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# A societal transition of MSW management in Xiamen (China) toward a circular economy through integrated waste recycling and technological digitization☆

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A B S T R A C T

Recently Xiamen (China) has encountered various challenges of municipal solid waste management (MSWM) such as lack of a complete garbage sorting and recycling system, the absence of waste segregation between organic and dry waste at source, and a shortage of complete and clear information about the MSW generated. This article critically analyzes the existing bottlenecks in its waste management system and discusses the way forward for the city to enhance its MSWM by drawing lessons from Hong Kong's effectiveness in dealing with the same problems over the past decades. Solutions to the MSWM problem are not only limited to technological options, but also integrate environmental, legal, and institutional perspectives. The solutions include (1) enhancing source separation and improving recycling system; (2) improving the legislation system of the MSWM; (3) improvement of terminal disposal facilities in the city; (4) incorporating digitization into MSWM; and (5) establishing standards and definitions for recycled products and/or recyclable materials. We also evaluate and compare different aspects of MSWM in Xiamen and Hong Kong SAR (special administrative region) under the framework of 'One Country, Two Systems' concerning environmental policies, generation, composition, characteristics, treatment, and disposal of their MSW. The nexus of society, economics of the MSW, and the environment in the sustainability sphere are established by promoting local recycling industries and the standardization of recycled products and/or recyclable materials. The roles of digitization technologies in the 4$^{th}$ Industrial Revolution for waste reduction in the framework of circular economy (CE) are also elaborated. This technological solution may improve the city's MSWM in terms of public participation in MSW separation through reduction, recycle, reuse, recovery, and repair (5Rs) schemes. To meet top-down policy goals such as a 35% recycling rate for the generated waste by 2030, incorporating digitization into the MSWM provides the city with technology-driven waste solutions.



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**List of abbreviations**

| | |
|---|---|
| 4IR | $4^{th}$ Industrial Revolution |
| 5Rs | reduce, recovery, recycle, reuse, repair |
| BRI | belt and road initiative |
| CE | circular economy |
| CWTC | chemical waste treatment center |
| DRS | deposit refund system |
| DSB | district sanitation bureaus |
| EHM | environmental health management |
| EPD | environmental protection department |
| EPR | extended producer responsibilities |
| FEH | Food and Environmental Hygiene |
| GDP | gross domestic products |
| GHG | greenhouse gases |
| ISWM | integrated solid waste management |
| IOT | internet of things |
| LFG | landfill gas |
| MOC | Ministry of Construction |
| MOEP | Ministry of Environmental Protection |
| MSB | municipal sanitation bureau |
| MSW | municipal solid waste |
| MSWM | municipal solid waste management |
| Mg | megagrams |
| Mgd | megagrams per day |
| OWT | organic waste treatment |
| PAYT | pay as you throw |
| PCB | polychlorinated biphenyl |
| PEO | product eco-responsibility ordinance |
| PPP | public-private partnership |
| PRS | producer responsibility schemes |
| RTS | refuse transfer stations |
| SAR | special administrative region |
| SDG | sustainable development goals |
| SEZ | special economic zone |
| SW | solid waste |
| SWM | solid waste management |
| WDO | Waste Disposal Ordinance |
| WTE | waste-to-energy |
| WEEE | waste electrical and electronic equipment |

## 1. Introduction

Solid waste management issues universally affect everyone. On average, every day about 7.8 billion of the world's population generate about 0.74 kg of municipal solid waste (MSW) per person. The composition of their MSW consists of organic and non-organic waste from residential, institutional, commercial establishments, as well as non-processing waste from industries (Figure S1). In 2018, the total amount of MSW generation worldwide reached approximately 2.01 billion Mg (Kaza et al., 2018). With its annual growth rate of 5.5%, this would increase by 70% to about 3.40 billion Mg by 2050 (Figure S2). About a half of the waste consists of organic fractions.

Globally, 70% of the MSW is currently disposed of in landfills or open dumps, while only 13.5% of the waste is recycled and recovered (Figure S3) (Chen et al., 2020). It is estimated that about 1.6 billion Mg of $CO_{2eq}$ were emitted in 2018 from the MSW disposed of in open dumps without having landfill gas (LFG) collection systems, contributing to 5% of global greenhouse gases (GHG) emissions (Kaza et al., 2018). Other environmental concerns, resulting from the waste disposal in open dumps, include groundwater contamination, odor emanation, vector transmission via insects. To minimize such environmental concerns, sound MSWM is essential to protect the environment and public health (Vause et al., 2013).

This MSWM issue has also become a cross-cutting subject directly related to 70% (12 out of the 17) of the sustainable development goals (SDGs), our global road map to 2030 for human health, environmental concerns, and resource recovery (Rodic and Wilson, 2017). Therefore, the United Nations (UN)'s 2030 Agenda for Sustainable Development cannot be achieved, unless this matter is immediately addressed as one of the top priorities. An improper MSWM would bring adverse effects not only to public health, but also to the environment, while contributing to global climate change in the long-term (Singh et al., 2014).

On the other hand, a sound MSWM would benefit its stakeholders and the environment through waste avoidance, resource recovery, and a net reduction of GHG emissions, protecting the planet from climate change and paving the way for an intra-generational equity. By applying these approaches, the rich and the poor in our society mutually share the costs and benefits of a sound MSWM. As it is vital to recognize the importance of a proper MSWM as a driving force to attain the SDGs by 2030, translating the UN's Agenda into a reality has become a priority for all countries to continuously march towards a global partnership for promoting sustainable development (Singh et al., 2020). Consequently, they need to cooperate and collaborate in implementing their commitment towards each target of the SDGs into action plans locally (Lebreton and Andrady, 2019). Otherwise, they are only a statement of intents from the world's leaders.

With 1.44 billion of population, 9.6 million $km^2$ and a gross domestic product (GDP) of USD 14.14 trillion in 2019 (NBS, 2020), as the second-largest economic power, China represents one of the emerging superpowers. As the world's most populous country with 18.7% of the global population, from the very beginning China has committed itself to meet the 2030 UN Agenda through international partnership in the framework of South-South cooperation (Huang et al., 2016). By aligning its Belt and Road Initiative (BRI) and the $13^{th}$ Five-Year Plan (2016–2020) for economic and social development, respectively, with the 2030 UN Agenda, China has led the world in promoting a sustainable, inclusive, and low-carbon development for balancing between environmental protection and economic growth at the same time (Yang et al., 2018).

In spite of its progress, recently China still has been confronted with serious environmental problems due to an over-generation of MSW and its disposal. The rapid economic development of China since the opening policy in 1978 has resulted in a continuous increase of MSW nationwide due to its population growth, industrialization, and changes in people's consumption and urban lifestyle (Li et al., 2016). With its annual population growth of 4.4% (Gosh, 2016), the presence of migrant workers contributed to the increasing number of inhabitants in urban areas over 60% of the country's population (Zhou et al., 2017).

In 2017, the amount of MSW production in 660 urban cities of China reached 215 million Mg (MEPC, 2019), contributing to 7.5% of the global annual volume of the MSW. The annual growth rate of MSW generation in China was 6.5% with its average per capita being

1.12 kg/day (Qiao et al., 2020). By 2030, the amount of MSW generation in China will be projected to attain 480 million Mg (Xiao et al., 2020). As a result, the country needs to increase its budget allocation for waste management to US$ 33.6 billion in 2030 (Zhou et al., 2019). As MSWM is one of the most important services a city provides, the way municipalities in China handle it would bring long-term implications to their local community.

In 2019, municipal agencies nationwide collected and transported 426,450 Mg of MSW daily. About 80% of the waste was disposed of in local landfills, 15% was incinerated, while the rest was being composted. Due to its cost-effectiveness and ability to adapt to changes in terms of the quantity and types of the MSW, landfilling is widely used in China for the final disposal of MSW (He and Fu, 2021). However, the majority of its landfills still have not complied with international standards of construction and design (Ferronato and Torretta, 2019). Despite new landfills in large Chinese cities have been covered with clay liners for intercepting leachate and equipped with leachate collection and treatment systems, outstanding pollution problems persists (Zhu et al., 2021). Hence, China still has a long way to deal with MSW with respect to seminal technologies for waste collection, recycling, treatment and disposal.

As one of China's four SEZs established since the 1980s, with a total population of 3.83 million and its GDP of USD 86.9 billion in 2019 (Table S1), Xiamen has special economic policies to promote overseas capital investments for developing its industry (Xiamen Statistics Press, 2014). With the continuous development of Xiamen as a popular tourist destination in China, the city's annual MSW production has increased rapidly by 254% in recent years from 0.67 million Mg in 1996 to 2.37 million Mg in 2014 (XMEPB, 2019). Unless immediately addressed, Xiamen would encounter an urban deterioration that exceeds its ability to handle the MSW. If the city's MSWM authorities could not meet the community's demand for its disposal, this would lead to a backlog of waste. In the long-term, this would derail its development towards environmental sustainability because maximizing productivity without minimizing the generation of waste has serious consequences for Xiamen if the city's capacity to support its growth has reached beyond its limit (Li and Lin, 2016).

For this reason, a proper waste management is one of the priorities for countries in the developed and the developing world. The introduction of the CE paradigm in the 2012 UN Conference on Sustainable Development in Rio de Janeiro (Brazil) has enabled the city's MSW problems to be addressed using a variety of ways at the local level to bring tangible impacts on a global scale. This is underpinned by a school of thought that a sound MSWM based on CE would transform the waste sector into strategic roles: from being a part of global environmental problems to be a part of solutions in the path of sustainable development. Circular economy (CE) refers to "an economic system that orients towards sustainable development and environmental protection through waste avoidance, reduction, and prevention at source by using resources efficiently through a continuous cycle from production to consumption" (Luttenberger, 2020).

In practice, CE principles would enable the industry to maintain secondary resources in circuit production and preserve primary reserves. For example, the use of agricultural waste to treat another form of wastewater facilitates the continuous cycle of recovery, recycling, regeneration and reuse of the solid waste for water treatment (Kurniawan et al., 2011). In the framework of resource recovery, the recovery, recycle, reuse, conversion and re-introduction of the waste into the supply chain of secondary materials as adsorbents for water purification provides a win-win solution for creating job and meeting consumer's demand, while protecting the environment (Pesce et al., 2020). Hence, the 5Rs scheme needs to be applied to address the MSW issues in Xiamen.

