

Comparative analysis of the contribution of municipal waste management policies to GHG reductions in China

Abstract

Waste generation and disposal have been a global issue for decades. The total global greenhouse gas (GHG) emissions in 2019 were 49,758 MtCO_{2e} with waste disposal accounting for 3.2%. With rapid urbanization trends, municipal solid waste (MSW) has become a global challenge which needs to be addressed. A large fraction of MSW such as food wastes, e-waste among others still ends up with unregulated dumps or openly burned in low-income countries. As a response, China initiated the “zero-waste” pilot program which has been running since 2019. To investigate the potential contribution of MSW management to GHG reductions, this study selected four “zero waste” cities in China, namely Shenzhen, Panjin, Xining and Tongling, as case studies to assess the impacts of different MSW management policies on GHG reductions from 2015 to 2019. Results demonstrated that Shenzhen city achieved progress in reducing GHGs, which decreased by more than 40% between 2015 to 2019. This study provides policy recommendations and waste management approaches and practices to optimize MSW management and reduction of GHGs.

Keywords: Municipal solid waste; Greenhouse gas reductions; Waste management policies; Zero-waste program; Circular economy; China.

1. Introduction

According to the 'what a waste 2.0' report released in 2018, the world generates 2.01 billion tons of municipal solid waste (MSW) per year, the figure that will rise to 3.4 billion tons in 2050 (World bank group, 2018). With rapid urbanization trends, the rapid growth of MSW has raised serious environmental concerns for international community (Shen et al., 2019). MSW, commonly known as trash or garbage, consist of a combination of different waste fractions including packaging, furniture, clothing, plastic bottles, food waste, newspapers, appliances, paint, and batteries among others.

Waste management in China is the country's fourth-largest contributor to greenhouse gas (GHG) emissions, contributing 195 Mt CO₂e (CO₂e) in 2014 (NDRC), 2018). To respond to this environmental challenge, the term “zero-waste city” emerged in the 1990s and 2000s (Marine& Ben, 2006). Afterward, the International Zero Waste Alliance proposed the first working definition of "zero waste" in 2004 and made the latest revision to the concept of “zero-waste city” in 2018 (Zero Waste International Alliance, 2018). The concept of a “zero-waste city” emphasized that in urban settings, toxic/ hazardous substances use should be limited and the use of raw materials and waste generation should be reduced, and waste recycled, where possible, rather than just incinerated or sent to landfill. With increased environmental awareness, establishing "zero waste cities" had become a common goal for many countries and/or cities across the globe (Ministry of Ecology and Environment, 2019). For example, to promote the international cooperation on "waste-free cities" globally, European countries established the "Zero-Waste Europe Network" (Curran and Williams, 2012). Also, Japan established organizations such as the "Zero-Waste Research Institute" in

2018 (Ju and Chen, 2017), followed by 23 cities around the world jointly issuing a declaration for "Building a city without Waste" (Wang and Nakakubo, 2020).

Given its rapid economic development and urbanization, the generation of MSW in China has significantly increased in recent years (Bo et al, 2019). Excluding the total amount of domestic waste that cannot be accounted for in remote areas or disposed of by unofficial means, the total amount of MSW generation in China increased from 191,421 kilo tonnes (kMT)/year in 2015 to 242,062 kMT/year in 2019 (NBS, 2016; NBS, 2019), which accounted for more than 10% of global waste. Given the large amount of MSW generation each year, environmental issues associated with MSW management have aggravated in recent years. To respond to this, the Chinese government officially started to develop the "Zero-waste city" pilot program in 2019, aiming at promoting solid wastes resource recovery, recycling environmentally sound disposal. In China, the term "zero-waste city" refers to an advanced urban planning and management concept that strives to encourage environmentally friendly behaviors, reduce trash production, increase recycling programs, and make sure that waste released into the environment is safe. (Ministry of Ecology and Environment, 2019).The "Zero-waste City" Pilot Program focused on bulk industrial solid waste, agricultural waste, domestic waste, construction waste and hazardous waste to achieve substantial reductions at the source and safe disposal.

With regards to the topic of the "Zero-waste City", a few studies have been conducted in recent years. For instance, Rhodium Group made a comparative study on the differences in domestic MSW disposal systems and capacities in Chinese cities. Michel et al., (2021) analyzed the carbon dioxide (CO₂) emissions from MSW in Malaysia by using the IPCC 2006 waste estimation model. In this study, a SWOT analysis was made to outline the benefits and disadvantages and costs of MSW

management policies in Malaysia in terms of waste generation, impact on gross domestic product (GDP) and local gross product, regional GDP as well as detailed analysis of its policy landscape with related laws, decrees, regulations and study of waste characteristics, including composition, classification, collection and transportation systems and traceability. In response to the "zero waste" initiative of Finnish Sustainable Communities (FISU) (FISU, 2016), Sahimaa et al., (2017) explored the achievements of zero climate emissions, zero waste and living within the Earth's carrying capacity, The results of this study presents that Greenhouse gas emissions and material loss in cities varied more than ecological footprint in Finland. Ayeleru et al, (2018) measured the domestic waste generation and waste-free pathway potential of the City of Johannesburg in South Africa and designed a sustainable solid waste management model for the city. Ding et al., (2021) investigated eight regions along the eastern coast of China. MSW management practices in these areas were studied and compared to Berlin, Tokyo, and Singapore. The findings discuss the composition of MSW in China and point to deficiencies in the management system of MSW. The research suggested drawing from the experience of best performing countries to advance MSW management, including upgrading technology, in China. Climate change implications of MSW management are significant. CH₄ is generated during treatment of MSW in landfills, and there are emissions of GHGs during MSW incineration. Estimates of GHG emissions generated from MSW management has attracted interest in the literature in recent years. Qu and Chen (2011) estimated the carbon emission generated from MSW in China and predicted its peak. Xie et al, (2020) developed a forecast estimating the reduction potential range of GHG emissions under various MSW treatments in Guangzhou up to 2035. Currently, China is the largest producer of GHG emissions globally. In 2019, China's CO_{2e} emissions

amounted to 14,093 million metric tons (MMT) of carbon equivalent accounting for 27% of global GHG emissions, which has been more than three times that of the 1990 level. Furthermore, GHG emissions in China have been increased by 25% over the past ten years (Rhodium Group, 2021). Under such circumstances, China announced a series of policy commitments to CO₂ reductions, leading to CO₂ peak emissions by 2030 and carbon neutrality by 2060. In this regard, the studies indicated that optimized management of MSW has the potential to contribute to GHG emission reductions, through increased recycling, recovery and controlled disposal (Liu et al., 2017a; Liu et al., 2018a,b; Liu et al., 2019; Liu et al., 2021). In addition, findings suggest that different waste disposal approaches generated distinctive impacts on GHG emissions (Wang and Nakakubo, 2020). Nevertheless, research quantifying the effect of a range of MSW management policies in GHG emissions reduction is still limited. Therefore, research assessing the impact of MSW management practices on GHG reduction is still needed. This study aims to contribute to this area, by investigating the impacts of a range of policies deployed as part of the "Zero-waste City" programme in China on GHG reductions and highlighting effective policies.

