# Navigating Municipal Solid Waste Practices: A Comparative Analysis of the U.S., Canada, and China

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## ABSTRACT

Solid waste management is a critical global challenge, with approximately 11.2 billion tons of waste collected annually, contributing to 5% of global greenhouse gas emissions (UNEP, 2024). This paper offers a comparative analysis of waste management practices in the United States, Canada, and China, focusing on waste composition, factors driving increased waste, and waste diversion patterns. The study underscores the strengths and weaknesses of each country's management approach, providing insights for policymakers and stakeholders to enhance global waste management strategies.

## Introduction

Solid waste, colloquially referred to as garbage, is responsible for approximately 5% of global greenhouse gas (GHG) emissions (UNEP, 2024). Today, around 11.2 billion tons of solid waste is collected every year worldwide. It is crucial for countries to develop sustainable ways to manage waste as it is having detrimental effects on the environment and the health of people and animals. This paper provides a comparative analysis to review the evolution and current waste management efforts in three economies: the United States, Canada, and China. Our analysis focuses on the current composition of waste, explanatory factors of increased waste, and patterns of diverting or landfilling waste in these three countries. Through this overarching comparison of the literature, this review offers insights into the strengths and weaknesses of waste management in three of the leading economies of the world.

## United States

The United States is the largest producer of municipal solid waste (MSW) globally. Since the 1960s, accompanying economic growth in the nation, MSW generation in the U.S. has followed a pattern of increase, with the exception of recession years (EPA, 2023). From 1960 to 2018, the U.S. experienced a substantial increase in MSW generation from 88.1 million tons to 292.4 million tons. Per capita MSW generation also grew significantly, from 2.68 pounds per day in 1960 to 4.9 pounds per day in 2018. This stable positive trend is particularly evident in the 21st century, as the country saw a notable surge from generating 231.9 million tons of MSW in 2000 (EPA, 2002) to 292.4 million tons in 2018 (EPA, 2023). Furthermore, as the Environmental Protection Agency (EPA) included alternative food management pathways in 2018, the documented waste increased further. Currently, the U.S. remains the leading generator of MSW, producing 258 million metric tons annually, with a daily output rate of 624,700 tonnes (Nanda & Berruti, 2021).

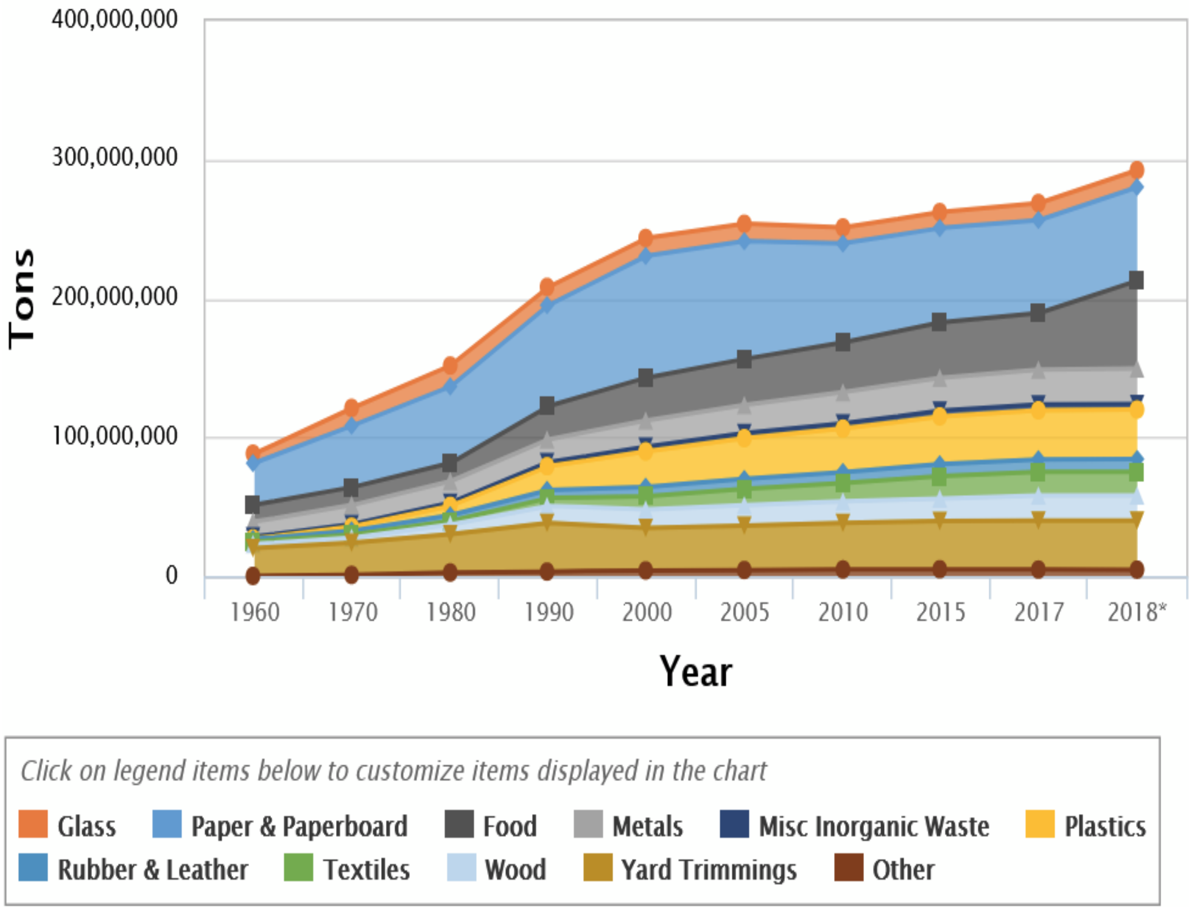


**Figure 1.** Generation tonnages in the US, 1960–2018 (EPA, 2023)

## Composition of Municipal Solid Waste in the U.S.

According to data collected by the EPA, an independent executive agency of the United States federal government tasked with environmental protection matters, the composition of municipal solid waste in 2018 revealed a significant presence of paper and paperboard and food waste, accounting for 23.05% and 21.59% of the waste stream, respectively. Plastics made up 12.20%, while yard trimmings constituted 12.11%. Metals and wood contributed 8.76% and 6.19%, respectively, with textiles at 5.83%, glass at 4.19%, and rubber and leather at 3.13%. Miscellaneous inorganic wastes comprised 1.39% of the total. However, through an analysis of 1,161 landfills (comprising 95% of American MSW landfills) and 15,169 solid waste samples across 222 sites, Powel and Chertow (2019) found that U.S. government sources vastly underestimated the quantities of paper, plastic, electronic, and food waste, with updated estimates reflecting increases of 359%, 364%, 96%, and 33%, respectively. Similarly, Kumar and Garg (2021) found that the U.S. government underestimates paper waste disposal by at least 15 million tons per year. Moreover, e-waste was not measured independently by the EPA and was likely included as “other” waste, estimated at 2.0% (Andeobu, Wibowo, & Grandhi, 2021). Despite these discrepancies, existing studies agree that the EPA’s estimates for food, plastic, and glass materials were accurate. These underestimations have important implications for the nation’s waste management policies.

Volume 13 Issue 3 (2024)

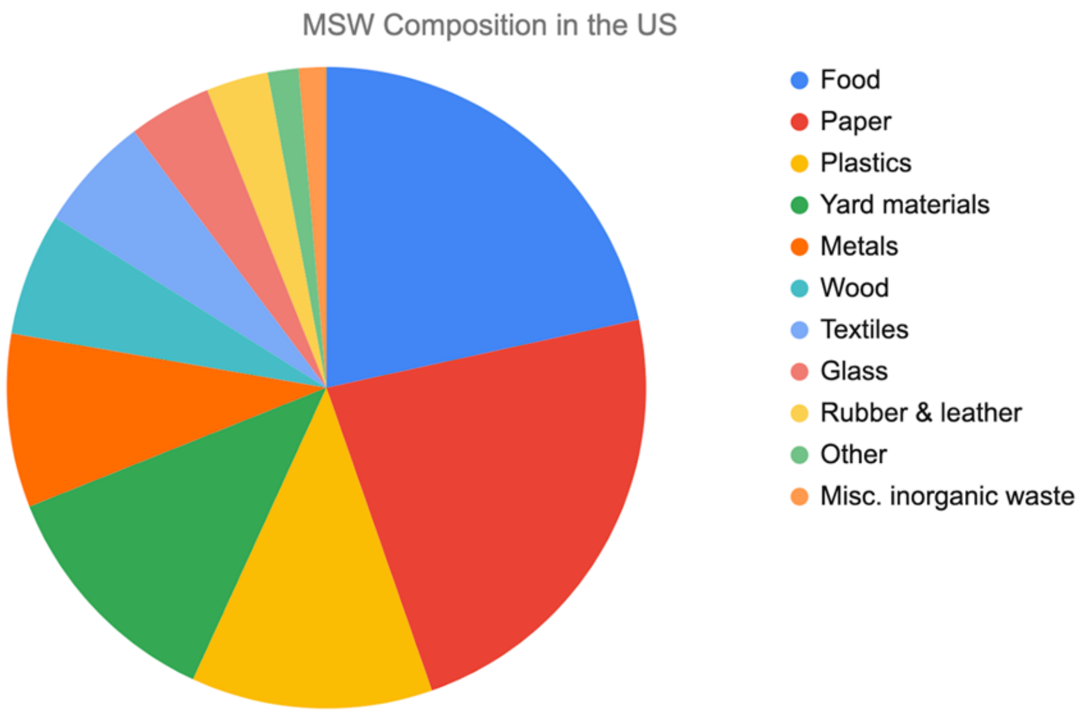


**Figure 2.** Municipal Solid Waste Composition in the U.S. (EPA, 2024)

The United States has established a federal system in waste management that involves collaboration and shared responsibilities among federal, state, and local governments. At the federal level, the government established the EPA on December 2, 1970, tasked with protecting human health and the environment. The 1976 Resource Conservation and Recovery Act (RCRA) provides the legal framework for managing both hazardous and non-hazardous solid waste, ensuring effective waste management practices (EPA, 2012). At the state level, each state's environmental department is responsible for developing its comprehensive plans to manage municipal solid waste (MSW) and non-hazardous industrial waste (ibid.). State legislations have played a significant role in implementing and enforcing federal waste management standards within their jurisdictions.