For this reason, the city needs to improve its MSWM to facilitate green growth, resulting from waste avoidance, energy recovery, and a net reduction of GHG emissions. A proper MSWM could improve a resource recovery and tackle environmental deterioration caused by a lack of resources, promoting sustainable development paths in the long-term through recycling (Kurniawan et al., 2010).

Resource recovery through waste recycling is essential not only to attain a zero-waste approach, but also to preserve natural resources and slow down climate change. Even organic matter can be valorized through mechanical biological treatment to minimize GHG emissions. Waste recycling enables less virgin resources to be reused in the production circuit. As a result, we could avoid the GHGs that might be emitted from manufacturing the virgin resources. Consequently, less waste would be disposed of in local landfills, thus minimizing methane emissions from the landfills. In addition, waste recycling would lessen environmental pollution since this activity would minimize air pollution, which results from power plants and/or water pollution due to the consumption of chemicals throughout a production process (Xue et al., 2015).

However, the city still lacks of integrated and coordinated policies in MSWM. As a result, the recovery rate of MSW remains low. A poorly managed MSW has long-term implications on the environment and economy because the benefits of professional MSWM not only create new jobs for the community, but also minimize GHG emissions from its disposal (Premakumara et al., 2014).

Presently, Xiamen adopts both landfilling and incineration for MSW disposal due to the lack of a classification system. The absence of waste segregation between organic and dry waste at source represents an obstacle to create economic values from the recovered waste. Although recently Xiamen has made a substantial improvement in MSWM by implementing new regulations and policies under the guidance of national laws, the city's recycling industry has not grown yet due to the absence of acceptable standards for recyclable materials and/or recycled products (Burgess et al., 2021). As a result, this might have hindered the city's MSW minimization strategy.

Recycling is economically attractive and environmentally sound for waste treatment. After sorting it out, the waste is recycled into useful material for other purposes. If the MSW growth in Xiamen could be reserved by tackling it from downstream to upstream, this would promote a sustainable resource recovery in the city in the long-term because resource recovery minimizes waste generation and increases material efficiency by manufacturing by-products from another production process to adopt a zero-waste paradigm. In addition, recycling promotes energy conservation and net carbon emissions. It consumes less energy to manufacture a new product from recovered materials than it does to produce the same goods from virgin materials.

Unlike Xiamen, Hong Kong is one of the SARs in China with unique administrative systems and economic development levels. The 'Asia's World City' acts not only as a gateway to China, but also as a business trade center of Asia-Pacific. With its high population density, Hong Kong has inevitably encountered MSW problems. Although both Hong Kong and Xiamen are coastal cities, the MSWM in Hong Kong has been in line with international practices (Dan et al., 2021), while the MSWM in Xiamen is similar to that of other cities in the Chinese mainland. Hong Kong has a long tradition of developing long-term strategies for its standardized MSWM with a relatively clear waste classification, information disclosure, and recycling through innovative technologies. Based on Hong Kong's mature experiences of MSWM and lessons learned over the past decades, waste management challenges and problems in Xiamen in the future can be foreseen, identified, and addressed.

Preliminarily studies were undertaken by Sun et al. (2016) as well as He and Fu (2021) to compare the waste management policy in Hong Kong, Shanghai and other cities nationwide. However, the studies did not sufficiently address the recent reform of waste management policy in China in the framework of CE. Therefore, novel approaches for a MSWM based on resource recovery in Xiamen's waste sector that includes recycling and reuse are necessary (PELB, 1989).

The Journal's topical special issue aims at novel contributions on innovative approaches to transform our society's paradigms towards a sustainable and zero-waste environment. To align with this goal, this article focuses on the societal transition of MSWM in Xiamen based on the Hong Kong's mature experiences through integrated waste recycling and innovations toward sustainable production and consumption by incorporating digitization technology. This article also critically reviews the current situation, the existing bottlenecks, and the way forward for Xiamen to enhance MSWM in the city by evaluating and comparing various aspects of MSWM in both cities concerning environmental policies, the generation, composition, characteristics, treatment, and disposal of their MSW. To indicate how the progress of the city's waste management took place, the nexus of society, economics of the MSW and the environment in the sustainability sphere are established by promoting recycling and reuse of the unused waste in Xiamen. The important roles of digitization technology in the era of the 4IR in the city for waste minimization and reduction in the framework of CE are also discussed.

To attract interest from scientific community in the field of study, this case-study examines the MSWM issues in both cities from technological and economic perspectives. Based on technical perspectives, we incorporate technological solutions in the form of digitization for waste minimization and reduction. From an economic point of view, we discuss the way forward for Xiamen's MSWM through a continuous cycle of recovery, recycling, reuse of non-organic waste, and public participation as the requirements of applying the principles of resource recovery based on the CE paradigm.

To address the recent challenges and obstacles encountered by Xiamen in MSWM, by drawing lessons learned from the Hong Kong's mature experiences in its MSWM, seminal solutions including incorporating digitization to enhance MSWM are proposed to improve the city's MSWM in terms of public participation in MSW separation, 5Rs, and choice of final disposal technology for its MSW. It is anticipated that corresponding policies and solutions from this work would assist policy-makers in other cities nationwide to improve their MSWM in line with the international practices of ISWM.

## 2. Geographical location and demography of Xiamen and Hong Kong SAR

Figure S4 presents the geographical location of Xiamen (longitude: 118°0894″E, latitude: 24°4798″N). As a sub-provincial city of the Fujian province, with an area of 1700.16 km$^2$ and a total population of 3,833,000 inhabitants in the 2020 census (Table S1), Xiamen is located in the southeast coast of China mainland and across the Taiwan Strait. Like Hong Kong, Xiamen is a coastal city that enjoys an international reputation as a garden city due to its excellent management of urbanization.

Compared to Xiamen, Hong Kong covers a smaller area, but with a higher GDP of USD 490.88 billion in 2020 (Table S1). The SAR's level of economic development is higher than other cities in the Chinese mainland due to the rapid development of finance, manufacturing, and service industries.

Since Xiamen is an SEZ of China, it has a considerable freedom to encourage market-driven economic reforms and provide tax incentives to stimulate local innovation and green investments from Taiwan. Although the economy in Xiamen has continued to grow steadily in recent years, there are existing gaps between Xiamen and Hong Kong not only in economic development, but also in MSWM.

## 3. Overview of legislation on SWM in Xiamen and Hong Kong SAR

### 3.1. Regulations and policies on SWM in Xiamen

Since the 1980s, a series of environmental regulations and laws have been enacted by China to protect the environment. Initially, China's environmental policies have been influenced by the UN's 2030 Agenda, the global goals that aim at poverty reduction and environmental protection for peace and prosperity. For this purpose, by 2030 the country is ambitious to attain an environmentally sound management of all types of waste throughout their life cycle based on international conventions and minimize their emission into the environment for the sake of public health and the environment.

However, the actual implementation and enforcement of the country's macro-policy are delegated to each local provincial and municipal government nationwide to adopt and change the policies based on local conditions. They are the actors in implementing the country's vision not only in environmental protection such as $SO_2$ and $PM_{10}$ reduction, but also in energy conservation through renewable and green energy sources (National People's Congress of PR China, 1995,2008; 2013).

Local government authorities also play critical roles in delivering the MSWM services to their people. Coordination, collaboration and cooperation among stakeholders are necessary for an effective MSWM. The absence of proper MSWM would lead to environmental and public health problems. Therefore, recognizing and providing legitimatization to informal waste sectors would improve the performance of environmental service (Ministry of Environmental Protection of China, 2019).

Considering that waste management is fragmented and dispersed, sometimes the existing legislation and regulations are difficult to apply to MSWM due to its dynamic circumstances. For this reason, the legislation of MSW in Xiamen includes national and local regulations. To conserve natural resources and protect the environment, the national law dealing with the MSWM is the 2013 Law on Prevention and Control of Environmental Pollution Caused by Solid Waste of PR China (NPC, 2013). The law, which established a legal and regulatory framework of MSW collection, recycling, processing, and disposal, regulates the principles of MSWM, pollution control measures, corresponding legal duty, responsibilities for waste management and supervision. Since the local legislation on MSWM has to meet the national law, all decision-makings processes related to its operation and maintenance are centralized in the framework of a centrally controlled economy.

The first national law was passed in October 1995 and then revised in December 2004 with specific goals: (1) to promote the development of CE; (2) to define the responsibilities of government and manufacturers of MSW disposal; and (3) to set the discharge limit and import of industrial waste. Among various changes, the most important amendment of the law was the setting-up of extended producer responsibilities (EPR) (NPC, 2005), of which producers are required to be responsible for recycling and management of the products, even after the products are used and disposed of. If the manufacturers were responsible for the disposal cost of their products at the end of their life cycle, they would have an attractive incentive to design recyclable or reusable packaging, as reflected by the additional cost of their products. As waste generators, consumers are responsible for their return to whom they purchase the products and cover the costs of the collection, transportation and recycling of the products.

At the national level, the MSW regulation has been led by the Ministry of Construction (MOC) and the Ministry of Environmental Protection (MOEP). The MOC is responsible for MSW collection, transportation, storage, and processing, while the work of MOEP includes the treatment of special waste and hazardous waste. After the introduction of the Law on Circular Economy Promotion in 2008 (NPC, 2008), Xiamen needs to promote CE by implementing a cleaner production paradigm.

Presently, issues related to the MSWM in China's laws include a centralized responsibility of MSWM, an unknown regulatory body and industrial responsibility, and multiple levels of management (Tao et al., 2006). The arrangement by a centrally planned economy minimizes incentives for other stakeholders such as the MSB and DSB to conduct MSWM efficiently and effectively. Ideally, a sustainable MSWM needs to be decentralized so that any decisions could bring impacts directly to the local community with respect to the quality and efficiency of environmental service in the city.

Xiamen's legislation has been enacted by the provincial congress and their standing committees according to the Constitution, national law, and its real conditions. The city's law is the Certain Rules for Prevention and Control of Environmental Pollution by Solid Waste in Fujian province (Standing Committee of the Fujian People's Congress, 2009). The local waste management law includes waste recovery and its penalty system. The Law authorizes the city's government to enact monetary penalties (fines) if there are illegal acts. Although the legislation was in place, its enforcement and implementation were still weak (National People's Congress of PR China, 2008, 2013).

Recently Xiamen has standardized management of hazardous waste and strictly implemented a comprehensive review on MSW transportation to maximize its recovery and recycling rate. The efficiency of waste transportation depends on how effective is the waste collection. It is a basic service, which makes substantial differences to the city's inhabitants and their environmental health. Therefore, the haul distance to the disposal facility needs to be considered.