2. Methodology and Data

Since the climate change has turned to a focused issue in the world, the research on the GHG emissions of MSW treatment pathways is crucial and abundant. There are three primary methods for estimating GHG emissions: life cycle assessment (LCA), mass balance (MB) method of Intergovernmental Panel on Climate Change (IPCC) and IPCC first-order decay (FOD) model (Kang et al, 2020). An immensely improved holistic vision of waste management, including waste flows and potential environmental repercussions, has been made possible through LCA in the field of waste management (Christensen et al, 2020). As for methods suggested by the IPCC's

GHG inventory guidelines, MB and FOD are both “bottom-up” accounting methods to calculate GHG emissions (Cai et al, 2018). The bottom-up approach, which is a quantitative rather than an experimental strategy, employs activity data and emission factors from the regional waste sector in contrast to the top-down approach. The main research orientation using the bottom-up accounting methods is to estimate GHG emissions from the treatment of MSW. The MB approach is based on the overall amount of CH₄ created or the CH₄ pledges for landfills. The default activity data method suggested by the IPCC may not be suitable to reflect the situation in China (Liu et al, 2014).

The mass balance method is also the recommended method in China’s provincial-level GHG emissions inventory compilation guidelines (Bai et al, 2013). which is frequently used to calculate the GHG emissions of the separate provinces in China. The recommended values in this calculation process are based on default parameters of the IPCC 2006, combined with China's climate conditions, waste treatment, and other comprehensive background data, which provide a more accurate description of the MSW management in specific regions (IPCC, 2006a; IPCC, 2006b). Unlike the First Order Decay (FOD) model developed by IPCC 2006, this method, based on the annual production of MSW in the area, reduces limitations associated with primary data gaps (e.g. data from waste treatment plants) to estimate GHG emissions (Liu et al, 2017b). In terms of the spatial distribution of emissions, Xie et al (Xie et al) used the MB method and found that landfill disposal accounted for about 95% of the total GHG emissions from waste disposal. Using the MB technique, Kang et al. (Kang et al , 2022) completed the breakdown of the influencing factors and computed the GHG emissions of 297 prefecture-level Chinese cities. According to the study, CH₄

emissions accounted for between 63.41% and 88.96% of the total GHG emissions from MSW treatment in China, rising from 39.34 Mt CO₂e in 2006 to 128.81 Mt CO₂e in 2019.

2.1 Estimation of GHG emissions generation in the landfill site

According to this method, all potential methane is exhausted in the year of treatment, just like the waste model of IPCC, the values of the fraction of degradable organic carbon (DOC) and the CH₄ correction factor for aerobic decomposition (MCF) needs to be identified on the basis of the waste composition and treatment capability of MSW disposal sites (SWDS). The estimation formula is:

$$E_{CH_4} = (MSW_T \times MSW_F \times L_0 - R) \times (1 - OX) \quad (1)$$

In equation 1, E_{CH_4} is methane emission (ten thousand t/a-CH₄) based on the different landfill disposal. MSW_T is the total MSW generation (10000t-wet), MSW_F is the disposal capability of the MSW in the landfill sites. R refers to the methane recovery, which means the amount of methane generated in MSW disposal sites and collected or burned or used in power generation units (MHDC), 2009, 2012). L_0 is the methane production potential in various solid waste disposal sites. R is the value of methane recovery.

$$L_0 = MCF \times DOC \times DOC_F \times F \times 16/12 \quad (2)$$

In equation 2, the estimation of DOC is based on the different fractions in the MSW, which is calculated by the average weight of the proportion of degradable organic carbon in various components/ fractions.

$$DOC = \sum_i(DOC_i * W_i) \quad (3)$$

In equation 3, DOC refers to the degradable organic carbon in waste, DOC_i refers to the proportion of degradable organic carbon in waste type i , these default values are described in Table 1, which is provided by the guideline. W_i is the proportion of the waste fraction i , they are shown in the Table 2. Table 2 shows the specific fractions of domestic waste composition in the selected case studies.

Table 1. The proportion of degradable organic carbon in different waste types. (IPCC, 2006a. 2006 IPCC Guidelines for National Greenhouse Gas Inventories. Vol. 5, Waste, Chapter 2, Waste generation, composition and management data.), (Writing Group of the Provincial Greenhouse Gas Inventories, 2010.).

	The proportion of degradable organic carbon in waste type i (%)	
	Recommended value	Range
Paper	40	36-45
Textiles	24	20-40
Food residue	15	8-20
Wood waste	43	39-46
Garden	20	18-22
diaper	24	18-32
Rubber and leather	(39)	(39)

Table 2. Characteristic variation of MSW in the four case studies.

City	Food residue	Paper	Textiles	Wood waste	Garden	Other waste	Reference
Shenzhen	51.1%	8.4%	6.9%	5.9%	Unknown	28%	(et al, 2020)
Xining	23.91%	11.89%	1.19%	0.93%	25.04%	37.04%	(Li et al, 2014)

Panjin	59.77%	7.58%	3.61%	2.52%	5.34%	23.59%	(Ma, Z., 2010)
Tongling	61.59%	3.32%	3.96%	0.66%	12.26%	18.21%	(Wu et al, 2008)

MCF is affected by the waste treatment methods and management systems in different regions. Because of the various backgrounds, the selected cases have different types of landfill sites. There are two forms of waste disposal, managed and non-managed disposal respectively, which are associated with the default of MCF. According to the depth of the landfill, the non-managed type is also classified into two groups, including the unmanaged deep (UD) landfills (deep dumpsites) (waste height ≥ 5 m) and unmanaged shallow (US) landfill (shallow dumpsite) (waste height < 5 m). The detailed default values could be found in Table 3. According to the formula and the situation of landfill site, the comprehensive MCF value could be estimated as shown in equation 4.

$$MCF = A \times MCF_A + B \times MCF_B + C \times MCF_C \quad (4)$$

Table 3. The default of MCF in different types of landfill sites. (IPCC, 2006a. 2006 IPCC Guidelines for National Greenhouse Gas Inventories. Vol. 5, Waste, Chapter 2, Waste generation, composition and management data.), (Writing Group of the Provincial Greenhouse Gas Inventories, 2010.), (Liu, J., MA, Z., ZHANG Y., SONG,L., Li W., Li, Y., GAO, Q., 2014.Key methane emission factors from municipal solid waste landfill treatment in China[J]. Research of Environmental Sciences, 2014, 27(9) : 975-980. (in Chinese) et al, 2014).

The type of landfill sites	The default of MCF
----------------------------	--------------------

Managed deep (MD) landfills: A	1
Unmanaged deep (UD) landfills (deep Dumpsites (waste height ≥ 5 m): B	0.8
Unmanaged shallow(US) landfill (shallow dumpsite) (waste height < 5 m): C	0.4
Unclassified landfills: D	0.4

If there is not concrete data related to the landfill site, the default could be identified as the unclassified landfills, 0.4.

2.2 Estimation of GHG emissions in the incineration site

GHG emissions from incineration plants are mainly related to the carbon content of waste, the proportion of mineral carbon in total carbon and the combustion efficiency of incinerators. In equation 5, E_{CO_2} refers to CO_2 from waste incineration, IW_i represents the amount of incineration of type i. CCW_i is the proportion of carbon content in type i; FCF_i means the proportion of mineral carbon in total carbon in type i; EF_i represents the combustion efficiency of type i waste in the waste incinerator; and 44/12 refers to the conversion coefficient of carbon to CO_2 .

$$E_{CO_2} = \sum_i (IW_i \times CCW_i \times FCF_i \times EF_i \times 44/12) \quad (5)$$

2.3 Data collection

The mass balance method requires waste activity data and the emission parameters of solid waste disposal sites similar to the requirement of IPCC, such as the parameters of generation volume and the composition of MSW in different regions and the landfill disposal ratio. The inventories provide some default values that describe the MSW management in a given region (Writing Group of the Provincial Greenhouse

Gas Inventories, 2010). In this study, the panel data are primarily from Shenzhen, Tongling, Panjin, and Xining in terms of municipal solid waste from 2015 to 2019. The annual data including the annual production of MSW, the total amount of waste treated by different treatment methods, were collected from were found in the China Urban Statistical Yearbook (National Bureau of Statistic (NBS), 2015-2020), China Statistical Yearbook on Environment (Ministry of Ecology and Environment, 2015-2020) and China Urban Construction Statistical Yearbook (MOHURD,2015-2020).Comparing to the data collected by the four city themselves, the information from these three sources may generally be relied upon to be reliable. The practical characteristic variation of MSW and the resources in four cities were shown in Table 2.