The EPA has developed a non-hazardous materials and waste management hierarchy, prioritizing reducing, reusing, and recycling over other disposal methods. It has become the primary government agency collecting and reporting data on waste generation and management for over 35 years to measure the effectiveness of materials management programs and characterize the national waste stream (EPA, 2024). Recently, the United States has been actively working towards a circular economy, aiming to ensure that all consumed materials are reused, reduced in production, and recycled (Allevi, Gnudi, Konnov, & Oggioni, 2021; Vines et al., 2023).

## Landfilling as the Predominant Practice

Despite Washington's recent moves towards sustainable waste management, landfilling remains a dominant waste management practice historically and currently in the United States. In 2018, the United States generated 292.4 million tons of municipal solid waste (MSW), with 146 million tons (53%) landfilled (EPA, 2024). This compares to 69 million tons recycled, 25 million tons composted, 17.7 million tons of food managed by other methods, and nearly 35 million tons combusted with energy recovery. Landfills are the dominant disposal method, particularly in the Midwest, while the West Coast favors recycling and composting (Mukherjee et al., 2020).

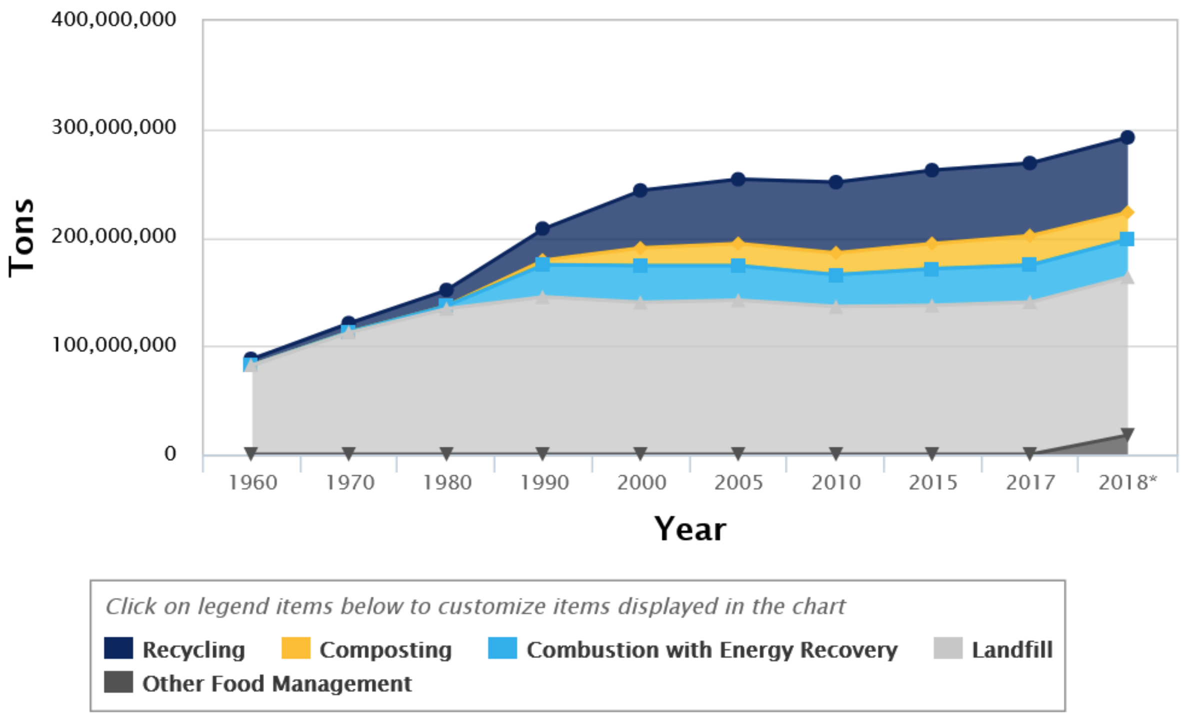


**Figure 3.** Municipal Solid Waste Management in the U.S., 1960–2018 (EPA, 2023)

The predominant use of landfills has resulted in significant environmental impacts. According to the EPA (2024), landfills account for 15% of methane emissions. However, Powell and Chertow (2019) estimated that landfill methane emissions were 14% greater than what the U.S. government had reported. This conclusion is also supported by research by Cusworth et al. (2024). Based on aerial surveys of more than 200 active landfills between 2018 and 2022, the research found that methane emissions from U.S. landfills are significantly greater than the EPA estimates. Moreover, waste landfilling and open dumping have led to underground water pollution, which has also been associated with harmful environmental impacts and health risks in the United States (Siddiqua, Hahladakis, & Al-Attiya, 2022).

Such environmental and health impacts have driven the evolution of landfilling practices in the country over the years. For instance, the EPA regulatory framework on landfills includes new standards to minimize environmental impact, such as controlling odors, preventing leachate seepage, and capturing greenhouse gases (Mukherjee et al., 2020). Meanwhile, the government leads in advanced landfill technology research and waste-to-energy initiatives to promote sustainable materials management and minimize landfill usage (Nwachukwu et al., 2017). Advancements in technology and societal awareness have also played a vital role in the transformation process. Karimi et al. (2022) found that with public preferences to remove waste facilities from neighborhoods, the use of regional landfills is on the rise in the United States. The increase in waste collection and transportation costs, as a result, has led to improved efficiency in waste management. Vu et al. (2020) also found that advanced technology helped optimize the waste collection system. In a small region in Austin, Texas, using GIS Network Analysis has led to higher waste density and collection frequency, which can save up to over 18% and 41% in travel time and distance, respectively.

## Modest Progress in Incineration and Waste-to-Energy (WTE)

As environmental concerns grew, the United States has also begun adopting alternative waste management practices. For example, advanced techniques such as methane capture for energy production are used to mitigate environmental impacts. One significant shift is towards incineration and waste-to-energy (WTE) technologies in reducing waste volume and generating renewable energy. The U.S. has 86 WTE facilities, using Mass-Burn and Refuse-Derived Fuel technologies, concentrated in the Northeast and Florida (Mukherjee et al., 2020). In 2018, approximately 35 million tons of MSW, reflecting 32.1% of the total mass, were combusted with energy recovery. Incineration significantly reduces waste volume by up to 90% and produces renewable energy through the combustion process (Aslam et al., 2020). Additionally, WTE technologies can transform incinerator ashes into resources for cement, concrete, and ceramic manufacturing, addressing environmental concerns (Khan et al., 2022).

However, it is noteworthy that the achievements of the United States in this area are relatively modest. The U.S. and Canada only divert around 30% of their waste, respectively. By contrast, China has taken the lead in diverting MSW, as it incinerates close to half (46%) of its waste, which will be explained later in the article. Notably, while the diversion rate in the United States has generally increased from 6% since the 1960s, it has grown more slowly in the recent two decades. In 2000, the diversion rate was 29%, with a slight decrease from 35% in 2017 to 32.1% in 2018 (ibid.). According to Mukherjee et al. (2020), these methods have faced public opposition in the United States due to emission concerns and health risks. Despite the benefits of waste volume reduction and energy generation, WTE facilities can emit harmful pollutants, including heavy metals and dioxins, which pose health risks such as cancer and impaired brain function (Environment America, 2021). Public opposition to WTE facilities, particularly in poorer neighborhoods, raises environmental justice concerns and highlights the need for equitable waste management solutions (Mukherjee et al., 2020).

In response, both the federal and state governments have issued policies and guidelines ensuring effective regulation and management of WTE facilities, balancing energy recovery with environmental protection. The United States and Canada have also included rules on solid waste incineration guidelines to cultivate non-toxic air through the Canada - United States Air Quality Agreement (2023) (Huang & Eckelman, 2021; Sunderland et al., 2016). Additionally, these incineration facilities have also begun utilizing advanced air pollution control technologies to mitigate emissions of harmful substances such as heavy metals, mercury, and dioxins (Environment America, 2021). However, as emphasized by the EPA (2024), comprehensive public education and engagement are still needed to address misconceptions and build support for WTE technologies as part of an integrated waste management strategy.

## Advancement in Recycling and Composting with Weaknesses

The other important shift is the promotion of recycling and composting. In fact, the regulatory framework in the United States places reducing, reusing, and recycling at the top of the waste management hierarchy to move toward sustainability. The Resource Conservation and Recovery Act (RCRA) prioritizes reducing, reusing, and recycling over other disposal methods. Subsequent federal legislation, such as the RECOVER Act of 2019, the RECYCLE Act of 2019, and the Break Free from Plastic Pollution Act of 2020, also aims to enhance recycling programs, establish minimum recycled content standards, implement a beverage container deposit scheme, and enforce extended producer responsibility for packaging.

According to available data, the U.S. recycled 69 million tons and composted 25 million tons of MSW in 2018. Recycling rates are relatively high for certain materials, such as paper and paperboard, which were diverted at a rate of 68% of their total generation (EPA, 2024). This is followed by yard waste at 63%, steel at 33%, and glass at 25%. Notably, aluminum and wood were recovered at a rate of 17%, respectively, while only 9% of plastics generated were diverted (Yunis & Aliakbari, 2021).

An outstanding example of these new sustainable practices is the composting of organic waste. Composting is generally a sustainable practice as it diverts waste from landfills, reduces emissions from landfills, and provides soils with recycled nutrients. State legislation has played a significant role in reducing yard trimmings disposal in landfills by encouraging practices such as backyard composting and leaving grass trimmings on lawns. Several states have also prohibited the disposal of recyclables in landfills. Vermont, for example, became the first state to ban all compostable materials from landfills in 2020. As a result, the U.S. has witnessed a decline in yard trimmings generation since 1990 (EPA, 2024).

Particularly in food waste, the U.S. employs co-digestion of food waste with other biodegradable wastes for combined heat and power (CHP) generation to promote energy recovery (Jin et al., 2021). An additional 17.7 million tons of food were managed through more sustainable methods such as animal feed, anaerobic digestion, and donation, rather than landfilling (EPA, 2024). The U.S. has led collaborative research with other major powers on MSW utilization, especially in biomaterials and bioplastics (Kaur et al., 2021). These methods, based on existing studies, are far more environmentally friendly in terms of greenhouse gas and air pollutant emissions compared to landfilling. Nordahl et al. (2023), for example, found that emissions of nitrous oxide ($N_2O$), ammonia ($NH_3$), and volatile organic compounds (VOC)—the largest contributors to global warming—tend to be relatively lower when compared to untreated MSW that has been anaerobically digested before being composted.

Moreover, the United States has achieved high recycling rates (approximately 70% during 2014–2015) in construction and demolition waste (CDW) (Aslam et al., 2020). The large population—particularly the 82.06% urban population—and continuous urban expansion have resulted in substantial CDW in the country. However, the U.S. has a well-established regulatory framework for CDW, influencing waste generation and management practices. Approximately 7 billion USD investments have been allocated to CDW recycling businesses, further driving efficient waste management practices (Aslam et al., 2020).