If the city's landfills are located at a significant distance from the points of collection, setting up transfer stations is necessary. The transfer stations will act as central sites, where trucks dump collected waste and reload it into bigger trailers. In urbanized areas, it is economical to reduce the haul distance by providing trailers at transfer stations. As their presence for this purpose would reduce the cost of waste transportation by employing fewer employees and the total distance of hauling kilometers, the transfer stations need to be situated at the center of service areas.

Introducing CE into the city's waste management requires political decisions in legislation and public participation. Their involvement would provide inputs for improvement directly and indirectly. With different perspectives, the stakeholders have various roles in the MSWM, as they are benefited from waste improvement for a variety of reasons. Public-private partnerships should be set up to invest in local waste treatment, as MSWM needs a multidisciplinary approach to cope with any scenarios. This requires additional skills and hands-on experiences of professionals involved, as waste recycling contributes to sustainable development in our shift from a linear economy to the CE.

### 3.2. Regulations and policies on SWM in Hong Kong SAR

As a developed region, Hong Kong SAR has established a comprehensive MSWM including its recycling system to deal with GHG emissions. Therefore, MSW generation is included as a part of the SAR's disposal systems. In Hong Kong, the legislative framework that deals with the management and control of waste is the Waste Disposal Ordinance (WDO), enacted in 1980. The Ordinance regulates and controls all activities of waste management including generation, collection, transport, recycling, treatment, and disposal. The WDO also governs the licensing of services, facilities and persons related to any waste management activities, and the import and export of waste according to the requirements under the 1992 Basel Convention on the Control of Transboundary Movements of Hazardous Wastes (Shittu et al., 2021).

In the 1980s, the annual generation rate of MSW in Hong Kong was 4%. To cope with this, in 1989 a 10-year Waste Disposal Plan was set up for the collection and disposal of solid waste including MSW, chemical, clinical and construction waste (PELB, 1989). The MSWM policy relied on the establishment of three strategic landfills, located in remote areas for waste disposal.

Such a MSWM policy based on landfill disposal was unsustainable. The operating landfills were eventually exhausted in 2019. Ideally, a long-term MSWM needs to integrate waste minimization, recycling, reuse, and recovery across sectors and macroeconomic policies. However, those strategies do not play roles in the MSWM policy, although they represent novel approaches for waste reduction and generating income for informal waste sectors.

To respond to this challenge, in 2005 the Government launched a "Policy Framework for the Management of Municipal Solid Waste (2005–2014)" (HKEPD, 2005a, b). The Policy Framework implemented a three-tiered approach based on the MSW's hierarchy (Figure S5) by involving: (i) avoidance and minimization; (ii) reuse, recovery and recycling; and (iii) volume reduction and disposal.

To promote waste reduction, recovery and recycling within the first and second tiers, three major policy tools including MSW charging, producer responsibility schemes (PRS), and landfill disposal bans are employed to change people's attitude and behavior towards waste. Environmental liability or fines is applied to ensure that the cost of environmental remediation becomes the responsibility of the polluters, instead of drawing resources from public coffers. The fine is charged to those, who illegally or incorrectly dispose of their waste. Under the newly enacted rubbish regime rule, residents in Shanghai could be fined up to CNY 200 (US$ 30) and companies can be penalized with a CNY 50,000 (US$ 7300) fine if they incorrectly sort out their waste into the right category: household waste, residual waste, recyclable waste, or hazardous one (Zhang, 2019).

To reflect the "Polluter Pays" principle, Hong Kong needs to require polluters to pay the treatment cost of industrial waste and household waste through MSW charging, while the PRS provides economic incentives for waste reduction and recycling. Incentives may be present in tax reduction such as an exemption of waste collection service fees.

To build up public compliance, awareness and participation, the policy tools need to be strengthened by legislation, public education, and partnership. Information and tips about the city's garbage sorting rules are disseminated from office buildings to residential communities. The public campaigns have been widely circulated to make residents aware of the benefits of waste recycling such as environment protection and resource conservation by less consumption of resources; less energy consumption; less pollution as compared to landfilling and/or open dumping; resource utilization; and an extension of landfill life due to waste avoidance, instead of waste disposal into landfills.

The Product Eco-responsibility Ordinance (PEO) has been in force since 2008 to establish the statutory framework for implementing PRS. The third major policy tool is the landfill disposal ban that can extend the serviceable life of local landfill sites. To increase the supply of recyclable materials to the local recycling industry, recyclable and unstable MSW are prohibited from entering the landfills.

To manage the critical MSW challenges, in 2013 the Environment Bureau unveiled the “Hong Kong Blueprint for Sustainable Use of Resources (2013–2022)”, which outlined a road map on the strategy, policy and action plans for the MSWM in the next 10 years (HKEPD, 2013). WTE-integrated waste management facilities were built for the treatment of unavoidable and non-recyclable waste. Their existence not only prevents waste disposal into the landfill, but also minimizes the significant quantity of emission and most importantly, supplies economically and eco-friendly alternative energy.

Compared to Xiamen, the MSWM of Hong Kong started earlier because the latter has a limited land supply to tackle its MSWM challenges. Therefore, the ways of MSWM in Hong Kong are more comprehensive and integrated than those of Xiamen. Practically, there are discrepancies to the corresponding rules and regulations concerning MSW collection, recycling, treatment, disposal, and the working condition of treatment facilities between Xiamen and the Hong Kong SAR.

## 4. MSW generation, characteristics, and composition of Xiamen and Hong Kong SAR

### 4.1. Xiamen

The MSW consists of domestic waste, hazardous and industrial waste (XMEPB, 2014a, b). The domestic waste comes from households, markets, and restaurants, while hazardous waste is mainly generated by medical waste, electronic manufacturing, and fabricated metal industries. The industrial waste originates from nonmetal mineral and refined tea manufacturing (Chen et al., 2017a, b).

Fig. 1 presents the trends of annual MSW generation in Xiamen from 1996 to 2014. The daily output of the total MSW in Xiamen has escalated by 251% from 1849 Mg in 1996 to 6501 Mg in 2014 due to rapid economic growth, population growth, and change in consumers’ lifestyles. The domestic waste represented a lion’s share of the total MSW. Statistics shows that the domestic waste in Xiamen has increased by 80% from 0.266 million Mg to 1.314 million Mg in the same period. As a famous tourist destination in China, in 2013 over 46.63 million people visited the city (SAR Year Book for Xiamen, 2014). Therefore, the waste generated from the catering industry has increased rapidly.

In both Xiamen and Hong Kong, domestic waste represents the major fraction of the total MSW, although the density of population in Hong Kong (7140 inhabitants/km$^2$) is much higher than that of Xiamen (2253 inhabitants/km$^2$) (Tables S1). The daily output of domestic waste alone in Xiamen has increased by 80% from 730 Mg in 1996 to 3600 Mg in 2014. It is estimated that kitchen waste, which accounted for 70% of domestic garbage, originated from the catering industry. This might be related to Xiamen residents’ eating habits of seafood and fresh fruits. Therefore, fish heads, shell shrimps, and core garbage were predominant in the refuse (Huang et al., 2016).

The MSW in Xiamen has an organic matter content of 65%–99% with higher water content. However, the waste is not treated in such a way that its value can be recycled and reused for other purposes. Although the technology substantially reduces the need for empty lands for landfills and conserves the city’s limited resources, incineration is not ideal for the city’s final waste disposal because the treatment cost is high due to energy consumption. The resulting dioxins and fly ash also affect not only the city’s air quality, but also public health. The fly ash is not only hazardous, but also toxic due to the presence of dioxin and heavy metals. If it is required to completely remove the dioxins in the tail gas, the treatment cost is too high, becoming an additional burden to taxpayers.

The increasing demands on the city’s finite resources and the growth of industrial development resulted in the increasing amount of industrial waste, harmful when being released into the environment. The proportion of industrial waste included coal ash (41%), cinder (29%) and sludge (4%), while two-thirds of the city’s MSW is food waste (Fig. 2). This indicates that heavy industries played important roles in the city’s economic development. The industry contributed about 55% to the city’s GDP in 2013 (SAR Year Book of Xiamen, 2013).

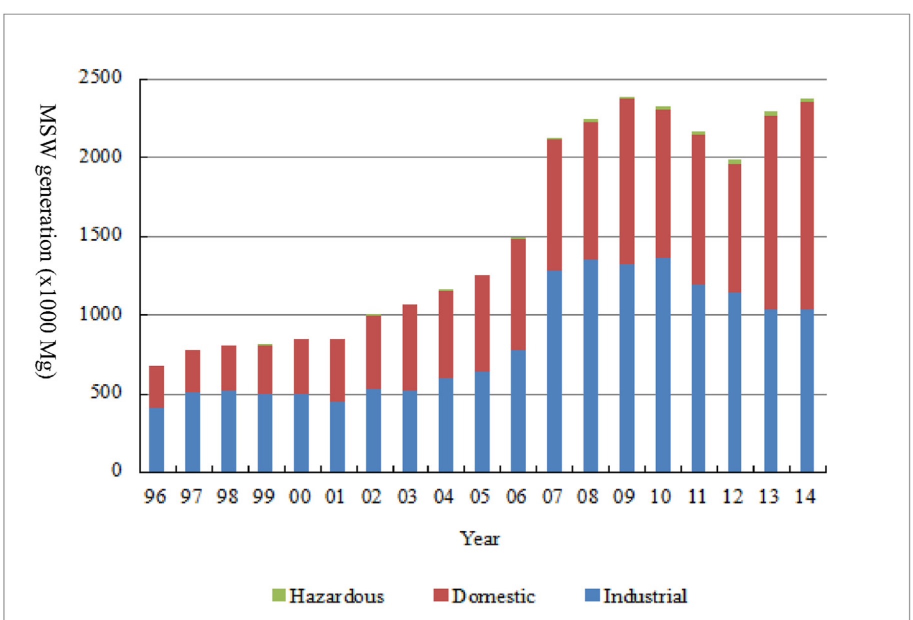


**Fig. 1.** Development of municipal solid waste generation in1996–2014 in Xiamen. (Source: Xiamen city environmental quality communique, 1996–2014).