There are some glaring data gaps in the collection, despite the fact that the amount of MSW produced and disposed of in each city is documented in the national database. It indicates that the amount of MSW gathered and handled in cities by the unofficial sector is not legally documented. In China, informal recycling currently lacks a significant amount of focused policy direction in the process of switching to formal recycling since the country's domestic waste management system has not been strengthened and recycling measures have not been created in the waste disposal system (Fei et al, 2016). The corresponding recycling data cannot be aggregated in the short term. Only a few studies have investigated into the possibilities, drivers, and distribution channels of informal recycling in certain cities (Chi et al, 2011, Hu and Wen, 2015). Therefore, this study cannot include this data in the total MSW recycling, but we will propose the improvement of the corresponding database as a policy recommendation.

In addition, waste composition was investigated in different cities according to the previous research. Due to data gaps, we estimated the change in waste composition in the past five years. For instance, in the absence of specific data on the composition of domestic waste in some cities, based on similarities in urban planning, economic system, and population structure, the waste composition data from the capital cities in the province were used as a proxy of the selected cities. For example, in calculating the MSW disposal in Panjin and Tongling cities, composition data was based on data from Shenyang and Hefei. The composition of MSW in Shenzhen and Xining were obtained directly, and the data closest to the study year was chosen in the selection process. The information related to the technologies used for treating MSW or the detailed characteristics of MSW derived fuels were not critical for the calculations and only considered where available.

3. Case studies

This research selected the four representative cities from the list of "Zero-waste cities" for investigating the GHG emissions reductions achieved by the range of management policies for MSW. The criteria for selecting the case studies were based on their geographical differences, population, different industrial structures and the level of economic development. In China, landfills for MSW disposal are widespread used in the northwest in China whilst a combination of landfill and incineration is more common in eastern and southern China (Wang and Nakakubo, 2020). From the geographical perspective, the four cities are located in the eastern, western, central, and northeastern areas in China respectively. Each of the four cities applies different strategies for dealing with urban waste generation, collection, transportation, and waste management treatment since the four cities have their distinctive industrial structure and technological capability. The specific composition of domestic waste, as

shown in Table 2, varies significantly among the four cities. In addition to that, the development patterns of emerging industries differs across the four cities, leading to specific strategies and practices towards achieving "Zero-waste cities" status. In sum, Panjin, Tongling, Xining, and Shenzhen city as the case studies are representative of a range of urban formulations of the "zero waste city" pilot program in China, which is dedicated to investigate the impacts of GHG reductions brought by different waste management approaches. Therefore, this study can contribute to the scientific basis and provide policy recommendations from a national perspective as a backdrop of the "zero-waste city" initiatives across the nation.

4. Results and Discussion

4.1 Analysis of the MSW components in the case studies

In the past five years, various significant changes have taken place in the MSW management practices among the four case studies as shown in Fig 1, Taking Panjin as an example, as shown in the figure, landfill-based MSW management was predominant from 2015 to 2019. MSW management in Xining was predominantly landfilling between 2015 and 2017 but increased the share of other forms of waste disposal since 2018. The city of Shenzhen adopted a more integrated treatment model, combining landfill and incineration since 2015, with a similar amount of landfills and incinerators. While in 2019, the total mass of landfill disposal was far exceeded by incinerated waste, resulting in a difference of more than 1.7 MMT. Tongling opted for the incineration model from 2015 to 2019 but increased the number of landfills from 2019. Apart from landfill and incineration disposal, composting and recycling have increased their relevance as MSW management approaches, although still much progress is needed in this area.

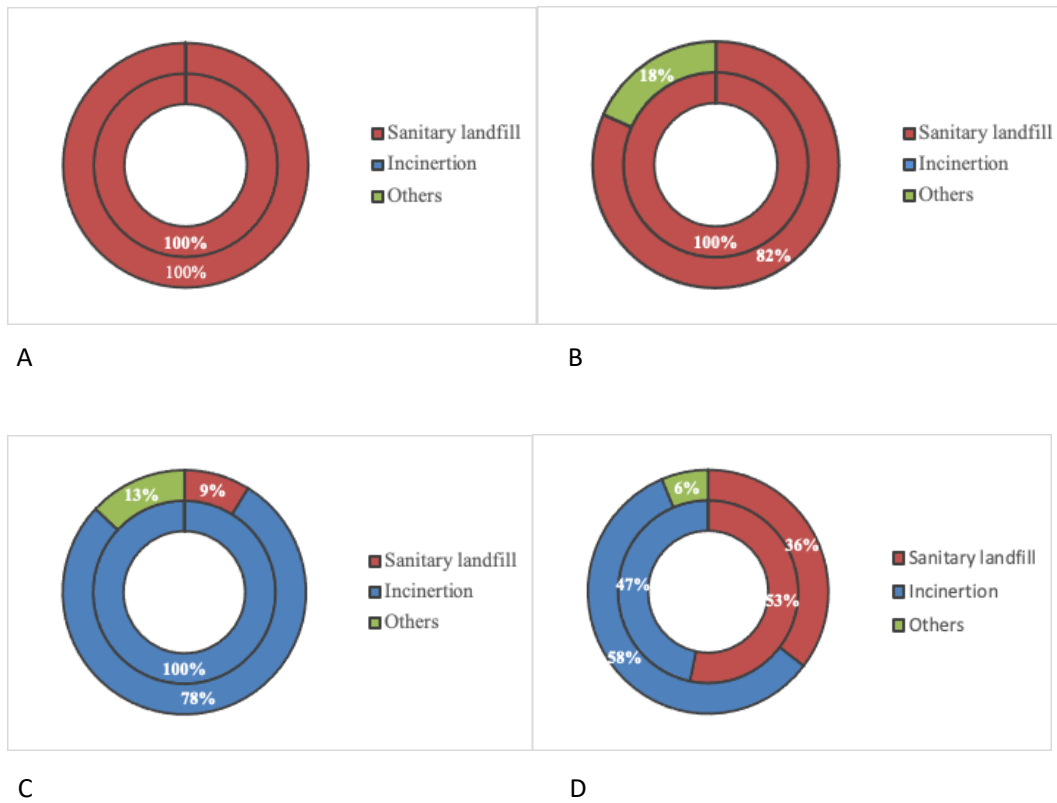


Fig. 1. The total treatment ratio using landfill, incineration and other approaches for MSW disposal in Panjin (A), Xining (B), Tongling (C), Shenzhen (D), inner: year 2015; external: year 2019.