Despite the success in food waste and construction and demolition waste management, the United States still lags behind in plastic recycling. To date, eleven states have enacted bans on single-use plastic bags, and seven states have banned expanded polystyrene containers. However, over 91% of plastic waste was landfilled or incinerated in 2018. The U.S. discards enough plastic every 15.5 hours to fill AT&T Stadium, with the volume increasing yearly. Furthermore, an estimated 16.5 million tons of plastic enter the oceans annually, posing a severe threat to marine biodiversity (Environment America, 2021). The U.S. continues to struggle with compliance regarding the 2019 amendments to the Basel Convention, which introduced regulations on the global trade of plastic waste to reduce marine plastic pollution.

## Challenges Ahead

More broadly, the U.S. faces many structural challenges in transforming its waste management practices. Most notably, although landfilling has decreased, it remains a significant method of waste disposal. As most of the MSW in the U.S. is landfilled and not composted, the impact of composting on the American carbon footprint remains considerably lower. This is reflected in the carbon footprint via composting, which increased from 1.00 megatonnes of $CO_2$ in 2014 to 1.08 megatonnes of $CO_2$ in 2016 (Thapa et al., 2022). From a political economy perspective, this is primarily driven by the U.S. model of a linear material economy, whereby natural resources are extracted to produce goods, which are then disposed of after short-term use without being recycled or reused. The system encourages consumption and disposal, leading to resource waste and pollution, impacting health, the environment, and the global climate (Environment America, 2021).

In this system, the costs associated with waste also fall on society rather than on producers and consumers. Meanwhile, the adoption of new technologies, such as WTE systems, is rare due to high capital costs, operational and maintenance expenses, and financial risks associated with new facility construction (Mukherjee et al., 2020). Producers, distributors, and waste haulers benefit from the current waste system and often resist changes that could reduce waste. Consequently, landfilling remains the most economically viable option due to land availability, although tipping fees for landfilling can be higher in some states than for incineration (Kurniawan et al., 2022). However, as many landfills have closed in densely populated areas, finding new sites is difficult and involves long transportation distances. These factors together result in minimal incentives—and even public opposition—for systemic change. Until 2021, Maine implemented a law mandating producer responsibility for packaging and paper products, shifting recycling costs from taxpayers to producers.

Finally, numerous political factors influence the future of U.S. waste management practices. Waste management is one of the mundane everyday activities that are politicized. Local corruption has hindered the development of proper waste management systems in places like St. Louis and New Orleans (Strach & Sullivan, 2022). Local opposition towards biosolids recycling in Amelia County, VA, voices concerns about public health risks and environmental justice (Robinson, Robinson, Raup, & Makrum, 2012). For Indigenous communities residing on Tribal lands, the government and waste disposal industry view their lands as appropriate dumping grounds for waste, including nuclear waste (Angel, 1991; Ortiz, 2003). Consequently, the issues of municipal solid waste among Indigenous populations of the U.S. are vastly understudied, in contrast to the greater awareness of this issue in Canada. Similarly, rural U.S. communities of lower socioeconomic status are more likely to face health concerns due to greater exposure to environmental pollutants (Ameh et al., 2020).

Internationally, China's 2016 import ban on various waste types and the 2019 Basel Convention amendments drastically reduced the U.S.'s ability to export waste, highlighting inadequacies in domestic waste management infrastructure (Law et al., 2020). The U.S.'s withdrawal from international climate agreements under the Trump administration also impacted its overall transformation in waste management and sustainability efforts.

## Canada

Canada ranks as the 17th worst country in the world for municipal solid waste (MSW) generation. In 2020, Canada produced 49,616 tonnes of MSW daily, compared to the U.S., which generated 624,700 tonnes daily (Nanda & Berruti, 2021). Similar to the U.S., Canada has witnessed a notable increase in its waste production; however, this pattern has somewhat stabilized over the past decade. For example, the total amount of waste produced increased from 26.4 million tonnes in 2006 to approximately 34 million tonnes in 2008. However, the figure for the total amount of municipal solid waste generated in 2016 remained at 34.2 million tonnes (Karimi et al., 2022) In 2020, solid waste generated in Canada increased to 36.0 million tonnes (Environment and Climate Change Canada, 2023).

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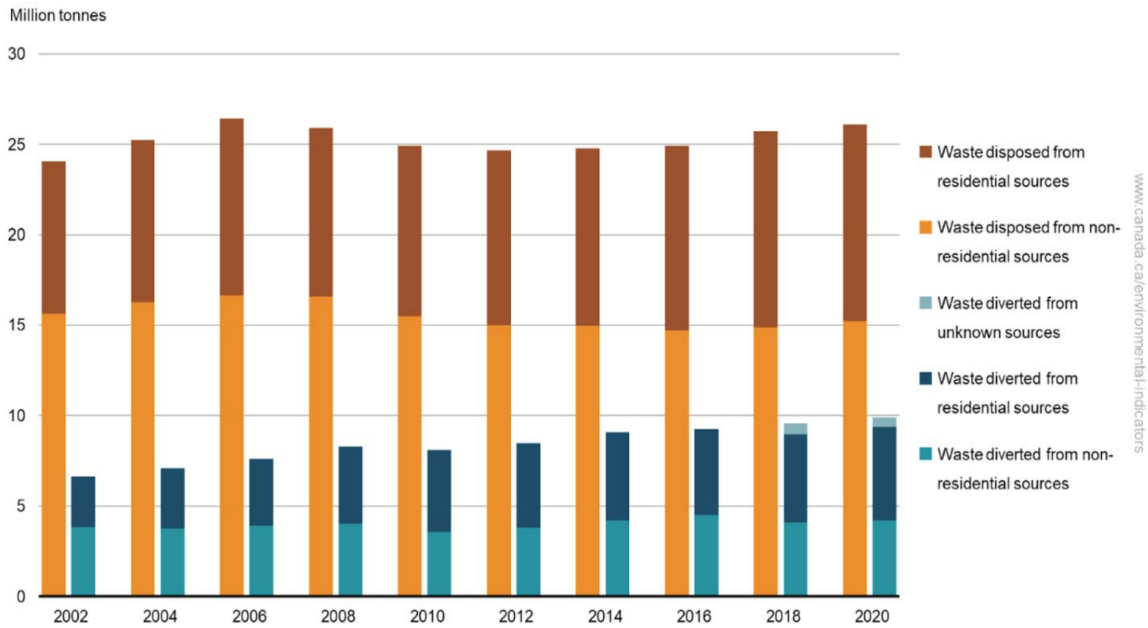


**Figure 4.** Solid Waste Generation, Diversion, and Disposal in Canada, 2002–2020 (Statistics Canada, 2024)

Meanwhile, while MSW generation has increased in Canada over the past two decades, Canadians are actually generating less waste per person. From 2002 to 2020, the country witnessed a decreasing trend in waste per person, dropping from 0.766 tonnes in 2002 to 0.687 tonnes in 2020. Population growth and income levels are known to be positively correlated with solid waste generation (Dyson & Chang, 2005). Therefore, the stabilizing pattern in the total amount of MSW generation may be partly attributed to Canada's Gross Domestic Product (GDP) decreasing by 23% from 2002 to 2018. Concurrently, however, the Canadian population experienced steady growth, from 31.5 million in 2002 to 38 million in 2020. When taking into account population and economic growth, we can observe a commendable reduction in individual waste production in Canada. This also reflects a decoupling between Canada's economic growth and waste generation (Yunis & Aliakbari, 2021).

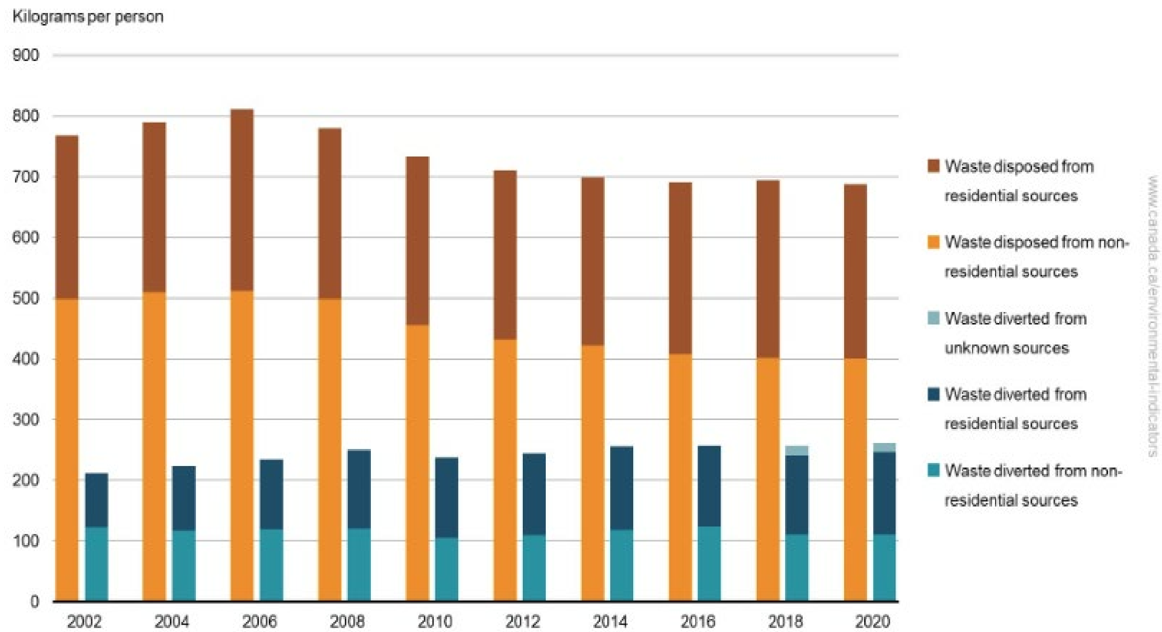


**Figure 5.** Solid waste diversion and disposal per person in Canada, 2002–2020 (Statistics Canada, 2024)

Despite this, we must acknowledge that Canada still has one of the highest per capita waste generation rates in the world (Karimi et al., 2022). In 2008, Canadians generated 1,031 kg of waste per capita, significantly more than Japan (377 kg) and the UK (580 kg in 2008) (UN, 2009). The U.S. generated 720 kg per capita in 2008, which was lower than Canada (Shiaeb, 2014). In 2020, Canada's output rate per capita was 2.33 kg daily, the second worst in the world, followed by 2.58 kg per capita per day in the U.S. (Nanda & Berruti, 2021). These unique patterns make Canada an interesting case to study in terms of its waste management practices, aiming to understand how the complex interplay between population dynamics, environmental policies, and societal behaviors shapes a nation's waste landscape, offering valuable insights for future sustainability endeavours.