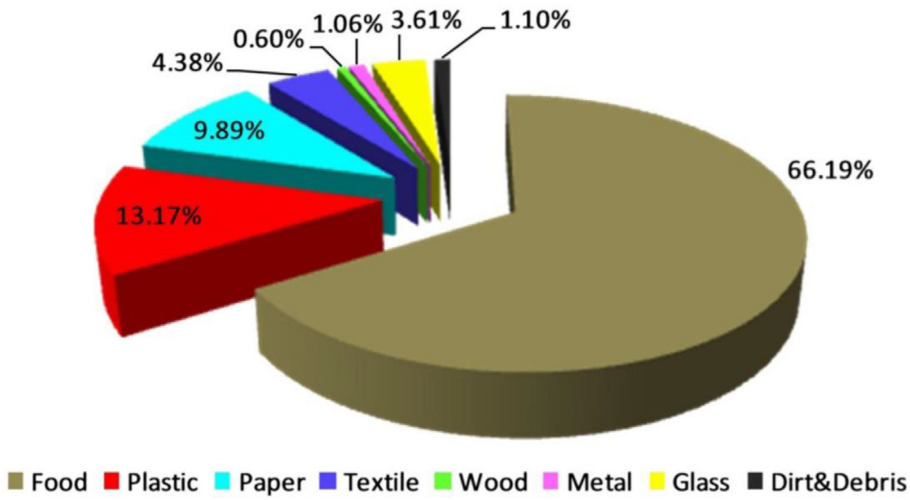


**Fig. 2.** Composition of industrial waste in Xiamen in 2014 (Source: Xiamen Municipal Bureau of Environmental Protection, 2014).

### *4.2. Hong Kong SAR*

In Hong Kong SAR, solid waste is classified into MSW, construction waste, and special waste such as chemical waste and clinical waste. With respect to its sources, the MSW includes domestic waste, commercial waste, and industrial waste (HKEPD, 2019) (Fig. 3).

In terms of the total MSW generation, Hong Kong is relatively higher than Xiamen. The magnitude and complexity of the MSW generated reflect the challenges that need to be dealt with by the Hong Kong SAR Government. Fig. 4 shows the domestic waste generation in Hong Kong from 1999 to 2018. The total generation of domestic waste has slightly increased by 1.78% from 2.80 million Mg in 1999 to 2.85 million Mg in 2018, while its population has increased by 22% over the same period. A Hong Kong resident generated an average of 763 kg of domestic waste annually or 2.09 kg/day in 2018, as compared to 635 kg annually or 1.74 kg/day by a Xiamen resident (HKEPD, 2020a, b).

It is interesting to note that the quantity of the waste produced in 2002 (reaching $8 \times 10^6$ Mg) was higher than that of other years (Fig. 4). For decades, the Hong Kong government under the British rule treated solid waste as an asset, instead of liability. Due to a lack of physical space, appropriate environmental policy, and technological innovation, the colonial government failed to promote a sustainable and integrated waste management system for Hong Kong between the 1980s and 1990s (Fabian and Lou, 2019).

After its return to China in 1997, the Hong Kong SAR government still did not have suitable technologies in places such as mechanical

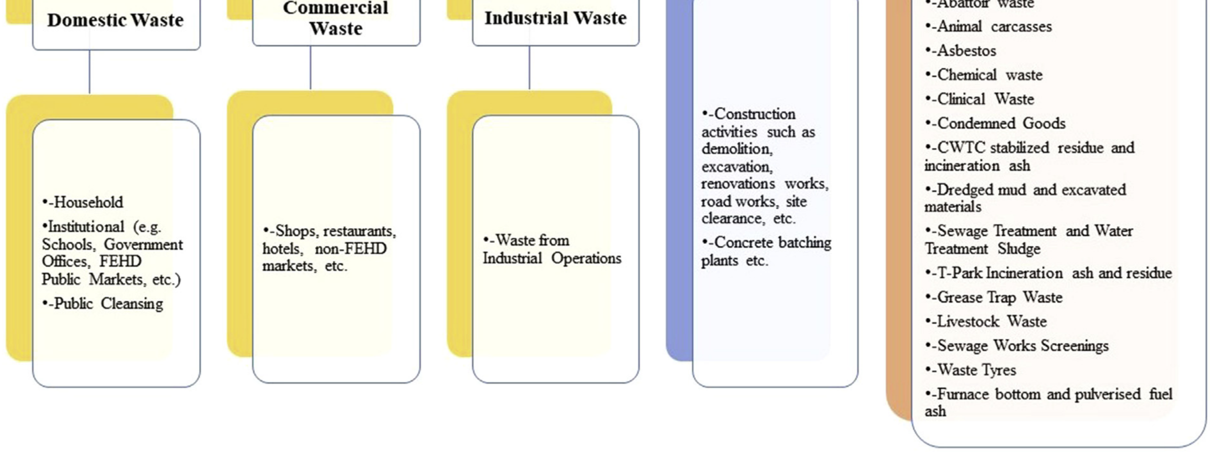


**Fig. 3.** Classification of solid waste in Hong Kong (Source: HKEPD, 2020a, b).

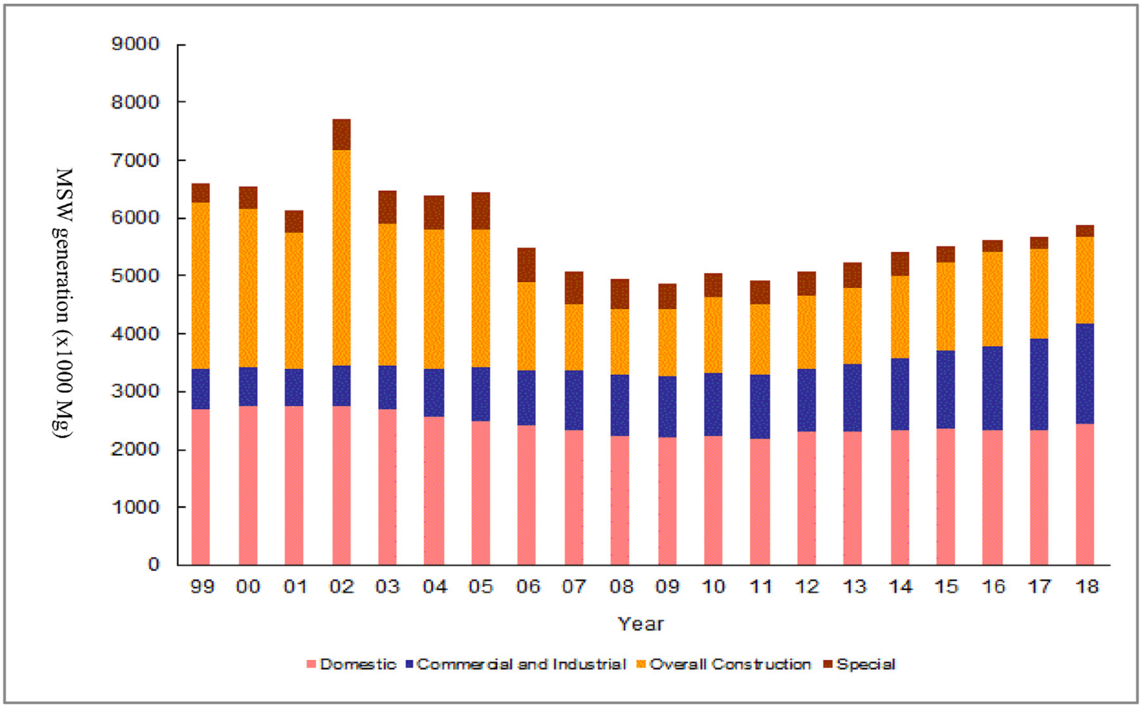


**Fig. 4.** Annual generation of municipal solid waste in Hong Kong (1999–2018). (Source: HKEPD, 2019).

waste sorting and separation, composting, incineration, and/or converting waste to fuel as a basis for long-term strategic options. To minimize the volume of MSW disposed of at landfills, recycling and waste recovery alone were insufficient because Hong Kong did not have primary and secondary industries. Consequently, only very few incentives were available for business sectors to develop a local recycling industry. These are the historical facts that the Hong Kong SAR inherited under the British colonial rulers (Fabian and Lou, 2019).

Fig. 5 illustrates the MSW composition and its typical fraction (by weight) in Hong Kong (HKEPD, 2019). Domestic waste is the major component, constituting over 42% of the MSW. Industrial waste is made up of over 29% of the MSW. As in Xiamen, food waste is a major component of MSW in Hong Kong. The current practices of Xiamen and Hong Kong to dispose of biodegradable food waste into local landfills are unsustainable and undesirable in the long-term, because such practices not only deplete the limited space of existing landfills, but also generate bad odor, LFG, and landfill leachate, which need additional mitigation actions, thus increasing operational costs.

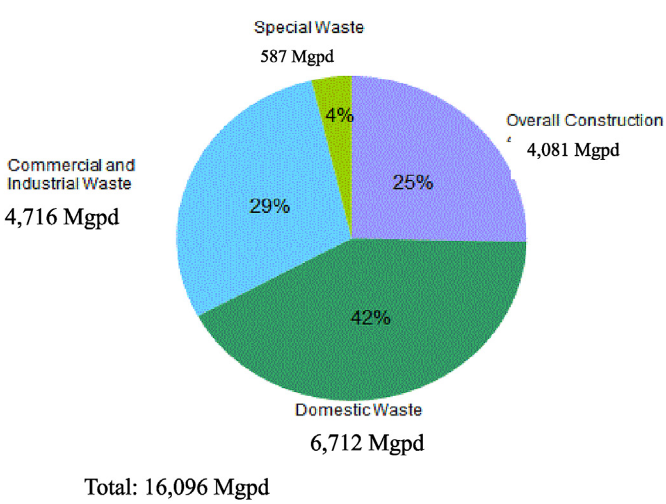


**Fig. 5.** Composition of solid waste in Hong Kong in 2018. (Source: HKEPD, 2019).

Due to its high moisture content and organic composition, the calorific values of Xiamen's MSW, which range from 4 to 5 MJ/kg, is lower than that of Hong Kong (7–10 MJ/kg) (He and Fu, 2021). Because of its less heating value, waste incineration is less efficient in Xiamen in terms of energy supply. Although incineration is not profitable from the electricity sold, the city's incineration plants remain in operation due to the government's subsidy. Despite it is difficult to strike a balance between environmental protection and economic growth, the local government prioritizes the former due to the city's reputation as the country's most appealing destination for tourism.

On the other hand, a higher living style and dietary habit in Hong Kong results in MSW with less moistures and higher caloric values. Therefore, incineration is more suitable and ideal for the final disposal of MSW in Hong Kong than that in Xiamen (Fabian and Lou, 2019).