Due to the distinctive MSW management practices in the four cities, the waste generation and disposal ratio were different. Panjin, Tongling, and Xining showed similar trend in terms of waste generation, ranging from 213,500 MT in 2015 to 265,700 MT by 2019, whilst the amount of waste in Tongling tripled in five years, from 107,400 tons in 2015- to 210,000 tons in 2019. From 2015 to 2018, Xining as part of joining the program of "cities without waste" in 2018 has significantly improved the measures for separating, treating, and recycling MSW. Due to its high urbanization level and large urban population, the amount of MSW disposal was the highest in Shenzhen among the four cities. From 2015 to 2019, it increased by more than 2 million tons.

4.2 GHG emissions associated with MSW

Based on various management approaches of MSW, the estimated GHG emissions from waste management consisted mainly of CH₄ and CO₂. As shown in Fig.2, due to the higher mass of waste generation, the total CO₂e emissions of Panjin, Xining, and Tongling associated with MSW management increased over the five years, from 30,000 to 70,000 MT, while CO₂e emissions in Shenzhen decreased significantly, in the region of 10.083 MMT. During the period between 2015 and 2017, CO₂e emissions associated with MSW management in Xining and Shenzhen fell by more than 15%, while in Panjin the decrease was of 3%. The reasons for the decline in CO₂e emissions in each of the three cities were different. The mass of MSW for disposal in Panjin and Xining decreased by 3% and 16%, respectively, while that in Shenzhen increased by 7%. While the amount of waste grew year by year, the capacity of waste landfill in Shenzhen also increased accordingly from 8,388 MT/day to 9,019 MT/day from 2015 to 2017. After the list of "zero waste cities" was released in 2018 and until 2019, relevant management measures to achieve "zero waste cities" were gradually implemented. Therefore, GHG emissions associated with the total MSW in Shenzhen and Xining decreased to varying degrees, with associated reduction in CO₂e of more than 1.046 MMT CO₂e, which is more than 40% compared to the previous period in Shenzhen, while in Xining the decrease was in the region of 0.11 MMT CO₂e. However, the total GHG emissions of Tongling and Panjin increased by 38,200 MT CO₂e and 17,400 MT CO₂e respectively.

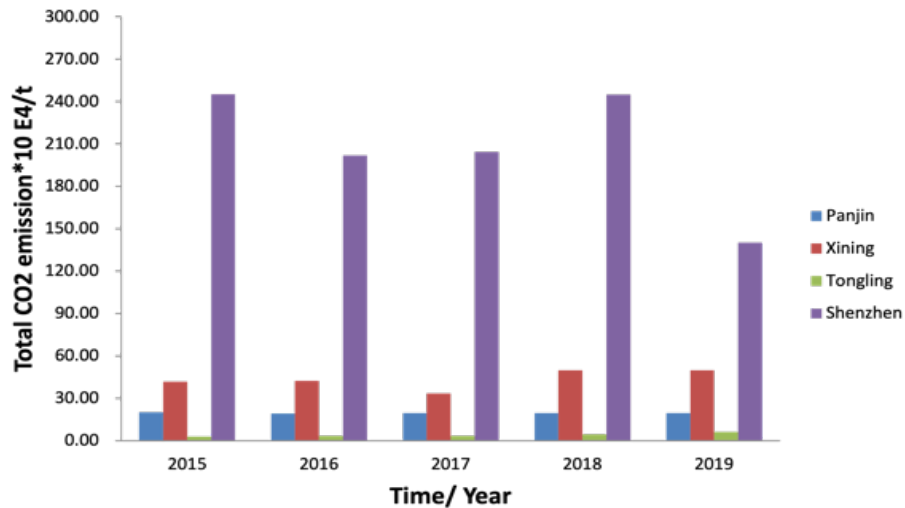


Fig. 2. Total CO_{2e} emission associated with MSW disposal during 2015-2019 among the four cities.

With the regard to the four cities' resident population during the period of 2015 and 2019, GHG emissions on a per capita basis associated with MSW management were calculated. Results demonstrated that the per capita levels of waste treatment in the four cities changed significantly in the past five years. By increasing the recovery rate of waste gas in landfills, and increasing the amount of domestic waste treated through incineration, recycling and other treatment modes , the CO_{2e} emissions per capita declined in both Panjin and Shenzhen. Panjin dropped by 39.73 kg CO_{2e} per capita, even when total population of Panjin increased significantly in recent years. In fact, Shenzhen has created a relatively efficient waste management model, which increases the amount of MSW treated by incineration on the basis of the total waste generation control. From 2015 to 2019, the amount of municipal solid waste incinerated in Shenzhen increased by 1.74 MMT, up more than 60%. In Shenzhen, CO_{2e} emissions per capita fell by 111.23 kg CO_{2e} from 2015 to 2019 as a result of the efforts to develop waste segregation, better management and the construction of a green

environmental park that integrated waste incineration plants and controlled landfill sites.

Conversely, Xining and Tongling experienced increases of CO_{2e} emissions associated with MSW management practices in the same period. Xining was the city with the highest average per capita emissions in CO_{2e} in the past few years. However, there were some periods where CO_{2e} reductions were achieved such as between 2018 and 2019, possibly due to policy measures such as an updated domestic waste measurement standard, certain types of waste will no longer be included in the total amount of MSW which results in significant reductions in the total amount. The decrease in 2019 was related to an increase in the recovery ratio of CH₄ from the Xining landfill, which was accompanied by the reduction of the proportion of waste sent to landfill, resulting in per capita GHG emissions reduction of 4.3 kg CO_{2e} between 2018 and 2019. It is noteworthy that the city of Tongling performed better than the other three cities in terms of total and per capita emissions, the reason was that the use of incineration for main treatment route for MSW from 2015 to 2019. In addition, in terms of the relationship between emissions and urban population, Shenzhen's population was much larger than the other three cities. Thus, per capita CO_{2e} emission associated with MSW management remained low. However, in Panjin and Xining with medium-sized populations, the per-capita CO_{2e} emissions were higher.