## Composition of Municipal Solid Waste in Canada

According to Statistics Canada, there are two main sources of waste across the country: residential and non-residential waste. In 2020, nearly 10.9 million tonnes of residential waste were generated nationwide. This is the highest amount of residential waste recorded, reflecting a significant increase of 2.4 million tonnes from 2002 and an increase of 13,880 tonnes since 2018 (Statistics Canada, 2023). This also underscores the growing role of residential waste, as it comprised 42% of the total waste in the country in 2020, compared to 35% in 2002 (ibid.). In 2020, 15.2 million tonnes of non-residential waste were generated in Canada, reflecting an increase of 360,820 tonnes from 2018 (ibid.). However, different from the trend in residential waste, the overall trajectory of non-residential sources in Canada experienced a decline of 389,004 tonnes between 2002 and 2020 (ibid).

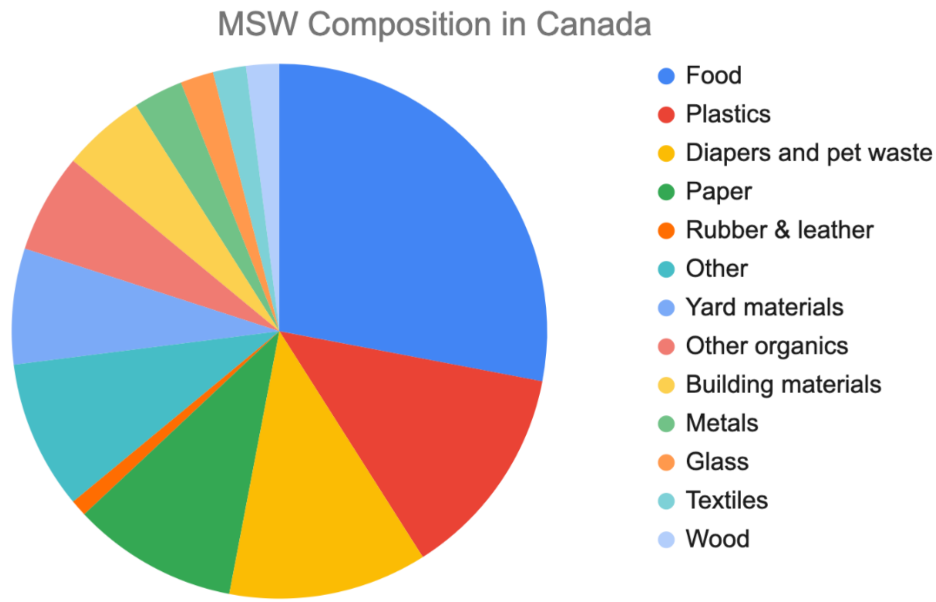


**Figure 6.** Municipal Solid Waste Composition in Canada (Statistics Canada, 2023)

Similar to the United States, food is the main component of municipal solid waste in Canada, generated from both residential and non-residential sources. Specifically, in 2016, food accounted for the majority (28%) of residential MSW in Canada, followed by plastics (13%), diapers and pet waste (12%), and paper (10%). Other materials such as yard and garden waste, as well as building materials, accounted for the remaining 37% (Yunis & Aliakbari, 2021). The pattern was similar in Canadian non-residential MSW. There, food accounted for 25% of the solid waste, followed by plastics (16%), paper (14%), other materials (9%), other organics (9%), and materials such as wood and metals accounted for the remaining 37% (Yunis & Aliakbari, 2021). More specifically, as analyzed by Wilcox (2024), food waste is the heaviest and largest volume of material in the waste stream for many businesses and is a major contributor to GHG emissions due to methane release. The highest proportions of food waste come from sectors like restaurants, hospitality, shopping centers, and senior living facilities. Canada also shares with the United States the challenge of increasing e-waste. In 2019, Canada generated 757 kilotonnes (kt) of e-waste, or 20.2 kg per capita, but only collected and recycled 101 kt, reflecting 13% of the generated waste. Similarly, the U.S. collected and recycled merely 14% of its e-waste, amounting to 1020 kt out of the 6,918 kt, or 21.0 kg per capita, of e-waste that it generated in 2019 (Andeobu, Wibowo, & Grandhi, 2021).

## Major Waste Management Practices in Canada

Similar to the United States, waste management in Canada involves various methods and practices, ranging from landfilling to incineration, recycling, composting, and emerging technologies. Among these, landfilling remains the primary method of municipal waste disposal in the country. In 2008, 26 million tonnes of waste (roughly 76.5% of total waste generated of the year) were disposed of in landfills or incinerators (Statistics Canada, 2012), while 8 million tonnes were recycled or processed (Shiaeb, 2014). By 2016, 97% of waste requiring final disposal was still sent to landfills, with only 3% incinerated (Government of Canada, 2024).

Landfills pose significant health risks, including various cancers due to residues like bottom and fly ash leachate (Ecoissues.ca, 2024). Additionally, landfilling, predominantly used for organics, accounts for 20%

of national methane emissions in Canada. Moreover, hazardous waste in landfills, such as chemicals and batteries, requires special handling to prevent health and environmental risks (Government of Canada, 2024) and contributes significantly to climate change (Sebastian & Louis, 2022). These risks are exacerbated by aging landfills, especially in Ontario. In response, the federal government has promoted the adoption of modern municipal solid waste landfill practices to minimize these social and environmental impacts, potentially capturing greenhouse gases for energy production. Additionally, Ottawa aims to divert 50% of waste from landfills by 2030, with significant investments in waste management infrastructure (Ecoissues.ca, 2024).

In the meantime, the Canadian government has also been working on alternative waste treatment methods to improve waste diversion and reduce greenhouse gas emissions. On one hand, Canada has various types of incinerators, including waste-to-energy (WTE) facilities that convert waste into renewable energy. Incineration can significantly reduce the volume of municipal solid waste by up to 90%. Despite the risks of releasing harmful pollutants, advanced pollution control technologies utilized in modern incinerators in Canada can remove up to 99% of harmful emissions (Government of Canada, 2024). However, compared to the United States and China, incineration is less prevalent in Canada and remains small-scale. A recent 2023 study has begun to highlight the potential for large-scale WTE projects in Canada (Government of Canada, 2024).

On the other hand, composting biodegradable waste, including food and yard waste, and recycling programs have become crucial for diverting a substantial portion of organic and recyclable waste from landfills. In 2008, 8 million tonnes (roughly 23.5%)—254 kg per capita—of waste were recycled or processed (Shiaeb, 2014; Statistics Canada, 2012). By 2016, this proportion had increased to about 30% of municipal solid waste being recycled or composted (Government of Canada, 2024). However, this proportion remains quite limited overall. In 2020, 9.9 million tonnes of waste were diverted, reflecting merely 27.5% of the solid waste generated in that year. A large amount of solid waste (26.1 million tonnes, or 72.5% of the total solid waste) was still disposed of in landfills (or incinerated) (Environment and Climate Change Canada, 2023). Interestingly, the majority of waste diversion occurred from residential sources as opposed to non-residential sources. Specifically, 52% of the diverted solid waste was residential in 2020, reflecting an increase of 2.4 million tonnes (or 85%) since 2002. While this is a positive trend, the amount of disposed residential waste (sent to landfills) also increased by 2.4 million tonnes (or 29%) during this period. The non-residential sector also increased its diversion rate from 2002 to 2020, albeit to a lesser extent than the residential sector, by 0.4 million tonnes (or 9%) (ibid.).

Unlike the U.S. system which provides minimal incentives for systematic change to producers and consumers, several provinces in Canada have implemented Extended Producer Responsibility (EPR) programs to increase recycling rates and manage waste more effectively, though with varying results. These EPR programs aim to make producers responsible for product end-of-life management, encouraging recycling and reducing landfill waste (Ecoissues.ca, 2024). For example, the *Waste Management Act* (1993) and the *Waste Diversion Act* (2002) in Ontario require the separation of recyclable materials and share the costs of waste management between the government, producers, and users (Shiaeb, 2014). British Columbia has implemented a full product stewardship policy that is 100% producer-funded and operated, placing the entire cost and responsibility on producers and users (Shiaeb, 2014). In Nova Scotia, the solid waste strategy includes industry stewardship programs and beverage container stewardship, aiming to reduce beverage litter in the province. A regional EPR strategy is also recommended for all Atlantic Canadian provinces (Newfoundland and Labrador, New Brunswick, Prince Edward Island, and Nova Scotia) to align with Canada's move towards zero plastic waste under the Ocean Plastics Charter (Diggle & Walker, 2020).

Under these programs, companies in Canada are reportedly very active in adopting sustainable waste management practices to cut costs and reduce waste volumes. For example, to align with cities starting to ban businesses from disposing of food waste in the garbage, McDonald’s Canada aims to recycle guest packaging in all its restaurants by 2025 (Ecoissues.ca, 2024). Additionally, businesses are increasingly using sensors and cloud-based technologies to optimize waste management service levels and monitor waste performance, in order to measure and reduce the carbon footprint of their waste to lower greenhouse gas emissions (Wilcox, 2024).

## Vast Regional Difference in Waste Management Across Canada

What distinguishes Canada from the United States and China in waste management are the vast regional differences in municipal solid waste (MSW) within the country, which present unique governance challenges. Although we acknowledge that the federal systems of the United States and Canada, as well as the fragmented authoritarian governance in China, result in waste management being organized primarily through different levels of government, we find that regional differences in MSW policies and outcomes are particularly pronounced in the Canadian context. According to Shiaeb (2014), this is primarily because Canada's solid waste policy is based on provincial legislation rather than a national framework. Waste management in Canada involves shared responsibilities across municipal, provincial, and federal levels. More specifically, provincial and territorial authorities establish waste reduction policies, approve, and monitor waste management facilities including incinerators, landfills, and composting facilities. Municipalities manage the collection, recycling, composting, and disposal of household waste (Government of Canada, 2024). However, a coherent national framework for consistent and effective solid waste management is still lacking (Nicol & Thompson, 2007). This multi-tiered governance leads to differences in waste management practices between provinces, recycling programs that are less structured, and overlapping responsibilities causing inefficiencies. Furthermore, it complicates data availability and planning. Scholars have found that major differences exist in management systems and tools between regions in Canada (Dyson & Chang, 2005), which significantly impact the effectiveness of solid waste management strategies. Different municipalities also face different financial situations. Municipalities with limited income struggle to implement new solid waste management technologies and systems due to high costs, despite reasonable payback times (Ghosh & Ng, 2021).