Although the incineration of MSW in Hong Kong also generates dioxin, sulfur, particulate matters and other substances, their emissions are very low so that the resulting air pollutants could meet the stringent emission standards set by local legislation and they are strictly under control (Roberts and Chen, 2006; Cloirec, 2012; Titto and Savino, 2019). Therefore, this would not result in adverse health impacts on public health and the environment (Allegrini et al., 2015; Romanelli et al., 2019). Further actions such as ceasing the MSW feeding and shutting down the incineration system will automatically take place when the emitted effluent of dioxin attains 95% of the effluent limits set by the legislation.

## 5. Waste collection and disposal system in Xiamen and Hong Kong SAR

### 5.1. Xiamen

Presently, the end-of-pipe of MSW treatment in Xiamen are landfilling and incineration (Yu et al., 2012). Since 2012, the Xiamen Eastern Solid Waste Management Center has been the main landfill, while the incineration plants included the Hou Keng, the Western, and the Eastern incineration plants. Their daily capacities are 400, 600 and 600 Mg, respectively. The second phase of the Eastern incineration plants with a daily treatment capacity of 1200 Mg have been completed in 2016 (Yu and Dong, 2020). The Eastern landfill with a total capacity of 20 million m$^3$, located 60 km from the city's island, covers a total area of 2.07 km$^2$ and disposes of MSW from Xiang'an and Tong'an districts.

With respect to the overall collection system of MSW in Xiamen (Fig. 6) (Chen et al., 2017a, b), the MSW needs to be disposed of on the same day by the collection and transportation unit. After the MSW in the urban area is collected by the local residential committees, property management companies, and sanitation cleaners, it is then transferred to the garbage storage center.

The hazardous waste and industrial waste are disposed of by incineration. In 2014, 457,200 Mg of the two waste were incinerated, while 798,800 Mg of MSW were transported to the Eastern landfill for disposal and 58,100 Mg for recycling (XMEPB, 2014). The MSW's disposal rate in Xiamen was over 90%. There was a significant decrease of waste disposal rate by 50% from 2002 to 2003 in Xiamen (Fig. 7) due to the government's waste management policy that required Xiamen residents to conduct a source separation of the waste first by themselves before waste collection by the city's collection services (Mian et al., 2016). As a result, non-organic wastes were recovered, recycled and reused, instead of being disposed into local landfills.

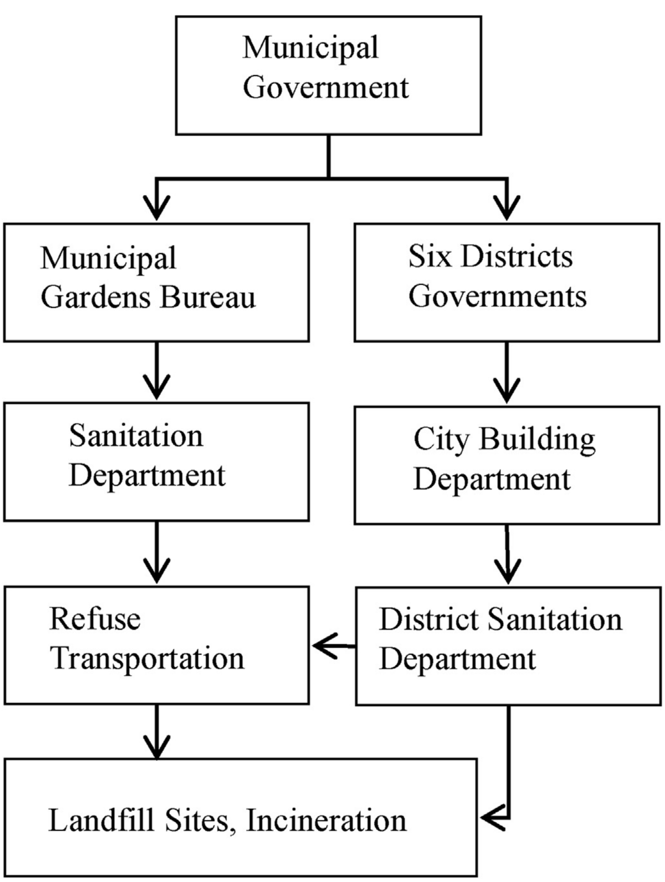


**Fig. 6.** Collection and disposal paths of MSW in Xiamen.

Although greening the waste sector results in multiple benefits to the economy and the environment, the MSWM in Xiamen still has not fully adopted the 5Rs scheme, as the proportion of MSW recovered and recycled is less than that of being landfilled. The absence of waste segregation between organic and non-organic in Xiamen offers scavengers to be involved in the local recycling industry, which creates economic benefits and values from the recovered materials. Waste recycling starts when scavengers bring their recyclable materials to sell to shops, which subsequently sell them to the manufacturing companies for additional income. Then, the companies convert the recyclable waste into raw materials for the manufacturing process using technologies to increase their economic values.

To address this issue, an improvement in the city's MSW collection and recycling is essential to promote CE through resource recovery (Zhu et al., 2019a). As recycling is a cornerstone in the MSWM, China government targets a 35% recycle rate in 46 large cities, including Xiamen, by 2025.

### 5.2. Hong Kong SAR

In Hong Kong SAR, the MSW is firstly collected and taken to private and public refuse collection points by cleaning workers, and then transferred by the SAR's Food and Environmental Hygiene (FEH) Department or its contractors to refuse transfer stations (RTS) (Fig. 8). The RTS are centralized collection facilities for waste compaction in standard containers before being transported to the landfills for final disposal. Presently, seven RTS are located in an incineration plant with a daily treatment capacity of 9000 Mg. A service fee is charged for waste disposal at the RTS. The EPD is responsible for managing the RTS and facilities for transportation and disposal of different types of waste.

Since the 1960s, landfilling has been widely used in Hong Kong for MSW disposal. Additionally, the incinerators, located in Lai Chi Kok, Kennedy Town, and Kwai Chung, with a total operating capacity of 2550 Mg daily were commissioned to treat publicly-collected domestic MSW in 1967, 1969 and 1978, respectively. In 1988, 0.694 million Mg of the MSW was incinerated, while 0.165 million Mg was landfilled (Table S2). However, due to public concern about air pollution, the three incinerators were eventually phased out in 1990, 1993, and 1997, respectively.

Nevertheless, new incinerators were not installed immediately after the de-commissioning of three incinerators, in spite of high calorific value of Hong Kong's MSW. This was attributed to the failure of the city's first incineration implementation between the 1960s and 1990s (Fabian and Lou, 2019). The incinerators contributed serious air pollution to the city's urban areas. About one-fifth of all highly toxic particulates are emitted into the atmosphere. Because of public pressure on the government at that time, all of the incinerators no longer operated in the 1990s. As a result, this makes landfilling become the sole method of MSW disposal since 1998 (Table S2).

Sanitary landfills (the West New Territories Landfill, South East New Territories Landfill and North East New Territories Landfill) with a total capacity of 140 million m$^3$ operated throughout 1993–1995. The landfills were equipped not only with a LFG management system for power generation, but also with a liner system, leachate collection, and treatment as well as surface and groundwater management systems to control water pollution.

The annual generation of the MSW disposed of in local landfills significantly increased by 102% from about 1.646 million Mg in

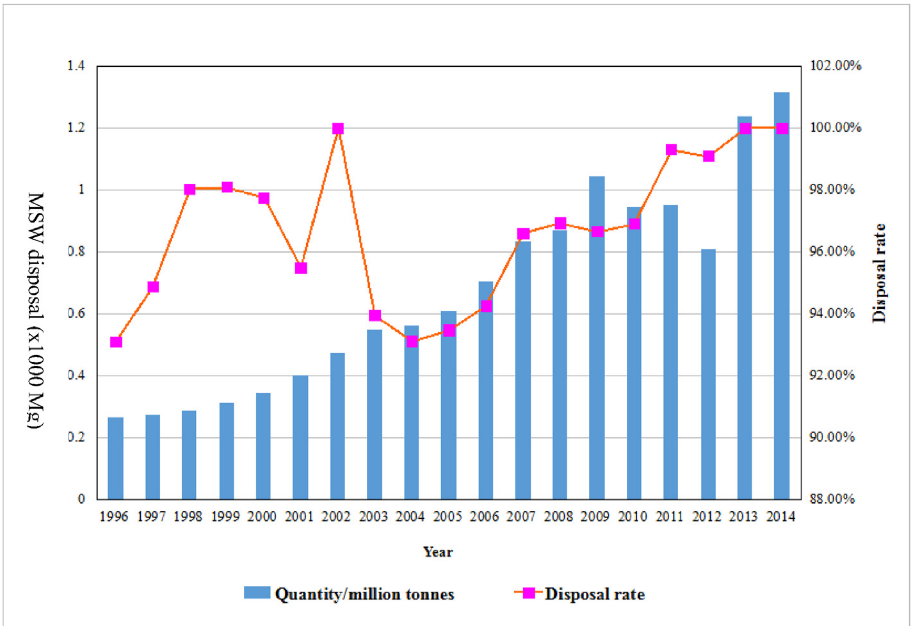


**Fig. 7.** Disposal rate of domestic waste in Xiamen between 1996 and 2014. (Source: Xiamen city environmental quality communique, 1996–2014).

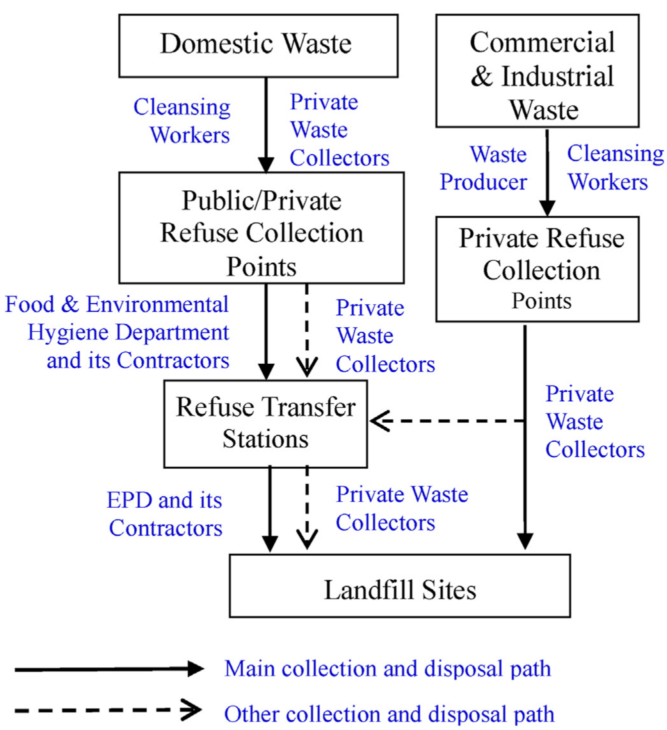


**Fig. 8.** Collecting and disposal paths of MSW in Hong Kong.

1988 to 3327 million Mg in 2019 (Table S2) with the commissioning of the SAR's three sanitary landfills. Not only the MSW, but the construction waste and special waste such as livestock waste and sewage treatment sludge were also disposed of into the landfills.

