aggressively promoted through recycling. In doing so, the heat value of incinerated waste will improve. Waste classification can also be improved through campaigns that emphasize the moral obligations of citizens to separate household wastes. Such campaigns should seek to improve the environmental knowledge and waste separation abilities of individuals [41]. At the same time, the government should promote waste separation though marketing operations, to encourage more enterprises to engage in waste separation, recycling, and reuse.

Given the high moisture content of China's MSW, it has to be pretreated prior to WTE incineration. The mechanical-biological treatment before WTE incineration can be a good way of separating the organic putrescent fraction and the inert fraction from the high-energy content fraction.

Mechanical-biological treatments not only reduce the erosion of WTE facilities, but also improve the efficiency of energy production [57].

5.3. Standardize the Waste-to-Energy Market and Upgrade Existing Plants

The WTE industry has expanded quickly in China, and the Chinese government has formulated many standards, including standards with regard to the location of WTE sites and allowable pollutant emission levels. However, there is a significant gap between China's waste management practices and those in developed countries. Thus, it is important to learn from the developed countries, and further improve WTE technologies, to guide, and standardize the WTE market. Government supervision could be strengthened by adopting the following three strategies: First, establish specialized regulatory agencies to supervise the construction and operation of WTE incineration plants, to be responsible for the daily monitoring, examination, and annual inspection of WTE incineration instruments, and to track and investigate the leachate, fly ash, and slag from the plants. Second, assign clear legal responsibility for ensuring that WTE incineration enterprises meet acceptable standards for pollutant emissions, hold officials accountable for substandard pollutant emissions, and increase the penalties imposed in these instances. Third, conduct regular monitoring of waste incineration plants' impacts on the environment.

Only 65 of the 160 WTE operational incineration plants investigated by researchers disclosed their pollution emission data, and 45 of them cannot meet China's new national standard. To correct these deficiencies, it will be necessary to increase government investments, upgrade existing WTE incineration plants, improve operational supervision, and control flue gas emissions using the most advanced technologies available, coupled with the application of stringent standards, to ensure environmental safety.

5.4. Increase Public Participation to Improve Public Understanding

WTE is a controversial issue in China; thus, it is unsurprising that the public doubts its safety; however, the government must face the challenge of bringing forward sufficient evidence and supportive measures to overcome this suspicion. Before putting a WTE project into operation, public opinion must be surveyed through visits, symposia, and other means. In this way, official decisions will reflect the feelings of the people. It will be necessary to establish mechanisms for the effective participation of, and supervision by, members of the public, whose interests relate to issues that were identified after the WTE incineration facilities were constructed. Government supervision is typically temporary, and is neither timely nor reliable. If public participation satisfies the expectations associated with the third stage of the Ladder of Citizen Power Theory (Figure 6), the outcome is likely to be greater public understanding, and the following approach would be useful. First, residents near the WTE incineration plant must be offered a certain number of job opportunities at the plant, and be assured that the incineration is always under supervision. Second, large-scale WTE incineration projects should be constructed to ensure environmental protection, and this concern for safety should be made public and be demonstrated. Informing the public about MSW treatment-related knowledge on an on-going basis will gradually help the public understand that MSW incineration is harmless. Moreover, the government should regularly publish user-friendly information, and establish clear operational guidelines, policies, and regulations for urban public utilities. Risk perception and previous experiences with stench influenced the decision to protest [58]. Therefore, introducing third-party regulatory agencies that include those who reside near WTE plants, and publishing coherent real-time information regarding the plants' pollutant emissions would also help to dispel public doubts. In addition, no matter how advanced the technology of waste incineration plants is, the government should not expect citizens to voluntarily sacrifice their own interests. Thus, the government should compensate residents near incineration plants, either by giving them money, or by providing them with heat and electricity at discounted prices.

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