Most notably, different provinces and territories in Canada face unique challenges in waste management practices. Northern and remote communities in Canada, for example, suffer from limited access to recycling programs, proper hazardous waste disposal, and well-designed waste management facilities. The distance between communities, long winters, lack of trained personnel, high turnover, and low waste generation affect the economies of scale for waste treatment facilities. Remoteness, subarctic climate, logistical difficulties, and historic stockpiles characterize waste management challenges, requiring a synergistic approach for minimal environmental and health impacts (Sebastian & Louis, 2022). These limitations lead to increased environmental and health risks, particularly when open waste burning is employed as a disposal method (Government of Canada, 2024).

In Québec, residents have one of the highest energy consumption rates globally due to severe weather conditions. The government aims to increase the renewable energy supply to 60.9% by 2030, with a 50% increase in bioenergy production. Therefore, they need to address the mishandling of organic waste, which is a significant issue, through methods like bio-methanation.

By contrast, the Prairie provinces (Alberta, Saskatchewan, and Manitoba) rely heavily on landfills for waste disposal. Saskatchewan has the highest number of landfills per capita in Canada. Although there was a significant shift in waste management facilities, with a 54% reduction in landfills and a 55% increase in transfer stations (Ghosh & Ng, 2021), the presence of vast rural areas with scattered populations, low density, and limited access to waste facilities and recycling services complicates waste management practices in Canada. This situation calls for a unique waste management strategy with a larger annual budget compared to other regions. It also calls for a regional approach to address the unique needs of rural and Indigenous communities. In its 2020 solid waste management plan, the provincial government of Saskatchewan supports regional waste management collaboration, emphasizing regional cooperation and optimization (Karimi et al., 2022).

In Toronto, the rising costs derived from population growth and the resulting increase in waste generation present the greatest challenge for the city government. In 2013, operating Toronto's waste management system cost approximately $41.7 million. The budget and privatization rate need to adapt to these changes in waste generation over the planning horizon (Zhu & Huang, 2017). The waste management system in place must also cater to the needs of this large population.

These notable regional variations in waste management policies and results are vividly manifested in the tonne/person ratio across provinces in Canada. Alberta consistently stands out with the highest tonne/person values, peaking at 1.146 in 2008 and maintaining levels above 0.900 in subsequent years. This suggests a higher per capita waste generation in Alberta compared to other provinces. On the opposite end of the spectrum, Nova Scotia consistently reports the lowest tonne/person ratios, with values dipping as low as 0.378 in 2008. This indicates a more efficient waste management or recycling system in Nova Scotia, resulting in lower per capita waste generation.

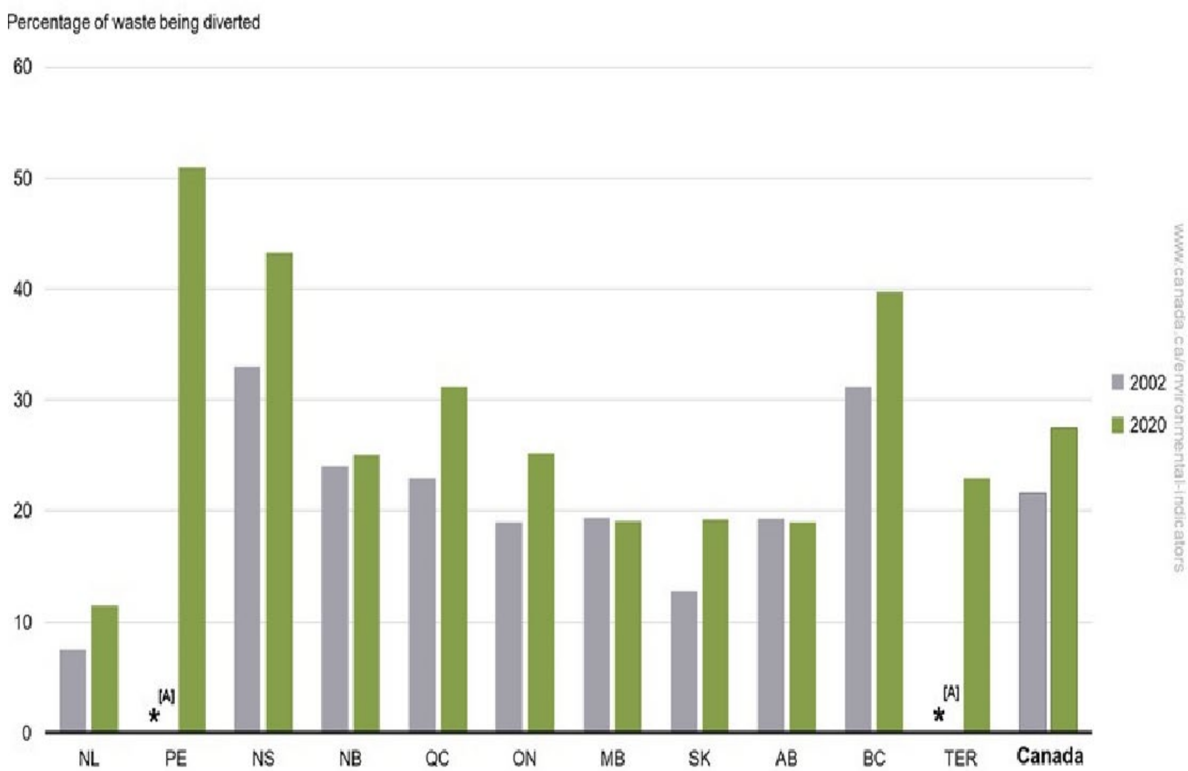


**Figure 7.** Provincial differences in solid waste diversion and disposal per person, Canada, 2002 and 2020 (Environment and Climate Change Canada, 2023)[1].

## Unique Challenges in Indigenous Nations

Finally, extant scholarship pays particular attention to the unique challenges First Nations and Inuit communities in Canada face in waste management. One major challenge is remoteness. The most common distance for First Nations communities to the nearest service center ranges from 50 to 350 km, with only 31% within a 50 km radius, 17% unknown, and 5% over 350 km (ISC, 2021). Another challenge concerns the seasonal effect on roads, as 17% of these communities do not have access to any year-round road to get to a service center.

Moreover, there is often a high percentage of organic waste in these First Nations communities, such as Temagami First Nation and M'Chigeeng First Nation in Ontario, Canada. However, they have limited access to comprehensive waste processing facilities. Fly-in communities need to transport their waste collectively by air or water to larger cities. As a consequence, some of these communities resort to open dumping and open burning due to a lack of budget for waste transport. While the Government of the Northwest Territories (GNWT) has enforced guidelines regarding what MSW should not be subjected to open burning (ENR, 1993), this practice still occurs in the territory (Sebastian & Louis, 2022). The presence of open dumping sites in Garden Hill and Wasagamack, for example, indicates inadequate waste management infrastructure and practices, as well as a lack of regulatory enforcement and economic resources to implement safer disposal methods (Wang et al., 2023). These practices have led to soil contamination with chromium, arsenic, copper, and zinc levels significantly exceeding guidelines, highlighting severe pollution issues. They have also increased the risk of wildfires.

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[1] NL: Newfoundland and Labrador, PE: Prince Edward Island, NS: Nova Scotia, NB: New Brunswick, QC: Quebec, MB: Manitoba, SK: Saskatchewan, AB: Alberta, BC: British Columbia, TER: Yukon, Northwest Territories and Nunavut

## China

China's municipal solid waste (MSW) generation has shown a significant upward trend over the past few decades. In 2004, urban areas in China produced approximately 90 million tonnes of MSW (The World Bank, 2005). By 2009, this figure had increased to 157 million tonnes and continued to rise to 228 million tonnes by 2018 (Ding et al., 2021; Mian et al., 2017). In 2016, China contributed over 10% of the world's MSW, highlighting its substantial impact on global waste generation (NBSC, 2016). By 2020, China generated around 235.12 million metric tons of MSW, maintaining an annual growth rate of 10% (Kurniawan et al., 2022). China remains the second-largest producer of MSW globally, following the United States (Nanda & Berruti, 2021).Projections indicate that by 2030, China's MSW will double that of the United States. In addition, China's solid waste treatment backlog was estimated at 70 billion tonnes in 2019, with a significant portion still disposed of in landfills or rivers (Odier, 2021).

The increase in MSW generation in China is primarily driven by the urbanization rate, road length, the tertiary sector's proportion, and the increase in GDP per capita (Gui, Zhao, & Zhang, 2019). Conversely, both sanitation investment and education level are "slightly" negatively correlated with MSW generation (ibid.). Moreover, MSW collection in China has gradually increased with the growth of the urban population (Zhu et al., 2021).

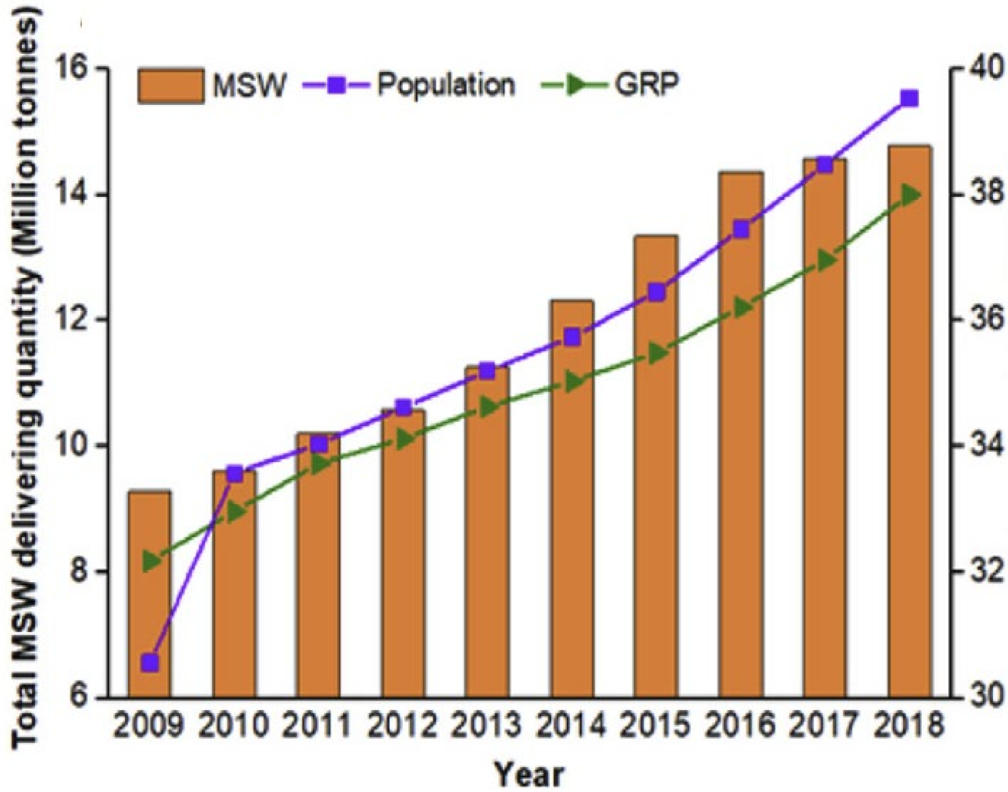


**Figure 8**. MSW generation, population and gross regional product (GRP) in China, 2009–2018 (Ding et al.,, 2021)

## Composition of Municipal Solid Waste in China

Similar to the United States, official data on municipal solid waste (MSW) in China tends not to distinguish between residential and non-residential waste. In terms of composition, food waste constitutes the majority of Chinese MSW at 47.7%, followed by dust and bricks (20.5%), plastic and rubber (10.3%), and paper (9.2%) (Zhu et al., 2021). Recyclable waste makes up about 26.7% of the MSW; around 24.9% of MSW is categorized as landfill waste; hazardous waste accounts for less than 1% of the MSW (Zhu et al., 2021).