To divert the waste away from landfills and increase its recovery rate, a ten-year program "Waste Reduction Framework Plan" was launched in 1998. After 20 years of its implementation, not only there was a slight increase of 5.3% in the annual quantity of MSW disposed of into the landfills in 2017, but there was also a substantial improvement in terms of its recovery rate from 33% in 1997 to 52% in 2017.

Since each of the existing sanitary landfills reached their full capacity in 2019, Hong Kong has to reduce both the quantity of MSW disposed of into the landfills and the generation of MSW. For these purposes, the Environment Bureau promulgated the "Policy Framework for the Management of MSW (2005–2014)" in 2005 (HKEPD, 2005a, b). The Bureau implemented the MSW charging fee and various PRS to improve the MSW's recycling rates. Economic instruments are effective to control environmental pollution in Hong Kong, while simultaneously altering people's behaviors to waste reduction through price mechanisms (Kurniawan et al., 2021a). As the quantity of its MSW has increased in recent years, Xiamen could draw lessons from the experiences of Hong Kong in adopting economic instruments such as MSW charging fees and waste disposal fees to tackle the challenges of MSWM. By implementing "Pay-As-You-Throw" (PAYT), Xiamen may decrease waste generation and increase recycling rates.

Table S3 presents the MSW generation and recovery rates in Hong Kong for 1997, 2004 and 2010 (HKEPD 1998; 2005a, b; 2011). In 2010, the total MSW generation was 6.93 million Mg and 52% of the MSW was recovered for recycling. The 2010 recovery rate of MSW was significantly higher than that of 1997 (32.7%) (HKEPD, 2011). The recovered materials were exported to the China mainland for recycling. The export value of the recycled materials was about US$ 1.1 billion.

To stimulate the growth of the local recycling industry and investment in recycling technologies, the Hong Kong SAR Government set up the EcoPark in Tuen Mun, providing inexpensive and long-term land leases to the recycling industry. The EcoPark has attracted small and medium enterprises (SME) to establish plants to recycle waste from wood, metals, plastics, batteries, and tires. The metals are unique for their fracture toughness, thermal conductivity, and performance at high temperatures.

In 2012, about 50,000 Mg of metal waste were recovered and recycled by the companies in the EcoPark. This is the first step to sort them out based on their quality and property. After they are squeezed and squashed to reduce their space, the metals are subsequently crushed for further processes. After completing the process, the molten metal is solidified. Some chemicals need to be added to enable them to possess the required properties. In Hong Kong, the recycling of recovered materials from complex waste streams offers a unique solution to the limited land supply for landfills, offering positive impacts in restoring a pristine environment.

A sustainable MSWM improves efficiency and builds the capacity of administration, manpower, and local community. Since 2013 the SAR Government has been implementing the "Blueprint for Sustainable Use of Resources 2013–2022" (HKEPD, 2013), as the recovery, reuse, and re-introduction of valuable materials into a supply chain contribute to sustainable consumption patterns of the CE.

To resort to a low carbon economy, WTE facilities like Integrated Waste Management employ incineration to reduce the volume of non-recyclable waste and recover energy in the form of electricity or heating. The WTE can minimize the volume of waste by 95% and reduce the mass of waste by 75%, coupled with energy recovery (Kurniawan et al., 2013). Waste reduction is one of the reasons for Hong Kong to construct WTE facilities citywide, in spite of the huge amount of initial investment and daily operational cost. At least, half of the capital cost is allocated for the boiler of the WTE infrastructure. Therefore, there is a growing need to resort to public-private partnership (PPP) models to attract and promote private investors into the WTE through supporting policies. By establishing favorable tax incentives, tax exemption on 5% of earned revenue, loan guarantees, and favorable pricing on electricity generation (Cheng, 2017), the government could make the WTE become a safe investment, minimizing risks for private investors. With the scheme of build-operate-transfer (BOT), the cost would be equally shared between public and private stakeholders (Figure S7) (Cheng, 2017).

The Organic Waste Treatment (OWT) facilities also promote material recovery to convert food waste into energy by adopting anaerobic digestion and composting. To maximize waste utilization, we need to consider the effectiveness and efficiency of the technologies and supporting facilities as well as skillful manpower to process the waste, regardless of its composition and amount to be treated.

## 6. Corresponding measures of MSWM under China's Thirteenth Five-Year Plan

In Xiamen, the MSWM work was coordinated by the Solid Waste Management Administration (XMEPB, 2014). This department, a subordinate to the Xiamen Bureau of Environmental Protection, is responsible for carrying out national and local MSWM (XMEPB, 2008) with respect to industrial waste, hazardous law, and waste electrical and electronic equipment (WEEE). The Environmental Protection Bureau formulates the MSW pollution prevention plan according to national environmental policy and supervises their implementation at the local level (National Bureau of Statistics of China, 2020).

### 6.1. Industrial waste

With the rapid development of industry along with the amount of industrial waste, the Thirteenth Five-Year Plan (2016–2020) anticipated that the total production of industrial waste and the total volume of waste dumped in China would reach 15,000 million Mg and 27,000 million Mg, respectively (Ministry of Environmental Protection of PR China, 2019). Under the guidance of national policy about waste prevention, local governments need to strengthen their inspection and supervision over law enforcement and institute a system of report and registration for this waste (Standing Committee of the Fujian People's Congress, 2019).

### 6.2. Hazardous waste

With its characteristics of being corrosive, toxic, or infectious, hazardous waste includes medical waste, chemical waste and electrical waste. In 2025, its amount will exceed 70 million Mg (Singh et al., 2020). In Xiamen, the collection, transportation, treatment, and disposal of hazardous waste from scientific research and medical institutions must be carried out according to strict regulations. The waste is incinerated to minimize the impacts on the environment and public health.

In Hong Kong, the same waste is managed by the HKEPD using a "cradle-to-grave" approach from its point of origin, collection, transportation, and treatment to the final disposal. Similar to Xiamen, strict regulations are also enforced from generation, recycling, transportation, treatment, and storage to its disposal.

In the SAR, the CWTC provides services for the treatment of chemical, industrial and clinical waste. With an annual capacity of 100,000 Mg of chemical waste, since 1993 the CWTC has been operating a high-temperature incinerator capable of achieving 99.99% of removal efficiency for the waste with polychlorinated biphenyl (PCB), equipped with an advanced system of air pollution control. While recovering useful materials and energy from the waste, the air emissions, treated effluents and stabilized residues are regularly controlled and monitored to ensure that the emission and discharge standard requirements comply with the limit set by national legislation.

### 6.3. Waste electrical and electronic equipment (WEEE)

The WEEE contains poisonous and harmful substances such as Pb, Cd and Hg. Unless properly disposed of, the heavy metals of the WEEE will penetrate the aquatic environment and/or soil. Subsequently, they can impair public health through food chain. In the 13$^{th}$ Five-Year plan (2016–2000), China applies a resource recovery paradigm to promote waste recycling. Xiamen has a strict rule on the WEEE treatment and the city's electronic dismantling job is conducted by the Oasis Environmental Protection Co Ltd. Its original capacity is 45,000 Mg annually (Table S5).

## 7. Characteristics of SWM in Hong Kong SAR and Xiamen: A comparison

While there is a public discourse on the solutions for MSW problems through composting and 5Rs, the way forward for the MSW problems in China have been confined to two approaches: (i) minimizing MSW at source; and (ii) disposing of the collected MSW using technological solutions (Kurniawan et al., 2013, 2021a) because in many cities, the presence of waste management facilities is not enough to treat and dispose of the MSW. The first has been done through recycling initiatives using 'blue box' to separate paper and plastic for recycling (Figure S6). For the second, organic waste is converted into fertilizer through anaerobic processes, which also produce biogas that contains $CH_4$ and $CO_2$ with 70% and 30% (v/v), respectively.

Although the methane contributes to climate change problems due to its global warming potentials of 28 stronger than that of $CO_2$, the biogas represents a sustainable energy, which may contribute to an energy configuration in the future. The production of biogas from the organic waste would compensate for the energy consumed by the wastewater treatment, promoting energy-neutral for water purification. Therefore, this technique is selected for its technological prowess. The novelty of anaerobic digestion for biogas production includes less odor, less environmental impacts on public health, adjustable plants from small to large size, and economic benefits from using the generated energy (Zhu et al., 2019b).

Although composting could recover valuable resources and reduce GHG emissions in line with the SDG No. 12 of “ensuring sustainable production and consumption pattern”, it may not overcome the waste problems in Xiamen once and for all. The biogas remains dissolved in the wastewater effluents discharged from the anaerobic reactor. If the biogas is subsequently treated by stripping aerobically, it will escalate the carbon print of the waste treatment. This requires another solution to prevent the biogas from being emitted into the atmosphere.

Table 1 compares the various aspects of MSWM in both cities. As compared to Hong Kong, Xiamen lacks of a comprehensive database of MSW, thus increasing the difficulty of its transportation and processing. Up-to-date information on waste generation, composition, processing and products from the city’s disposal facilities are insufficient. The monthly summary report opened to the public focuses on the disposal and composition of industrial waste (Table S4) (Chen et al., 2010; Pan et al., 2021).

The ISWM promulgated in Hong Kong and recognized internationally is ideal to tackle the MSW. The Law on Solid Waste Pollution and its Prevention of China has adopted this ISWM approach (Chung and Poon, 1998). However, measures to reduce waste generation and promote its recycling have so far been limited to industrial waste in Xiamen (State Environmental Protection Association, 2014).

To address this bottleneck, economic approaches need to be promoted to address the waste problem concertedly. The use of economic instruments for environmental protection provides a way to save cost by shifting the cost away from the poor to the richer ones, who usually generate more waste, while achieving environmental objectives simultaneously by consolidating the cost of environmental damages due to the waste into a full fee. However, revenue may not be used to manage the environment due to its low tariff because the waste disposal fee is not calculated based on a proper formula/standard.