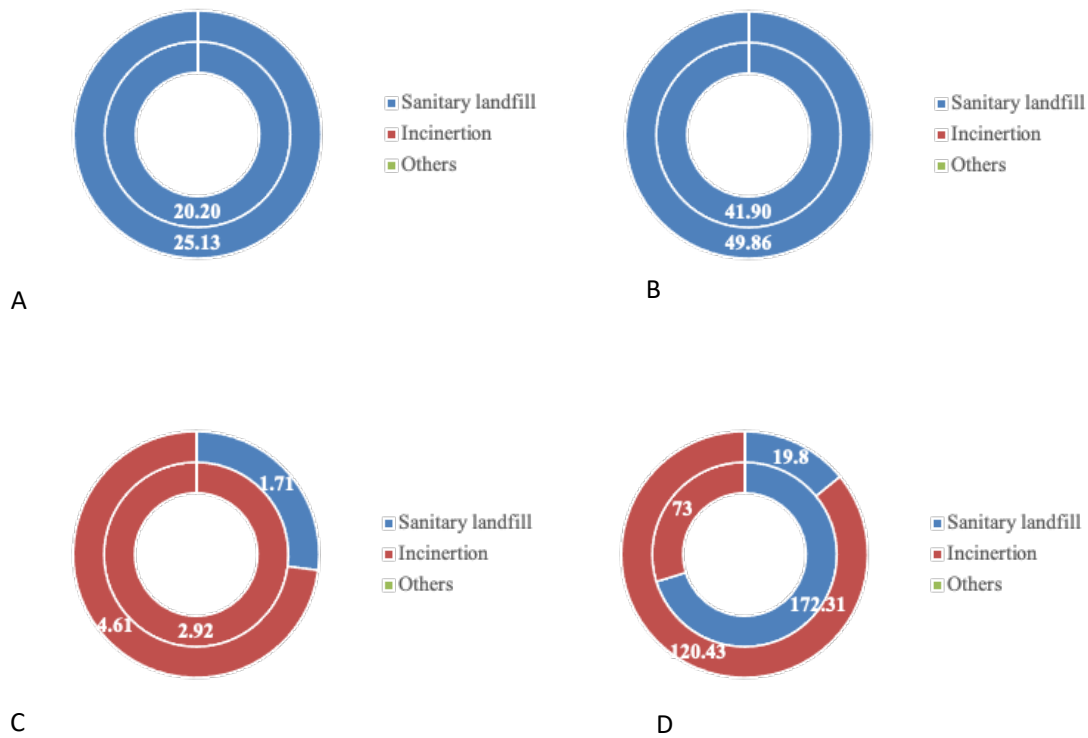


Fig. 3. Total CO_{2e} emissions associated MSW in different disposal approaches in Panjin(A), Xining (B), Tongling(C), Shenzhen(D) inner: year 2015; external: year 2019.

GHG emission variations reflected the corresponding approaches in dealing with MSW among the selected areas (Fig.3). GHG emissions associated with MSW management in Panjin and Xining arise mainly from the sanitary landfills, while the GHG emissions associated with MSW management in Tongling was originated mainly from incineration. In Shenzhen, the GHG emissions associated with MSW were from both the incineration and sanitary landfills. From the comparison, one could conclude that Shenzhen generated the most GHG emissions followed by Tongling, associated with incineration processes. In terms of sanitary landfilling, Shenzhen also generated the significant GHG emissions during the period 2015-2018. However, in 2019, the GHG emissions from sanitary landfilling in Shenzhen dropped

significantly. In the same year, Xining and Panjin were the two cities with largest share of GHG emissions associated with MSW management (see Fig. 4).

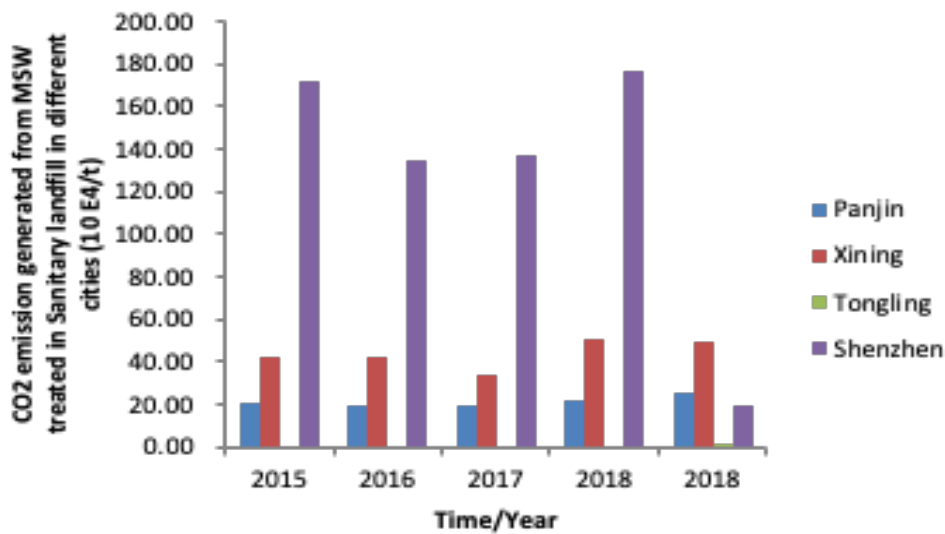


Fig. 4. Total CO_{2e} emissions associated with MSW treated in sanitary landfills in the four cases.

A significant data limitation is that recovery capacity of these waste treatment facilities is not detailed in the official reports. The information had to be gathered from the project declarations of some waste management companies in news reports, resulting potentially in an underestimation of recovery capacity. Xining mainly used landfill sites for waste disposal. In 2015, a methane power plant was installed the treatment plants, with an average annual methane capture mass of 3.75 million cubic meters. In optimizing MSW treatment and disposal facilities, some municipalities equipped waste treatment plants with new GHG emission reduction technologies. For example, only the Xiaping landfill site in Shenzhen had a methane gas recovery facility in the period 2015- 2018. However, since 2018, the Laohu Keng ecological environmental park and the Honghua Ling ecological environmental park had been equipped with GHG collection technologies, resulting in a GHG emission reduction of 40% between 2018 and 2019.

4.3 Policy implications

The each city should implement tailored mitigation measures in accordance with the GHG emissions from MSW treatment of the city and local conditions. According to the findings, the most efficient approaches to minimize GHG emissions are to lower the amount of MSW produced at the source and improve the way and structure of waste disposal.

The main strategy for reducing GHG emissions from the trash sector was source reduction. A policy should be carried on influencing how society's residents behave in order to decrease waste production, which would simultaneously help with GHG reduction goals and resource conservation. The amount of MSW disposed in landfills or burned should be kept under control, and recycling programs should be encouraged, in order to prevent domestic waste emissions from becoming more intense against the backdrop of a growing global population. An enhanced waste classification and segregation of waste fractions can not only increase recycling rates of recyclable materials, but also reduce inefficient utilization of energy in incineration processes. After the pilot policy was launched in 2019, all four cities introduced special measures to reduce the overall amount of waste. Xining boosted the integration of the waste collection and transportation network with the recycling network. Panjin promoted new recycling means by Internet (Government of Panjin, 2021), and Shenzhen blended the entire domestic waste classification into governance system (Municipal Bureau of ecological environment of Shenzhen, 2020). The results show that this source reduction measure has contributed to the reduction of greenhouse gas emissions. By 2020, all four cities have reached the target of 33%-37% of municipal domestic waste recycling rate, and greenhouse gas emissions from domestic waste have been reduced by 3%-15% in parallel.

The management of agencies and organizations may pay greater attention to waste disposal structure and technical advancement when the local authority and government announce the mitigation policies of the MSW sector. An optimized model of MSW management targeting waste reduction and GHG emissions reductions still needs to be developed. According to our study, the efficiency (in terms of GHG emission saving potential) of waste incineration is higher than that of landfill disposal. The incineration-based waste treatment method is being used in each pilot region, as can be observed from the "zero city construction pilot guiding program" released by each of the four cities. The case study of the city of Shenzhen shows how improvement in waste management approaches including new infrastructure such as the ecological environmental center, which integrates waste incineration, controlled landfilling, and dedicated treatment which combine Anaerobic Digestion and recycle method for kitchen/food waste, have significantly reduced the GHG emissions (methane and carbon dioxide) (Bureau of Urban Management and Comprehensive Law Enforcement of Shenzhen Municipality, 2022). This program has assisted Shenzhen in completing the management of urban kitchen garbage intelligently and greatly reducing the greenhouse gas emissions produced by the incineration of kitchen waste.