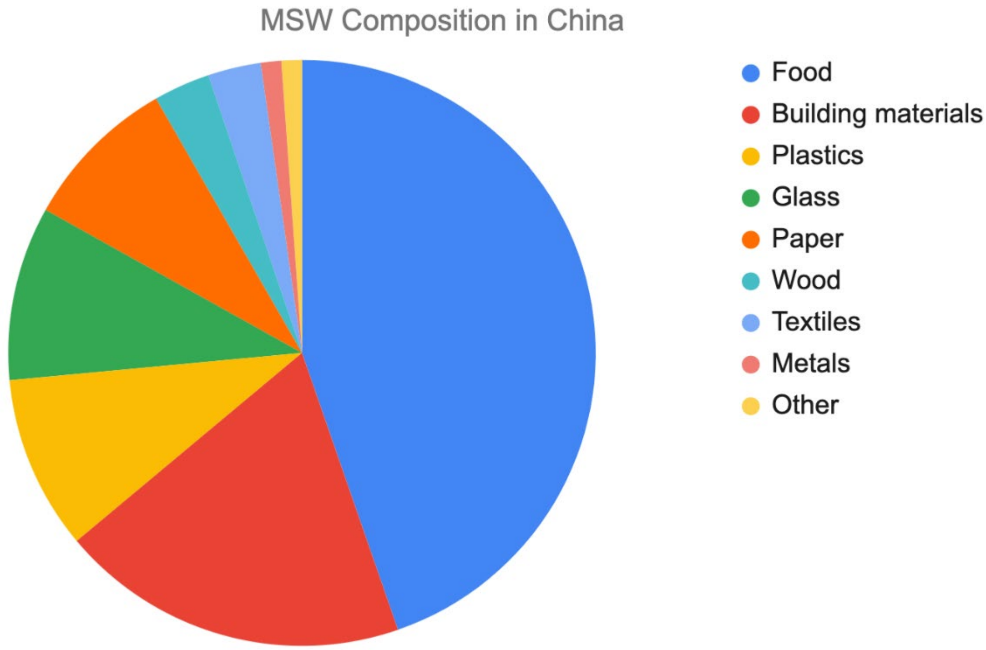


**Figure 9.** Municipal Solid Waste Composition in China (Zhu et al., 2021)

However, in the Chinese context, this food waste is notably moist, with the average moisture content of MSW being 50.3%. As a result, the average bulk density of MSW in China is also very high, reaching 325 kg/m³ (Ding et al., 2021). Moisture has been noted as a source of leachate and odors in the MSW processing of food waste in particular (Environment Canada, 2013). Additionally, it presents new challenges in waste collection, waste settlement, and slope stability, as well as potential gas generation (Krause et al., 2023).

Like the United States and Canada, China also faces the increasing issue of e-waste, which is another important component of modern MSW requiring proper recycling. In 2022, the accumulated stock of electronic products in China to be handled by the MSW system was close to $15,000*10^4$ tons (Yu, Gao, Yang, & Zhang, 2023), and the country has been estimated to collect and recycle around 18% of its e-waste (Baldé et al., 2017). Improper recycling of e-waste has posed significant health and environmental risks in China (Awasthi et al., 2018).

## Landfills and Incineration as Primary Waste Management Methods

In China, both landfilling and incineration have become primary methods in municipal solid waste (MSW) management. In 2020, 61% of MSW was sent to landfills, 35% was incinerated, and only 4.4% was recycled (Kurniawan et al., 2022). Similar to the situation in the United States and Canada, the heavy reliance on landfilling as the predominant method of waste disposal poses significant environmental challenges in China. Uncontrolled landfills in remote areas and leachate infiltration can lead to secondary pollution (Kurniawan et al., 2022). A case study on groundwater contamination from leachate of an MSW landfill in northern Jiangsu Province, China, revealed that it was the principal pollution source, accounting for 49.2% of the pollution in the local groundwater environment (Chen et al., 2019).

However, what sets China apart from the other two countries is that China has taken the lead in diverting MSW. It incinerates close to half (46%) of its waste, while the U.S. and Canada only divert around 30%, respectively. Since 1995, China has introduced incineration plants as an alternative to landfills, using the waste-to-energy (WTE) model to convert captured heat into electricity. China has heavily invested in waste incineration to manage the rapid increase in municipal solid waste from homes and businesses (Shapiro-Bengtsen, 2020). From 2004 to 2014, the number of incineration plants in China increased 3.5-fold, rising from 54 to 188 plants. This expansion led to a significant increase in disposal capacities, which grew from 4.49 million tons to 53.3 million tons during the same period (Mian et al., 2017). By 2018, incineration accounted for 45% of waste treatment, with a capacity of 102 million tons per year, generating 35 billion kWh of electricity in 2017. Therefore, the increased use of incineration, as opposed to landfills, helps reduce waste volume and generates renewable energy, which partially replaces coal consumption (Ding et al., 2021). It has also helped China decrease greenhouse gas emissions from 94.01 Mt in 2017 to 71.32 Mt in 2020 (Han et al., 2024).

## Limited Recycling Efforts

China's recycling efforts have also been notable, particularly in the context of plastic waste. Approximately 60–80% of plastic waste is recycled, a rate much higher than in many developed nations (Zhu et al., 2021). However, the overall recycling rate for MSW remains low, partly due to the absence of a secondary materials market and a lack of formal recycling initiatives (Kurniawan et al., 2022). The recycling rate increased from 12.1% in 2006 to 17% in 2011, though it decreased to 15.6% by 2015 (Ding et al., 2021).

## State-led Practices in Waste Management, with Local Experimentation

The Chinese state has been leading the country's waste management practices. The 12th Five-Year Plan (2012), for example, marked a substantial investment of 10.9 billion CNY aimed at the resource utilization and harmless treatment of food waste (Jin et al., 2021). This initiative laid the groundwork for the subsequent 13th Five-Year Plan (2016–2020), which emphasized sustainable waste management practices (Ding et al., 2021). During this period, the focus was on increasing the treatment capacity of MSW to 64,615 tons per day by 2020 (Jin et al., 2021). It showcases the state's commitment to enhancing waste processing infrastructure and reducing environmental impact.

At the core of China's current regulatory framework in MSW is the revised Solid Waste Law. Effective from 2020, the law aims to strengthen government supervision and management responsibilities (Odier, 2021). It imposes strict obligations on waste generators, focusing on enforcement and promoting product stewardship. It also includes a significant provision banning the import of foreign waste, reflecting China's shift towards self-sufficiency in waste management. Moreover, the Chinese government has established a series of complementary regulations over the years, such as the "Prevention of Environmental Pollution Caused by Solid Waste" (1996), the "Cleaner Production Promotion Law" (2002), the "Administrative Measures for Urban Living Garbage" (2007), and the "Domestic Waste Classification Regulation" (2017). The state's regulatory approach also includes specific standards like the "Classification Symbols for Municipal Solid Waste" (GB/T19095-2008) and the "Classification and Evaluation Standard of Municipal Solid Waste" (CJJ/T102-2004) (Ding et al., 2021). The enforcement of these standards and legislations ensures consistency in waste management practices across the country. The comprehensive "Law on the Prevention and Control of Environmental Pollution by Solid Waste," initially enacted in 1995 and revised in 2020, underscores China's ongoing commitment to mitigating environmental pollution through stringent waste management laws (Kurniawan et al., 2022; Ding et al., 2021).

A critical component of the Chinese strategy towards a more sustainable and efficient waste management system is its waste charging policies. Introduced in 2002, this financial incentive aims to promote the industrialization of waste treatment and decreasing MSW generation by charging people who generate more waste than what is allowed (Cheng, Shi, Yi, & Fu, 2020). Subsequently, the 2018 Opinions on Innovation and Improvement of Price Mechanism for Green Growth mandated cities to establish comprehensive MSW disposal fee systems by 2020, reinforcing the economic incentives for waste reduction (Cheng et al., 2020). These policies aim to control waste generation through economic measures, such as volume or weight-based taxes, which encourage households to minimize waste and enhance recycling efforts (Mian et al., 2017).

In the meantime, due to the sheer size and scope of the Chinese economy, waste composition and management practices in China vary significantly across regions. Firstly, there are significant disparities in the provincial contributions to MSW generation. This variation illustrates how local practices and regulations shape waste management strategies. In 2018, Guangdong led with 30.35 million tonnes of MSW, followed by Jiangsu (17.18 Mt), Shandong (17.01 Mt), and Zhejiang (14.75 Mt) (Ding et al., 2021; Wang et al., 2021; Mian et al., 2017). The economic growth and rapid urbanization in these areas, particularly in the eastern coastal provinces, have led to increased consumption and, consequently, more waste production. A more recent study, however, found that developing provinces generate more MSW than their developed counterparts (Liu, Li, Gu, & Wang, 2019). In the eastern coastal region, MSW generation has increased in provinces like Shandong, Guangdong, Zhejiang, and Fujian, while it has declined in other eastern areas (Khan et al., 2022).