For this reason, the waste generators need to bear the cost of waste management in Xiamen. As a part of sustainability solutions, the instruments, which include waste disposal fees based, or DRS (Table 2), may discourage environmental pollution and provide households incentives for their involvement in implementing 5Rs. Such incentives may attract and persuade waste generators to minimize the quantity of their waste through waste recycling. This activity would minimize problems associated with the need of empty land for waste disposal. With depleted natural resources, waste recycling offers optional resources (Zhang et al., 2020a). This facilitates the city to set up a market of resource recovery for its non-organic waste.

In addition to economic instruments (Table S6), technical approaches such as composting organic waste at source and/or waste segregation need to be incorporated in MSWM in Xiamen for waste reduction. In Sukunan (Indonesia), the compost generated may be utilized for farming or gardening and the rest may be commercialized (Kurniawan et al., 2021a). The local community adopt a resource recovery for recyclable wastes by converting them into handicraft articles. Alternatively, they sell the waste as scrap to local recycling centers for earning extra money. This approach would lessen the quantity of waste disposed of in local landfills.

## 8. Market needs of standardization for recycled products and/or recyclable materials

Although various policies have been enacted to promote the introduction of waste recycling and recovery, the city’s recycling industry has not been mature or established to match the existing opportunity in the market due to the absence of proper standardization for recyclable waste and a lack of economic incentives such as tax reduction for Xiamen’s residents, who recycle their non-organic waste voluntarily. As a result, recycled materials have been recovered by scavengers before the official recyclers come to collect them for reprocessing because waste recycling is operated by poor individuals as a small business. If the recycling industry is a mature market, companies need to offer specific products with competitive advantages (Ibrahim, 2020). For this purpose, the institutional arrangement of the recycling industry and market development needs to be promoted through appropriate policy and legislation to create acceptable standards for recyclable materials and/or recycled products (Burgess et al., 2021).

However, the absence of specific requirements for the waste recycling industry in Xiamen and/or standards for recycled products would hinder the city’s MSW minimization strategy through waste recycling. With the increasing amount of recycled waste, there is a growing need for the standardizations of waste recycling industry (Meys et al., 2020). Apart from providing a guarantee on the quality of recycled products as required by consumers, the standards not only promote fair transaction in the waste recycling industry, but also enforce fair values of the recyclable materials in the market. Eventually, this would strengthen market mechanisms for recycled goods (Liu et al., 2020).

The existence of the standards not only addresses environmental concerns and public health implications, resulting from the industry, but also sustains the future of the waste recycling industry. Standards for the emission of recyclable materials may be unnecessary if the recycling process meets China’s environmental requirements. To enable the city’s recycled goods to penetrate the global market, the government needs to synchronize local standards with global requirements for the sake of environmental compliance and export-import purposes (Peters et al., 2019).

For this reason, Xiamen needs to have specific definitions of recyclable materials and/or recycled goods. Their definitions are

**Table 1**
Comparison of MSWM in Hong Kong SAR and Xiamen.

| | Hong Kong | Xiamen |
|---|---|---|
| MSW policy | MSW charging; PRS; Landfill disposal bans | The combination of prevention, control and disposal |
| Policy actor | Hong Kong SAR Government and HKEPD | Xiamen Municipal Government and EPB |
| Drawbacks | Rapid depletion of landfill sites; Declining recovery rate of commercial waste | No good MSW classification and collecting system; Lack of MSW disposal facilities and technology |
| Obstacles | One-off consumption culture; The increase in population and limited land resources | Lack of a comprehensive data base; Lower level of public participation |
| Benefits | Integrated MSWM system; Strong sense for environment protection | Landfill gas recycling; Incineration power generation |

**Table 2**
Economic instruments for waste reduction.

| Purposes | Type | Applicability |
|---|---|---|
| Increasing revenue | Tax System | Pollution charge Pollution taxes |
| | Charge system | Waste collection and disposal services Waste generation |
| Providing revenue | Fiscal tax | Duty on waste treatment |
| | Financial instrument | Incentive for pollution control technology |

essential to create acceptable standards for the recycling industry. In addition, the standards need to include all the processes involved in waste recycling, such as the handling and transportation of recycling products that meet the requirement of the Basel Convention and their impacts on public health and the environment (Jain et al., 2020). The requirements for recyclable materials and/or recycled goods need to emphasize their quality and adherence to specification, as required by specific industries (Gu et al., 2020). The presence of the standards requires recycling players to meet such requirements. Therefore, appropriate legislation is required to support their standardization. For this reason, an accurate database about the characteristics of recycled products and/or recyclable materials should be developed to support the recycling industry in Xiamen (Huang et al., 2020). Consequently, the city needs to have mechanisms and infrastructures readily available for synchronizing the standards.

Developing new markets for recycled materials promotes an economically attractive scheme for the local community without government subsidies. Their presence could be enhanced by increasing the supply or demand, of which both are inherently linked. If either of the two were not in equilibrium, we would encounter difficulty in promoting a smooth system of material flow from waste generators to users (Zhang et al., 2020b). Both need to be taken into account when promoting green growth so that an unbalanced market would not affect the economic sustainability of the recovered materials. Green growth is defined as “an economy that does not degrade the environment” (Qu et al., 2020).

Second, the absence of an MSW classification and collection system in Xiamen contributes to the increasing MSW and waste disposal cost. Without a clear classification of MSW, this results in lower rates of MSW recovery and recycling. The city’s recovery rate of MSW was only 2%, while that of Hong Kong was 52% (HKEPD, 2020a, b). Although the city’s residents are ideally co-responsible with the municipality for sorting out their MSW before bringing it to the waste containers, they may have less environmental awareness of correct MSW classification and sorting out for reuse, while government’s propaganda could not suddenly change people’s behavior in urban consumption lifestyles in one night.

Unlike Xiamen, the Hong Kong SAR Government has actively promoted various propaganda of environmental protection by establishing websites on waste reduction and providing information on how to collect and reuse the MSW. In Hong Kong, the recyclable or non-recyclable waste belongs to the MSWM unit to collect, while in Xiamen, the two types of waste are collected by different bureaus, indicating segregation of responsibility between them (Troschinetz and Mihelcic, 2009).

The ‘One Country, Two Systems’ framework could be complicated in its implementation without media’s propaganda in influencing public participation and their environmental awareness (Table S7). However, if the cities have a good waste management system and a company, especially responsible for recyclables, environmental education, and programs like PAYT, or even reward the people that have recycled theirs, the waste management system could be enhanced accordingly (Kurniawan and de Oliveira, 2014).

Third, Xiamen still lacks the sorting facilities and waste disposal technologies. As a result, the city still adopts centralized and mixed treatment. Unlike Hong Kong with a comprehensive pollution detecting system in its landfills and incineration sites, Xiamen’s pollution control tools in waste disposal are still insufficient. In Xiamen, most of the MSW is landfilled because of a lack of waste management facilities. Due to the increasing waste generation, the city’s landfills are quickly overloaded before reaching the limit of their designated lifetime.

The original design capacity of the Dong Fu landfill site was 2.15 million $m^3$, but it became saturated in 2005. In 2006, the landfill site was expanded to 2.87 million $m^3$ and used for two years only . The landfill, which occupied a large number of land resources not only emitted bad odor that annoyed the environment, but its leachate also polluted the underlying groundwater.

## 9. Suggestions to improve MSWM in Xiamen

Due to the different socio-economic development in its six districts, Xiamen has encountered various challenges of MSWM in recent years. Solutions to the MSWM problem are not limited to technological solutions, but also need to link environmental, legal and institutional relationship. Several aspects of MSWM in Xiamen, which need to be improved based on the Hong Kong SAR’s mature experiences in MSWM, include:

### *9.1. Enhancing source separation and improving recycling system*

The MSWM represents one of the largest single budget items in Xiamen. The collection and transportation of MSW account for the bulk of the city’s annual budget, allocated from its budget to finance waste management (Taveres et al., 2009). In spite of the increasing public spending for enhancing MSWM, a lack of waste segregation between organic and non-organic sources contributes to the low rate of MSW’s recovery and recycling, making it difficult for sanitation cleaners to keep pace with the city’s MSW generation. Therefore, waste separation at source must be conducted from the outset to promote 5Rs as the key policy goals.

To cope with this, an improved collection system for its efficiency and performance would save a substantial budget allocation for the MSWM alone. With waste segregation practiced at the source, scavengers may get an additional income. For this reason, the city’s Environmental Health Management (EHM) Office may consider employing scavengers. While collecting the recyclable stuff from the disposed of MSW, after extracting the valuable by-products, they return the recovered materials to manufacturers through recycling. The EHM office may provide the scavengers with proper training, health insurance, and decent wages. A lack of competence and skills in waste management often results in an ineffective MSWM. Training them about how to deal with MSW effectively not only builds and enhances their knowledge and skills, which subsequently enhance the efficiency and cleanliness of the city’s waste collection, but also improves the employment rate of people with less education (Zhang et al., 2010). If this approach is integrated with RTS, the coverage of a garbage collection system will be more extensive than that of the current situation.

Xiamen may also develop a model of truck allocation to minimize the queuing time wasted at the RTS facilities (Xue et al., 2015). The refuse classification system should start at sources and be decorated with new classified collection bins to effectively reduce sorting work. At the same time, the government needs not only to increase public awareness towards garbage sorting, but also to encourage people to recycle their MSW and establish corresponding regulations for rewards and punishments. Recycling the MSW not only provides means of income for those, who participate, but this can also substantially minimize its quantity before landfill disposal, lessening the city's expenses and extending the lifetime of local landfills. In Xiamen, the key factors in promoting the 5R schemes are public participation and their environmental awareness as the foundations of CE. They need to sort out their waste properly and see it as a business opportunity to make an additional income or saving, as compared to processing virgin materials (Abdallah et al., 2020).

### 9.2. Improving legislation system of MSWM

To strengthen the production, transportation and disposal of MSW, the duty and responsibilities of the municipality's different bureaus and the county's departments must be proportionally distributed. Integrated legislation of MSWM reform is necessary to solve a complex situation. Enacting appropriate legislation for the MSWM is the first step toward an effective waste management service. This makes the use of administrative licensing, administrative fees, and punishment synchronize the implementation of MSWM between Xiamen and other cities nationwide (Mathew and Tan, 2016).

To enforce people to do correct waste category, local government have implemented various rules. In Shanghai, the Household Waste Management Regulation fines residents, who fail to sort out their waste. The Regulation educates people on how to sort out household waste and restrict disposable trash at the city's hotels and restaurants (He and Fu, 2021).