Further research needs to investigate optimal combination of treatments and technologies depending on contextual characteristics such as composition of waste, urban design, industry mix and other relevant aspects. MSW treatment facilities should be improved and upgraded with new technologies to promote higher efficiency of MSW treatment to reduce GHG emissions during the process. In terms of waste disposal technology, most of the landfills in China lack basic recycling facilities, such as those in Panjin and Tongling cities. At the same time, some advanced waste

incinerators in southeastern China achieved efficient processes, contributing to GHG reductions and energy recovery. Government departments can also refer to Prof. Raninger's organic waste management project in Shenyang. By collecting bio-waste, we can increase the recovery rate of bio-organic materials, reduce the amount of domestic waste in landfills and implement the "source separation" environmental protection idea (Bernhard Raninger, 2007). On behalf of promoting efficient recycling and recovery of waste and reduce GHG reductions, governments and public-private partnerships need to collaborate to upgrade existing waste treatment facilities with advanced technology and equipment to increase rate of recovery, both in terms of material recovery through recycling and energy recovery from waste.

5. Conclusion

This study evaluated GHG emissions related to MSW in the selected four cities of the national "Zero waste city" pilot program during the period 2015 and 2019 to investigate the impacts on GHG emission reduction by various MSW management practices. In this study, the composition of MSW waste in the selected case studies and its associated GHG emissions are analyzed. In addition, the corresponding waste policy strategies of the four cases towards MSW management are described and compared. The results indicated that MSW management in Shenzhen has achieved remarkable results in terms of GHG reduction. In the past five years, the GHG emissions associated with MSW in Shenzhen decreased by more than 40%, while the per capita GHG emissions of Panjin waste treatment decreased significantly, by 39.73 kg CO₂e per capita per year. After becoming a pilot area as part of the "Zero waste city" program in 2019, the amount of MSW generation treated by landfill and GHG emissions in Xining city dropped, which may be attributed to the policies and strategies introduced as part of the "Zero waste" program.

Due to the differences among the four cases, the GHG reductions related to MSW have followed distinctive patterns, and thus approaches to MSW management have also been different. Despite improvements made in the four cities towards achieving the “Zero waste city” status, the predominant routes for MSW treatment and disposal are still sanitary landfills and incineration. Rate of reutilization and recycling of MSW are still far compared to those of more developed nations, with an important unrealized potential to improve circulation and contribute to GHG emission reduction targets. For example, promoting policies that enable informal recycling to become a contributor to renewable energy recovery. To reduce GHG emissions during MSW management, the results have shown that government interventions to optimize waste treatment facilities have resulted in very significant GHG emission reduction. In addition, more stringent commitments to waste reutilization and recycling can further contribute to GHG reductions in the future but requires important investments in infrastructures and optimization of collection and treatment processes.

References

- Bai, W.G., Zhuang, G.Y., Zhu, S.X., 2013. Progresses and Prospects of Municipal Greenhouse Gas Inventory Research in China. *China Population, Resources and Environment* 23(01), 63-68.
- Bernhard Raninger, 2007. Why do I collect waste in China?
<https://en.sau.edu.cn/info/1039/1047.htm>
- Bo, X. , Zhao, Y. , Mei-Ting, J. , Chu, C., Zhang, Z., 2019. Regional differences of municipal solid waste generation in china based on the stirpat model. *China Environmental Science* 39(11), 4901-4909
- Bureau of Urban Management and Comprehensive Law Enforcement of Shenzhen Municipality, 2022. List of large kitchen waste disposal facilities in Shenzhen.
http://cgj.sz.gov.cn/zwgk/ztl/ztl1/wgkz/fwgk/ccljclss/content/post_9731371.html
- Cai, B., Lou, Z., Wang, J., Geng, Y., Joseph, S., Liu, J., Gao, Q., 2018. CH₄ mitigation potentials from China landfills and related environmental co-benefits. *Science Advances*. 4 (7), eaar8400.
- Cai, B., Liu J., Zeng, X.,Cao D., Liu L.,Zhou Y., Zhang Z., 2013. Estimation of CH₄ emissions from landfill in China based on point emission sources. Progress inquisitions de mutatione climate. 9(6): 406-413. (in Chinese)
- Curran, T., Williams, I. D., 2012. A zero-waste vision for industrial networks in Europe. *Journal of Hazardous Materials*. 207–208.
- Cheng, J., Shi, F., Yi, J., Fu, H., 2020. Analysis of the factors that affect the production of municipal solid waste in China. *Journal of Cleaner Production*. 259 (120808). <https://doi.org/10.1016/j.jclepro.2020.120808>

- Chi, X., M. Streicher-Porte, Wang, M.Y.L., M.A. Reuter, 2011. Informal electronic waste recycling: a sector review with special focus on China, *Waste Management.*, 31 (4) 731-742
- Christensen, T. H. , Damgaard, A. , Levis, J. , Zhao, Y. , & Bisinella, V. , 2020. Application of lca modelling in integrated waste management. *Waste Management*, 118, 313-322. <https://doi.org/10.1016/j.wasman.2020.08.034>.
- Climate Watch. 2022. Washington, DC: World Resources Institute. Available online at: <https://www.climatewatchdata.org>.
- Ding, Y., Zhao, J., Liu, J. W., Zhou, J., Cheng, L., Zhao, J., Shao, Z., Iris, Ç., Pan, B., Li, X., Hu, Z. T., 2021. A review of China's municipal solid waste (MSW) and comparison with international regions: Management and technologies in treatment and resource utilization. *Journal of Cleaner Production*. 293 (126144). <https://doi.org/10.1016/j.jclepro.2021.126144>
- Duan, N., Li, D., Wang, P., Ma, W., Wenga, T., Zhong, L., Chen, G., 2020. Comparative study of municipal solid waste disposal in three Chinese representative cities. *Journal of Cleaner Production*. 254 (120134). <https://doi.org/10.1016/j.jclepro.2020.120134>
- Fei, F., Qu, Lu, Wen, Z., Xue, Y., Zhang H., 2016. How to integrate the informal recycling system into municipal solid waste management in developing countries: Based on a China's case in Suzhou urban area, *Resources, Conservation and Recycling*, 110, 74-86, <https://doi.org/10.1016/j.resconrec.2016.03.019>.
- FISU (Finnish Sustainable Municipalities), 2016. FISU municipalities (in Finnish) <http://www.fisunetwork.fi/fi-FI/Fisukunnat> (accessed 5th September 2016).

- Gu, B., Tang, X., Liu, L., Li, Y., Fujiwara, T., Sun, H., Gu, A., Yao, Y., Duan, R., Song, J., Jia, R., 2021. The recyclable waste recycling potential towards zero waste cities - A comparison of three cities in China. *Journal of Cleaner Production*. 295(126358). <https://doi.org/10.1016/j.jclepro.2021.126358>
- Government of Panjin, 2021. Implementation Plan for Urban and Rural Domestic Waste Classification and Resource Utilization in Panjin City. https://www.mee.gov.cn/home/ztbd/2020/wfcsjssdgz/wfcsxwbd/wfcsmtbd/202103/t20210312_824544.shtml
- Hu, S., Wen Z. Why does the informal sector of end-of-life vehicle treatment thrive? A case study of China and lessons for developing countries in motorization process resources *Resources, Conservation and Recycling*, 95 (2015), 91-99
- IPCC, 2006a. 2006 IPCC Guidelines for National Greenhouse Gas Inventories. Vol. 5, Waste, Chapter 2, Waste generation, composition and management data. https://www.ipcc-nggip.iges.or.jp/public/2006gl/pdf/5_Volume5/V5_2_Ch2_Waste_Data.pdf
- IPCC, 2006b. 2006 IPCC Guidelines for National Greenhouse Gas Inventories. Vol. 5, Waste, Chapter 3, Solid waste disposal. https://www.ipcc-nggip.iges.or.jp/public/2006gl/pdf/5_Volume5/V5_3_Ch3_SWDS.pdf
- Ju, A., Chen J., 2017. Waste Classification, Collection and Disposal Mode in the Zero Waste City of Japan: An Example from Kamikatsu of Tokushima Prefecture. *Environmental Sanitation Engineering*. 25, No. 3.
- Kang Y., Yang Q., Wang L., Chen Y., Lin G., Huang J., Yang H., Chen H., China's changing city-level greenhouse gas emissions from municipal solid waste treatment and driving factors, *Resources, Conservation and Recycling*, 180(106168), <https://doi.org/10.1016/j.resconrec.2022.106168>.