China's provinces and cities also exhibit differences in habits, economic development, and material needs (Kurniawan et al., 2022). As a result, the challenges of waste management are not uniform across China, with remote areas facing distinct difficulties. Similar to Canada and the U.S., remote communities in China struggle with inadequate resources for managing MSW. These areas often lack the infrastructure and financial support necessary for effective waste management, resulting in the operation of uncontrolled landfills (Kurniawan et al., 2022).

Moreover, public response to waste management initiatives varies significantly across regions. MSW management is a personal issue that requires active participation from all residents, leading to diverse reactions. For example, anti-incinerator activism is common in Guangzhou, where residents oppose the construction of incinerators near their homes (Wong, 2021). In Guangzhou, such protests have successfully halted incinerator projects, reflecting strong community opposition. Conversely, in Hong Kong, despite similar protests, incinerator projects have proceeded (Wong, 2021).

In response to the vast regional differences, the central government of China has implemented a series of local experimentations. Unlike Canada, where a national regulatory framework on waste management is lacking, decentralized experimentation in China is supervised by the state, offering flexibility to reconcile differing perspectives and local ambitions. For instance, Beijing allows different provinces to try various methods for classifying municipal solid waste. Shanghai classifies MSW into residual waste, recyclable waste, domestic food waste, and hazardous waste, while Hangzhou employs a different categorization system (Khan et al., 2022). The implementation of waste classification management in cities like Shanghai has significantly increased food waste collection and reflects a shift towards more sustainable waste management practices (Jin et al., 2021; Zhu et al., 2021).

Beijing has also initiated the "Zero-Waste City" pilot program in 16 cities to promote source reduction and resource utilization, minimizing food waste in landfills and environmental impact. The Chongqing Black Stone Food Waste Treatment Plant, with a capacity of 365,000 tons per year, is an example of large-scale anaerobic digestion (AD) for food waste treatment (Jin et al., 2021). Additionally, the Shenzhen government promotes strategies like the Zero Waste Construction Site (ZWCS) to mitigate the environmental and economic impacts of construction waste. Successful projects include the reuse and recycling of over 90% of demolition waste in the New Campus Project of Southern University of Science and Technology (SUST) (Lu et al., 2021). These local initiatives and pilot programs highlight China's adaptive and region-specific approach to waste management, addressing the unique challenges and opportunities presented by different areas.

## Conclusion and Discussion

This article provides a comparative analysis of waste management practices in China, the United States, and Canada. Despite the increasing global demand to address municipal solid waste, these three countries exhibit distinct trends and patterns. The United States and China have become the largest waste generators in the world, both exhibiting high waste generation rates. In contrast, Canada's waste generation rate has remained relatively stable over the past decades, reflecting a decoupling between its economic growth and waste generation. However, Canada still generates one of the highest per capita waste rates globally.

Currently, all three countries primarily manage their municipal solid waste (MSW) through landfilling, but they have made varying progress in developing more sustainable methods, highlighting their differing approaches to waste management. The United States and Canada place a strong emphasis on landfill technology, waste-to-energy, waste reduction, and public participation. Advanced recycling technologies and continuous investment in infrastructure underscore the U.S. commitment to improving waste management outcomes. China's policy focus includes increasing incineration capacity and enhancing biogas production. Incineration has become a primary method of waste management in China, alongside landfilling. However, recycling and composting in China are less advanced compared to developed regions such as the United States and Canada. All three countries need to expand their usage of sustainable waste management practices, especially in underserved rural areas, while preserving the health of local communities and the environment.

The regulatory frameworks governing waste management in these three countries vary widely. Despite regional differences, the United States benefits from a comprehensive regulatory structure, ensuring effective enforcement and cohesive policies at both federal and state levels. China's centralized approach has established multiple regulations and policies in waste management, promoting the rapid development of waste-to-energy capacities. However, the Chinese government also relies on local experimentation and pilot programs to enforce these policies effectively. Among the three countries, Canada lacks a national framework for solid waste management, leading to inconsistencies and variations across its provinces. This results in unique challenges in waste management, particularly in remote areas and indigenous communities.

Significant gaps exist in MSW research and MSMW methods, including the need to address the international nature of sustainability. These comparative findings are significant for global policymakers, business leaders, and the broader public. Globally, developed countries like the United States, Canada, and European nations benefit from more resources, educated populations, and stronger economies, which support the implementation of sustainable waste management practices. In contrast, developing countries often struggle with weaker economies, technological limitations, and social challenges that hinder effective waste management. Policymakers and business leaders can draw effective solutions from the diverse practices of these three countries to benefit their economies and broader society.

## Acknowledgments

I would like to thank my advisor for the valuable insight provided to me on this topic.

## References

Allevi, E., Gnudi, A., Konnov, I. V., & Oggioni, G. (2021). Municipal solid waste management in circular economy: A sequential optimization model. *Energy Economics*, *100*, 105383. https://doi.org/10.1016/j.eneco.2021.105383

Ameh, G.G., Njoku, A., Inungu, J., & Younis, M. (2020). Rural America and coronavirus epidemic: challenges and solutions. *European Journal of Environment and Public Health, 4*(2), em0040. https://doi.org/10.29333/ejeph/8200

Andeobu, L., Wibowo, S., & Grandhi, S. (2021). An assessment of e-waste generation and environmental management of selected countries in Africa, Europe and North America: A systematic review. *Science of The Total Environment*, *792*, 148078. https://doi.org/10.1016/j.scitotenv.2021.148078

Angel, B. (1991). The toxic threat to Indian lands. *A Greenpeace Report.* Retrieved May 25, 2024. https://doi.org/10.1016/0025-326x(91)90391-5

Awasthi, A. K., Wang, M., Awasthi, M. K., Wang, Z., & Li, J. (2018). Environmental pollution and human body burden from improper recycling of e-waste in China: A short-review. *Environmental Pollution*, *243*, 1310-1316. https://doi.org/10.1016/j.envpol.2018.08.037

Baldé, C. P., Forti V., Gray, V., Kuehr, R., & Stegmann, P. (2017). The Global E-waste Monitor – 2017, United Nations University (UNU), International Telecommunication Union (ITU) & International Solid Waste Association (ISWA), Bonn/Geneva/Vienna. https://doi.org/10.59117/20.500.11822/44316

Ballent, A., Corcoran, P. L., Madden, O., Helm, P. A., & Longstaffe, F. J. (2016). Sources and sinks of microplastics in Canadian Lake Ontario nearshore, tributary and beach sediments. *Marine Pollution Bulletin*, *110*(1), 383-395. https://doi.org/10.1016/j.marpolbul.2016.06.037

Baxter, J., Ho, Y., Rollins, Y., & Maclaren, V. (2016). Attitudes toward waste to energy facilities and impacts on diversion in Ontario, Canada. *Waste Management*, *50*, 75-85. https://doi.org/10.1016/j.wasman.2016.02.017

Canada - United States. (2023). *Air Quality Agreement Progress Report 2020-2022*. Retrieved May 15, 2024, from https://epe.lac-bac.gc.ca/100/201/301/canada_us_air_quality_progress_report/En85-1-2022-eng.pdf

Chen, G., Sun, Y., Xu, Z., Shan, X., & Chen, Z. (2019). Assessment of shallow groundwater contamination resulting from a municipal solid waste landfill—a case study in Lianyungang, China. *Water*, *11*(12), 2496. https://doi.org/10.3390/w11122496

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

Cheng, K., Hao, W., Wang, Y., Yi, P., Zhang, J., & Ji, W. (2020). Understanding the emission pattern and source contribution of hazardous air pollutants from open burning of municipal solid waste in China. *Environmental Pollution*, *263*, 114417. https://doi.org/10.1016/j.envpol.2020.114417

Cox, K. D., Covernton, G. A., Davies, H. L., Dower, J. F., Juanes, F., & Dudas, S. E. (2019). Human consumption of microplastics. *Environmental Science & Technology*, *53*(12), 7068-7074. https://doi.org/10.1021/acs.est.9b01517

Cui, D., Xi, B., & Tan, W. (2023). Composting industry under the Chinese municipal solid waste sorting policy: challenges, opportunities, and directions. *Environmental Science and Pollution Research*, *30*(8), 19513-19519. https://doi.org/10.1007/s11356-023-25367-0

Cusworth, D. H., Duren, R. M., Ayasse, A. K., Jiorle, R., Howell, K., Aubrey, A., ... & Thorneloe, S. (2024). Quantifying methane emissions from United States landfills. *Science*, *383*(6690), 1499-1504. https://doi.org/10.1126/science.adi7735

Ding, Y., Zhao, J., Liu, J. W., Zhou, J., Cheng, L., Zhao, J., ... & 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

Dwyer, H., & Themelis, N. J. (2015). Inventory of US 2012 dioxin emissions to atmosphere. *Waste management*, *46*, 242-246. https://doi.org/10.1016/j.wasman.2015.08.009

Environmental Protection Agency [EPA]. (2002). *Municipal Solid Waste in The United States: 2000 Facts and Figures*. Retrieved May 12, 2024, from https://archive.epa.gov/epawaste/nonhaz/municipal/web/pdf/report-00.pdf

EPA. (2012). *Waste*. Retrieved May 25, 2024 from https://web.archive.org/web/20120106004256/http://www.epa.gov/lawsregs/topics/waste.html

EPA. (2023). *National Overview: Facts and Figures on Materials, Wastes and Recycling*. Retrieved May 24, 2024, from https://www.epa.gov/facts-and-figures-about-materials-waste-and-recycling/national-overview-facts-and-figures-materials

EPA. (2024). *Quantifying Methane Emissions from Landfilled Food Waste*. Retrieved May 10, 2024, from https://www.epa.gov/land-research/quantifying-methane-emissions-landfilled-food-waste

Fu, Z., Lin, S., Tian, H., Hao, Y., Wu, B., Liu, S., ... & Lv, Y. (2022). A comprehensive emission inventory of hazardous air pollutants from municipal solid waste incineration in China. *Science of The Total Environment*, *826*, 154212. https://doi.org/10.1016/j.scitotenv.2022.154212

Government of Canada. (2021). *Reducing municipal solid waste*. Retrieved May 12, 2024, from https://www.canada.ca/en/environment-climate-change/services/managing-reducing-waste/municipal-solid/reducing.html

Gui, S., Zhao, L., & Zhang, Z. (2019). Does municipal solid waste generation in China support the Environmental Kuznets Curve? New evidence from spatial linkage analysis. *Waste Management*, *84*, 310-319. https://doi.org/10.1016/j.wasman.2018.12.006

Han, Y., Wang, Y., Wang, X., Huang, J., & Ma, W. (2024). Exploring the greenhouse gas emissions inventory and driving mechanisms of municipal solid waste in China. *Environmental Impact Assessment Review*, *105*, 107428. https://doi.org/10.1016/j.eiar.2024.107428