- Kerdlap, P., Low, J.S.C., Ramakrishna, S., 2019. Zero waste manufacturing: A framework and review of technology, research, and implementation barriers for enabling a circular economy transition in Singapore. *Resources, Conservation and Recycling*. 151(104438). <https://doi.org/10.1016/j.resconrec.2019.104438>
- Lou, Z., Cai, B., Zhu, N., Zhao, Y., Geng, Y., Yu, B., Chen, W., 2017. Greenhouse gas emission inventories from waste sector in China during 1949–2013 and its mitigation potential. *Journal of Cleaner Production* 157, 118-124.
- Li, Y., Tan, J.Y., Dong, Q.Y., Liu, L.L., Li, J.H., 2020. Production and recycling of municipal solid waste in typical northwest city of China, Xining. *Environmental Pollution & Control* 42(3), 385-389. (in Chinese)
- Liu, J., MA, Z., ZHANG Y., SONG,L., Li W., Li, Y., GAO, Q., 2014.Key methane emission factors from municipal solid waste landfill treatment in China[J]. *Research of Environmental Sciences*, 2014, 27(9) : 975-980. (in Chinese)
- Liu, M.D., Meng J.J. , Liu B.H., 2014. Progress in the Studies of Carbon Emission Estimation. *Tropical Geography*. 34(2), 248-258. (in Chinese)
- Liu, X.Z., Sun, X., Zhu, Q.K., Shang, Y.T., 2017. Review on the Measurement Methods of Carbon Dioxide Emissions in China. *Ecological Economy* 33(11),21-27. (in Chinese)
- Liu, Z., Adams, M., Cote, R.P., Chen, Q.H., Liu, WL., Sun, L., Yu, XM., 2017. Comprehensive development of industrial symbiosis for the response of greenhouse gases emission mitigation: challenges and opportunities in China. *Energy Policy*. 102, 88-95.
- Liu, Z., Adams, M., Cote, R.P., Geng, Y., Chen, QH., Liu, W.L., Zhu, X.S., 2018a. Co-benefits accounting for the implementation of eco-industrial development strategies in the scale of industrial park based on energy analysis. *Renewable &*

- Sustainable Energy Reviews*. 81, 1522-1529.
- Liu, Z., Adams, M., Cote, R.P., Chen, Q.H., Wu, R., Wen, Z.G., Liu, W.L., Dong, L., 2018b. How does circular economy respond to greenhouse gas emissions reduction: An analysis of Chinese plastic recycling industries. *Renewable & Sustainable Energy Reviews*. 91, 1162-1169.
- Liu, Z., Liu, W.L., Adams, M., Cote, R.P., Geng, Y., Chen, S.L., 2019. A hybrid model of LCA and emergy for co-benefits assessment associated with waste and by-product reutilization. *Journal of Cleaner Production*. 236(117670), 1-9.
- Liu, Z., Liu, W.L., Walker, T.R., Adams, M., Zhao, J.J., 2021. How does the global plastic waste trade contribute to environmental benefits: implication for reductions of greenhouse gas emissions? *Journal of Environmental Management*. 287 (112283), 1-9.
- Lu, W., Bao, Z., Lee, W., Chi, B., Wang, J., 2021. An analytical framework of “zero waste construction site”: Two case studies of Shenzhen, China. *Waste Management*. 121, 343-353.
- Ma, Z., 2010. Domestic waste investigation and disposal method in Shenyang. *Environ. Sanit. Eng.* 18 (2), 13-14. (in Chinese)
- Marine Colon, Ben Fawcett, 2006. Community-based household waste management: Lessons learnt from EXNORA's ‘zero waste management’ scheme in two South Indian cities. *Habitat International*, 30, 916-931.
- Michel Devadoss, P. S., Agamuthu, P., Mehran, S. B., Santha, C., Fauziah, S. H., 2021. Implications of municipal solid waste management on greenhouse gas emissions in Malaysia and the way forward. *Waste Management*. 119, 135-144.
- Municipal Bureau of ecological environment of Shenzhen, 2020. Implementation plan of "zero waste city" construction in the 14th Five-year Plan period of

Shenzhen. http://meeb.sz.gov.cn/isz/hbxw/content/post_9858998.html

Ministry of Ecology and Environment, 2018. Work Plan on “Zero-waste City” Pilot Program in China. Available at: Ministry of Ecological Environment, Beijing, China. (in Chinese)

http://www.mee.gov.cn/home/ztbd/2020/wfcsjssdgz/dcsj/wfcszcwj/202006/t20200602_782280.shtml.

Ministry of Ecology and Environment, 2019. Case analysis report of zero waste cities. Available at: Ministry of Ecological Environment, Beijing, China (in Chinese).

http://www.mee.gov.cn/home/ztbd/2020/wfcsjssdgz/bczc/wfcs gjjy/201907/t20190726_712408.shtml. (Accessed 15 July, 2019)

Ministry of Ecology and Environment, 2019. Guidelines for Work Plan on “Zero-waste City” Pilot Program in China and The evaluation index system of "Zero-waste City" Pilot Program in China. Available at: Ministry of Ecological Environment, Beijing, China (in Chinese).

http://www.mee.gov.cn/xxgk2018/xxgk/xxgk06/201905/t20190513_702598.html (Accessed 8 May, 2019)

Ministry of Ecology and Environment, 2019. “Zero-waste City” Pilot Program.

Available at: Ministry of Ecological Environment, Beijing, China (in Chinese).

http://www.mee.gov.cn/home/ztbd/2020/wfcsjssdgz/wfcsxwbd/wfcsmtbd/201906/t20190606_705827.shtml (Accessed 14 May, 2019)

Ministry of Ecology and Environment, 2019. International experience and enlightenment on the construction of " Zero-waste City ". Available at: Ministry of Ecological Environment, Beijing, China (in Chinese).

http://www.mee.gov.cn/home/ztbd/2020/wfcsjssdgz/bczc/wfcs gjjy/201903/t20190329_697830.shtml. (Accessed 29 March, 2019)

MOHURD,2015. Urban and Rural Construction Statistical Yearbook. Available at:
Ministry of Housing and Urban-Rural Development, Beijing, China in Chinese.
<http://www.mohurd.gov.cn/xytj/tjzljxsxytjgb/jstjnj/>.(Accessed 23 December,
2016)

MOHURD,2016. Urban and Rural Construction Statistical Yearbook. Available at:
Ministry of Housing and Urban-Rural Development, Beijing, China in Chinese.
<http://www.mohurd.gov.cn/xytj/tjzljxsxytjgb/jstjnj/>.(Accessed 5 January, 2018)

MOHURD,2017. Urban and Rural Construction Statistical Yearbook. Available at:
Ministry of Housing and Urban-Rural Development, Beijing, China in Chinese.
<http://www.mohurd.gov.cn/xytj/tjzljxsxytjgb/jstjnj/>.(Accessed 5 January, 2018)