He, P., Chen, L., Shao, L., Zhang, H., & Lü, F. (2019). Municipal solid waste (MSW) landfill: A source of microplastics?-Evidence of microplastics in landfill leachate. *Water Research*, *159*, 38-45. https://doi.org/10.1016/j.watres.2019.04.060

Hoornweg, D., & Bhada-Tata, P. (2012). What a waste: a global review of solid waste management. The World Bank, Washington, DC. https://documents.worldbank.org/en/publication/documents-reports/documentdetail/302341468126264791/what-a-waste-a-global-review-of-solid-waste-management

Huang, K., & Eckelman, M. J. (2021). Estimating future industrial emissions of hazardous air pollutants in the United States using the National Energy Modeling System (NEMS). *Resources, Conservation and Recycling*, *169*, 105465. https://doi.org/10.1016/j.resconrec.2021.105465

Huang, Q., Chen, G., Wang, Y., Xu, L., & Chen, W. Q. (2020). Identifying the socioeconomic drivers of solid waste recycling in China for the period 2005–2017. *Science of The Total Environment*, *725*, 138137. https://doi.org/10.1016/j.scitotenv.2020.138137

Ji, L., Sun, Y., Liu, J., & Chiu, Y. H. (2023). Analysis of the circular economy efficiency of China's industrial wastewater and solid waste-based on a comparison before and after the 13th Five-Year Plan. *Science of The Total Environment*, *881*, 163435. https://doi.org/10.1016/j.scitotenv.2023.163435

Khan, S., Anjum, R., Raza, S. T., Bazai, N. A., & Ihtisham, M. (2022). Technologies for municipal solid waste management: Current status, challenges, and future perspectives. *Chemosphere*, *288*, 132403. https://doi.org/10.1016/j.chemosphere.2021.132403

Krause, M. J., Detwiler, N., Eades, W., Marro, D., Schwarber, A., & Tolaymat, T. (2023). Understanding landfill gas behavior at elevated temperature landfills. *Waste Management*, *165*, 83-93. https://doi.org/10.1016/j.wasman.2023.04.023

Kumar, V., & Garg, N. (2021). National and regional waste stream in the United States: conformance and disparity. *Environmental Research: Infrastructure and Sustainability*, *1*(3), 031002. http://dx.doi.org/10.1088/2634-4505/ac36bd

Kurniawan, T. A., Liang, X., O'Callaghan, E., Goh, H., Othman, M. H. D., Avtar, R., & Kusworo, T. D. (2022). Transformation of solid waste management in China: Moving towards sustainability through digitalization-based circular economy. *Sustainability*, *14*(4), 2374. https://doi.org/10.3390/su14042374

Lakhouit, A., Cabral, A. R., & Cabana, H. (2016). Two novel biofilters to remove volatile organic compounds emitted by landfill sites. *Water, Air, & Soil Pollution*, *227*, 1-9. https://doi.org/10.1007/s11270-016-2813-3

Liu, J., Li, Q., Gu, W., & Wang, C. (2019). The impact of consumption patterns on the generation of municipal solid waste in China: Evidences from provincial data. *International Journal of Environmental Research and Public Health*, *16*(10), 1717. https://doi.org/10.3390%2Fijerph16101717

Nanda, S., & Berruti, F. (2021). Municipal solid waste management and landfilling technologies: a review. *Environmental Chemistry Letters*, *19*(2), 1433-1456. https://doi.org/10.1007/s10311-020-01100-y

NBSC. (2018). *China Statistical Yearbook National Bureau of Statistics of China* [Dataset]. Retrieved May 12, 2024, from http://data.stats.gov.cn/easyquery.htm?cn¼C01

Nordahl, S. L., Preble, C. V., Kirchstetter, T. W., & Scown, C. D. (2023). Greenhouse gas and air pollutant emissions from composting. *Environmental Science & Technology*, *57*(6), 2235-2247. https://doi.org/10.1021/acs.est.2c05846

Ortiz, J. (2003). The tribal environment: Solid waste in Indian Country. *Environmental Management*, *31*, 0355-0364. https://doi.org/10.1007/s00267-002-2857-6

Pollans, L. B. (2024). *The Politics of Trash: How Governments Used Corruption to Clean Cities, 1890–1929*: Patricia Strach and Kathleen S. Sullivan (2022). Cornell University Press, 264 pages. $37.45 (hardcover). *Journal of the American Planning Association*, *90*(1), 177-178. https://doi.org/10.1080/01944363.2023.2247821

Powell, J. T., & Chertow, M. R. (2019). Quantity, components, and value of waste materials landfilled in the United States. *Journal of Industrial Ecology*, *23*(2), 466-479. https://doi.org/10.1111/jiec.12752

Qin, Z. H., Siddiqui, M. A., Xin, X., Mou, J. H., Varjani, S., Chen, G., & Lin, C. S. K. (2024). Identification of microplastics in raw and treated municipal solid waste landfill leachates in Hong Kong, China. *Chemosphere*, *351*, 141208. https://doi.org/10.1016/j.chemosphere.2024.141208

Robinson, K. G., Robinson, C. H., Raup, L. A., & Markum, T. R. (2012). Public attitudes and risk perception toward land application of biosolids within the south-eastern United States. *Journal of Environmental Management*, *98*, 29-36. https://doi.org/10.1016/j.jenvman.2011.12.012

Sebastian, R. M., & Louis, J. (2022). Waste management in Northwest Territories, Canada: current practices, opportunities, and challenges. *Journal of Environmental Chemical Engineering*, *10*(1), 106930. https://doi.org/10.1016/j.jece.2021.106930

Siddiqua, A., Hahladakis, J. N., & Al-Attiya, W. A. K. (2022). An overview of the environmental pollution and health effects associated with waste landfilling and open dumping. *Environmental Science and Pollution Research*, *29*(39), 58514-58536. https://doi.org/10.1007/s11356-022-21578-z

Statistics Canada. (2023). *Record amount of residential waste in 2020, but more was diverted.* Retrieved May 12, 2024, from https://www.statcan.gc.ca/o1/en/plus/4045-record-amount-residential-waste-2020-more-was-diverted

Statistics Canada. (2024). *Solid waste diversion and disposal.* Retrieved May 31, 2024, from https://www.canada.ca/en/environment-climate-change/services/environmental-indicators/solid-waste-diversion-disposal.html

Su, Y., Zhang, Z., Wu, D., Zhan, L., Shi, H., & Xie, B. (2019). Occurrence of microplastics in landfill systems and their fate with landfill age. *Water Research*, *164*, 114968. https://doi.org/10.1016/j.watres.2019.114968

Sunderland, E. M., Driscoll Jr, C. T., Hammitt, J. K., Grandjean, P., Evans, J. S., Blum, J. D., ... & Jacobs, W. (2016). Benefits of regulating hazardous air pollutants from coal and oil-fired utilities in the United States. *Environmental Science & Technology*, *50*(5), 2117-20. https://doi.org/10.1021/acs.est.6b00239

Taylor, S., Edwards, S. J., & Walker, T. R. (2020). A toxicity-based analysis of Canada's National Pollutant Release Inventory (NPRI): a case study in Nova Scotia. *Environmental Science and Pollution Research*, *27*, 2238-2247. https://doi.org/10.1007/s11356-019-06933-x

Thapa, P., Hasnine, M. T., Zoungrana, A., Thakur, S., & Yuan, Q. (2022). Food waste treatments and the impact of composting on carbon footprint in Canada. *Fermentation*, *8*(10), 566. http://dx.doi.org/10.3390/fermentation8100566

The World Bank. (2024). *GDP Ranking*. [Dataset] Retrieved May 12, 2024, from https://doi.org/10.57966/00f7-km24

UNEP. (2024). *Solid waste management.* Retrieved May 15, 2024, from https://www.unep.org/explore-topics/resource-efficiency/what-we-do/cities/solid-waste-management

Vines, V., Pasquali, M., Ganguli, S., & Meyer, D. E. (2023). Understanding the trade-offs of national municipal solid waste estimation methods for circular economy policy. *Journal of Cleaner Production*, *412*, 137349. https://doi.org/10.1016/j.jclepro.2023.137349

Wei, J., Li, H., Liu, J., & Zhong, R. (2022). National and provincial dioxin emissions from municipal solid waste incineration in China. *Science of The Total Environment*, *851*, 158128. https://doi.org/10.1016/j.scitotenv.2022.158128

Wong, N. W. (2023). Solid waste governance in cities. *Handbook on Local Governance in China*, 300-305, from https://doi.org/10.4337/9781800883246.00027

Yu, Y., Yu, Z., Sun, P., Lin, B., Li, L., Wang, Z., ... & Guo, S. (2018). Effects of ambient air pollution from municipal solid waste landfill on children's non-specific immunity and respiratory health. *Environmental Pollution*, *236*, 382-390. https://doi.org/10.1016/j.envpol.2017.12.094

Yu, Z., Gao, C., Yang, C., & Zhang, L. (2023). Insight into quantities, flows, and recycling technology of E-waste in China for resource sustainable society. *Journal of Cleaner Production*, *393*, 136222. http://dx.doi.org/10.1016/j.jclepro.2023.136222

Yunis, J., & Aliakbari, E. (2021). *Generation and Management of Municipal Solid Waste: How's Canada Doing?*. Canada: Fraser Institute. https://www.fraserinstitute.org/studies/generation-and-management-of-municipal-solid-waste

Zeng, J., Shen, X., Han, L., & Huang, G. (2016). Dynamics of oxygen supply and consumption during mainstream large-scale composting in China. *Bioresource Technology*, *220*, 104-109. https://doi.org/10.1016/j.biortech.2016.08.070

Zhou, C., Huang, N., Yang, G., & Ma, S. (2022). Assessing the sustainability of municipal solid waste management in China 1980-2019. *Sustainable Horizons*, *2*, 100020. https://doi.org/10.1016/j.horiz.2022.100020

Zhou, Q., Yang, J., Liu, M., Liu, Y., Sarnat, S., & Bi, J. (2018). Toxicological risk by inhalation exposure of air pollution emitted from China's municipal solid waste incineration. *Environmental Science & Technology*, *52*(20), 11490-11499. https://doi.org/10.1021/acs.est.8b03352

Zhu, Y., Zhang, Y., Luo, D., Chong, Z., Li, E., & Kong, X. (2021). A review of municipal solid waste in China: characteristics, compositions, influential factors and treatment technologies. *Environment, Development and Sustainability*, *23*, 6603-6622. https://doi.org/10.1016/j.jclepro.2021.126144