MOHURD,2018. Urban and Rural Construction Statistical Yearbook. Available at:
Ministry of Housing and Urban-Rural Development, Beijing, China in Chinese.
<http://www.mohurd.gov.cn/xytj/tjzljxsxytjgb/jstjnj/>.(Accessed 27 March, 2020)

MOHURD,2019. Urban and Rural Construction Statistical Yearbook. Available at:
Ministry of Housing and Urban-Rural Development, Beijing, China in Chinese.
<http://www.mohurd.gov.cn/xytj/tjzljxsxytjgb/jstjnj/>.(Accessed 21 December,
2020)

Ministry of Ecology and Environment, 2015. China Statistical Yearbook on
Environment.
<http://cnki.scstl.org/CSYDMirror/Trade/yearbook/single/N2018050254?z=Z008>

Ministry of Ecology and Environment, 2016. China Statistical Yearbook on
Environment.
<http://cnki.scstl.org/CSYDMirror/Trade/yearbook/single/N2018050254?z=Z008>

- Ministry of Ecology and Environment, 2017. China Statistical Yearbook on Environment.
<http://cnki.scstl.org/CSYDMirror/Trade/yearbook/single/N2018050254?z=Z008>
- Ministry of Ecology and Environment, 2018. China Statistical Yearbook on Environment.
<http://cnki.scstl.org/CSYDMirror/Trade/yearbook/single/N2018050254?z=Z008>
- Ministry of Ecology and Environment, 2019. China Statistical Yearbook on Environment.
<http://cnki.scstl.org/CSYDMirror/Trade/yearbook/single/N2018050254?z=Z008>
- Ministry of Ecology and Environment, 2020. China Statistical Yearbook on Environment.
<http://cnki.scstl.org/CSYDMirror/Trade/yearbook/single/N2018050254?z=Z008>
- Ministry of housing and urban-rural development of PRC (MHDC), 2009. The report on the 2nd national waste treatment facilities sanitary level assessment project. Technol. Munic. Solid Waste Treat. 4, 4e7 (in Chinese).
- Ministry of housing and urban-rural development of PRC (MHDC), 2012. The Grading Lists of Sanitary Level Assessment on MSW Landfills and Incineration Plants. http://std.solidwaste.com.cn/upfile/2013/04/78_1364967479.pdf (in Chinese, Accessed date 14 April 2017).
- National Bureau of Statistic (NBS), 2015. China Statistical Yearbook. China Statistic Press.
- National Bureau of Statistic (NBS), 2016. China Statistical Yearbook. China Statistic Press.
- National Bureau of Statistic (NBS), 2019. China Statistical Yearbook. China Statistic Press.

- National Development and Reform Commission (NDRC), 2018. The People's Republic of China second biennial update report on climate change. <http://big5.mee.gov.cn/gate/big5/www.mee.gov.cn/ywgz/ymqhbh/wsqtzkz/201907/P020190701765971866571.pdf> (accessed 17 June 2021).
- O. Sahimaa, M.K. Mattinen, S. Koskela, M. Salo, J. Sorvari, T. Myllymaa, J. Huuhtanen, J. Seppälä, 2017. Towards zero climate emissions, zero waste, and one planet living — Testing the applicability of three indicators in Finnish cities, *Sustainable Production and Consumption*, 10(121-132), <https://doi.org/10.1016/j.spc.2017.02.004>
- O.O. Ayeleru, F.N. Okonta, F. Ntuli, 2018. Municipal solid waste generation and characterization in the City of Johannesburg: A pathway for the implementation of zero waste, *Waste Management*, 79(87-97), <https://doi.org/10.1016/j.wasman.2018.07.026>.
- Qu, S., Yang, D., 2011. The Estimation of Greenhouse Gas emission from waste and its peak in China. *China Industrial Economics*. 11, 37-47. (in Chinese)
- Rhodium Group, 2021. China's Greenhouse Gas Emissions Exceeded the Developed World for the First Time in 2019. https://rhg.com/research/china-emissions-surpass-developed-countries/#_ftn1. (Accessed 6 May, 2021)
- Shen, L., Si, H., Yu, L., Si, H., 2019. Factors influencing young people's intention toward municipal solid waste sorting. *International Journal of Environmental Research and Public Health*. 16 (1708). <http://dx.doi.org/10.3390/ijerph16101708>
- Tai, J., Zhang, W., Che, Y., Feng, D., 2011. Municipal solid waste source-separated collection in China: A comparative analysis. *Waste Management*. 31(8), 1673-1682

United states Environment Protection Agency (USEPA), 2009. User's Manual, China Landfill Gas Model, Version 1.1.

<https://nepis.epa.gov/Exe/ZyNET.exe/P1006WID.TXT?ZyActionD=ZyDocument&Client=EPA&Index=2006+Thru+2010&Docs=&Query=&Time=&EndTime=&SearchMethod=1&TocRestrict=n&Toc=&TocEntry=&QField=&QFieldYear=&QFieldMonth=&QFieldDay=&IntQFieldOp=0&ExtQFieldOp=0&XmlQuery=&File=D%3A%5Czyfiles%5CIndex%20Data%5C06thru10%5CTxt%5C0000016%5CP1006WID.txt&User=ANONYMOUS&Password=anonymous&SortMethod=h%7C-&MaximumDocuments=1&FuzzyDegree=0&ImageQuality=r75g8/r75g8/x150y150g16/i425&Display=hpfr&DefSeekPage=x&SearchBack=ZyActionL&Back=ZyActionS&BackDesc=Results%20page&MaximumPages=1&ZyEntry=1&SeekPage=x&ZyPURL> (in Chinese)

Wang, K., Nakakubo, T., 2020. Comparative assessment of waste disposal systems and technologies with regard to greenhouse gas emissions: A case study of municipal solid waste treatment options in China. *Journal of Cleaner Production*. 260(120827). <https://doi.org/10.1016/j.jclepro.2020.120827>

World Bank Group, 2018. What a Waste 2.0: A Global Snapshot of Solid Waste Management to 2050. <https://www.worldbank.org/en/news/infographic/2018/09/20/what-a-waste-20-a-global-snapshot-of-solid-waste-management-to-2050>

Wu, K, Yu, ZM, Jin, J., Cai, JM., Chu, W., 2008. A Discussion of Selection of Schemes for Municipal Solid Waste Treatment in Hefei City. *Journal of Hefei University (Nature Sciences)*. 18 (3), 56-69. (in Chinese).

- Writing Group of the Provincial Greenhouse Gas Inventories, 2010. The Provincial Greenhouse Gas Inventories.
- <http://www.cbcsd.org.cn/sjk/nengyuan/standard/home/20140113/download/shengjiwenshiqiti.pdf>. (Accessed May, 2010). (in Chinese)
- Xie P., Wang W., Wang W., Liao C., Zhao D., 2020. Current Status and Forecasts of Greenhouse Gas Emissions from Urban Domestic Waste Treatment of Guangzhou. *Science and Technology Management Research*. 14, 247-252. (in Chinese).
- Yang, N., Damgaard, A., Scheutz, C., Shao, L.M., He, P.J., 2018. A comparison of chemical MSW compositional data between China and Denmark. *Journal of Environmental Sciences*. 74, 1-10 (in Chinese).
- Zero Waste International Alliance, 2018. Zero Waste Definition. <https://zwia.org/zero-waste-definition/> (Accessed 20 December, 2018)