Li et al. (2016) showed inherent conflicts in China's regulations on MSWM. Local governments might not be willing to deal with any risks that reduce the interest of potential investors to invest in MSWM if they treated waste recycling as a work of public service. Therefore, local government needs to work with private companies to recycle the recovered MSW to promote their economic benefits.

### 9.3. Improvement of terminal disposal facilities

Most of MSW in Xiamen is disposed of at landfills. However, landfilling has the lowest priority in the MSWM hierarchy (Figure S5). Due to the limited land supply, landfill should be reserved for MSW, which cannot be treated in other ways (Bai and Sutanto, 2002).

In MSWM, reduction and recycling are the best choices for waste treatment. Therefore, pre-treatment of MSW is necessary before landfill disposal. Mechanically pre-treated waste accelerates the degradation and decomposition of organic waste in landfills (Zhang et al., 2010). As a result, this can reduce the generation of leachate and LFG, emitting less GHG from local landfills. In addition, the benefits of mechanical pretreatment of the waste cover less organic waste treated by biological process, separation of recyclables from organic waste, and less initial investment, as compared to the other techniques, except composting.

For this purpose, Xiamen needs to invest and introduce advanced waste treatment technologies to promote sustainable and long-term solutions such as converting MSW into biogas. The methane in the biogas can be converted into biofuels. Through the combustion of MSW in an incinerator, the biogas can be produced to supply electricity cost-effectively, reducing carbon emissions and optimizing resource utilization.

Since 2005, China has adopted the Renewable Energy Law that encourages the use of MSW as one of its sources (Yang et al., 2018). In 2005, China had only 67 WTE plants that were transforming about 9% of the total MSW into energy (Xiao et al., 2020). In 2013, about 166 WTE plants were established to convert more than 30% of the nation's MSW into bioenergy (Vause et al., 2013). In incineration, MSW substitutes non-renewable energy such as fossil fuel as the alternative fuel for the combustion. The heat of the MSW is recovered to convert water into steam and transferred into a turbine generator to generate electricity. Waste incineration needs to take precautions to prevent the emission of toxic substances from harming public health and the environment.

### 9.4. Incorporating digitization into MSWM

In recent years, MSWM in China has evolved from labor-intensive activities carried out by scavengers on waste collection towards capital-intensive services. Providing them with attractive benefits would increase people's willingness to work in waste management. This transformation occurs in parallel with the emergence of the 2030 UN's Agenda as a driving force. Since China's population edges towards 1.44 billion in 2030, the strain on the country's resources has steadily intensified due to the increasing need for raw materials. Therefore, the MSWM needs to take into account not only environmental protection, but also CE (Bai and Sutanto, 2002).

A CE paradigm encompasses a sustainable consumption of resources through recovery and recycling of secondary materials from MSW. To promote CE, both manufacturers and consumers need to understand its quantity, quality, best use, and environmental benefits because complete and clear information on the circularity of products or materials is vital for recycling purposes (Mathew and Tan, 2016). For manufacturers, a certain proportion of their products needs to comply with the requirement of minimum recycled content to enable them to increase the use of recycled material in products. Therefore, manufacturers must orient toward sustainability when developing new packaging for their products. They need to design processes that minimize the generation of unwanted outputs that may be potentially harmful to the environment. For waste elimination, they need to close materials cycles in a more reasonable timeframe with lower energy costs. Recycling can be achieved by developing durable active material and constantly regenerating their structure.

For implementing 5Rs, Xiamen municipality needs not only to deploy significant manpower and financial resources, but also to make use of the digital economy revolution for environmental services (Zhu et al., 2019a). With the emergence of Baidu, Alibaba, Tencent and Xiaomi, incorporating the digitization technology into MSWM would assist the city not only to control its MSW generation, but also to promote the digital economy as a new anchor of its economic growth by removing inefficient, fragmented, uncoordinated, and low-quality offline markets. The global market of smart waste collection technology was about US$ 57.6 million in 2019, and this would be worth over US$ 223.6 million by 2025 (Chauhan et al., 2021).

As a leader of global digitization, the market size of China's digital economy reached US$ 4.2 trillion in 2018, while the country's market of the data center was worth US$ 26.9 billion (Sarc et al., 2019). The availability of the digital economy and data center markets provides Xiamen with opportunities to innovate in digital solutions for the city's waste reduction strategy. Digitization assists the community to coordinate and connect material and information flows through censoring, automated platforms, or the IoT for classifying, sorting, or recycling their waste (Chauhan et al., 2021). Automation and data exchange also enables the industry to gain productivity, while saving resources by avoiding overproduction and minimizing their wastage.

Users may take pictures of their waste in the apps to analyze and advise them where to discard it. Alternatively, apps with voice-activated smart speaker could do the same job after the waste is verbally illustrated. Artificial intelligence could assist users by scanning their waste on the phone cameras and advising them on the most appropriate category for the MSW they would dispose of (Nizetic et al., 2020). The development of this technological platform directly connects the waste generators with the operators of waste collection services. This solution enables the latter to reduce their charge for waste collection and to increase the volume of the recovered waste.

To transform the MSW problem into an economic opportunity, business solutions need to be scaled-up to support waste recycling. By adopting the CE paradigms, major companies may identify new business opportunity for their waste materials by recycling used products. By decoupling economic growth from environmental impacts, their products do not immediately become waste, but are reused to extract their value before safely returning to the biosphere.

This CE paradigm paves the way for a more sustainable business model in Xiamen to avoid unnecessary waste of resources, as residents are encouraged to adopt eco-friendly lifestyles such as a zero-waste approach, leading to a reduction in one's carbon footprint.

In the era of the 4IR, there is no trade-off between economic growth and environmental sustainability. By incorporating the digitization technology into MSWM, Xiamen would be able to meet top-down policy targets such as a 35% of recycling rate for the city's waste by 2030. This platform will offer new opportunities for technology-driven waste solutions citywide. Although digitization may provide the city with novel solutions in MSWM, the local community must embrace a new lifestyle that reflects the waste reduction in their consumption.

### *9.5. Establishing standards and definitions for recycled products and/or recyclable materials*

With the increasing number of recyclers and recycled materials, the need of standards for waste recycling industry has become very critical as the industry expands. The city's enforcement agency requires standards not only to sustain the waste recycling industry and protect the environment, but also to guarantee the quality of recyclable materials and/or recycled products for the market. The existence of such standards not only ensures fair practices in the industry, but also stabilizes the market values of recycled goods and enforces a market mechanism for recyclers and buyers. If properly implemented, the standards contribute to a green and clean environment in Xiamen in the long-term.

However, various barriers still exist in waste management systems in the city. They include a lack of specific industry standards, technological standards, classification standards, and test standards for recyclable materials and/or recycled products. The city's policymakers need to take into account the lack of regulatory norms to establish appropriate standards. For this reason, specific legislations are necessary to promote a recycling industry in Xiamen.

## 10. Greening waste sector in the framework of 'One Country, Two Systems'

'One Country, Two Systems' is a special administrative system in China, of which within the territory of China, the body of the state maintain its socialism, while Hong Kong SAR and Macao SAR carry on with their capitalist systems (Lam et al., 2017). Although Hong Kong SAR is an integrated part of China, the city retains its government, legislation, currency, and political structure. Hong Kong SAR and Xiamen do not belong to the same system under this constitutional principle.

Their legal system is different from each other. As an international city with a high level of economic development, Hong Kong has complete laws and regulations of environmental protection with the characteristics of Anglo-American laws. In terms of environmental protection, there is no unified law like that of the Chinese Mainland that has a series of environmental laws and regulations for specific environmental pollution. Although the ways, of which Xiamen and Hong Kong handle their MSW, are different, the 'One Country, Two Systems' ensures that both cities can formulate their corresponding environmental regulations according to the conditions of their regional differences.

Because Hong Kong and Macao are adjacent to China's inland, they belong to the same ecological environment. As a result, the environmental issues between Hong Kong SAR and the Chinese mainland have a common influence on each other. This makes it easier for Hong Kong SAR, Macao SAR and the China Mainland to strengthen regional cooperation in environmental protection. Such a cooperation between the China Mainland and Hong Kong SAR would enable other cities in the Greater Bay Area and neighboring Fujian Province to learn the latter's mature experiences in MSWM.

Figure S8 illustrates the conceptual framework of Xiamen and Hong Kong's cooperation in MSWM. Hong Kong transfers innovative technologies to Xiamen for an enhanced MSWM, while Xiamen coordinates and cooperates with Hong Kong in other environmental issues. Although both have different standards in terms of environmental law, such as the supervision and management of water quality or the effluent limits set for water pollutants, within the 'One Country, Two Systems' framework they are on the same page to build the same system for MSWM to facilitate a regional cooperation and strengthen their coordination in protecting the environment.

For greening the waste sector in Xiamen and Hong Kong, concerted actions in the future need to be taken to enhance waste recycling and its reuse by developing markets for secondary raw materials. It is expected that the existence of such markets would change consumer behaviors to facilitate the country's transition towards a CE nationwide. If people had resource recovery in their mind and did it through the 5R schemes, in the long-term China would eliminate the need for landfills for MSW disposal.

As the demand for energy and food would increase in the future, the scope of further research needs to be expanded to liquid waste. If resource recovery considers wastewater as a resource, we may close the nutrient recycling loop, facilitating a zero-waste approach and a cost recovery of waste treatment. If the paradigm of water treatment plants shifts to resource factories, certain nutrients in the wastewater such as nitrogen and phosphorus represent renewable resources (Kurniawan et al., 2021b; Fu et al., 2021).

## 11. Concluding remarks

Xiamen municipality has played important roles in developing a sound MSWM to address institutional challenges and financial constraints due to the over-generation of MSW. Through policy intervention, institutional coordination, capacities building, and public participation, the government has formed practical policies to ensure that the city's policies and institutions would promote a zero-waste approach and CE in the framework of resource utilization.

In line with China's emphasis on environmental protection, over the past years, the city's MSWM has been strengthened through gradual reform. However, due to the sustained growth of the city's economy, the MSWM issue has become difficult to deal with due to a lack of a comprehensive garbage sorting and recycling system, the absence of waste segregation between organic and dry waste at source, and the shortage of complete and clear information about the MSW generated.

In the framework of 'One Country, Two Systems', Hong Kong's mature experiences in MSWM over the past years has inspired Xiamen with novel solutions. The solutions to the MSWM problem are not only limited to technological options, but also integrate environmental, legal and institutional perspectives. They include: (1) enhancing segregation between organic and non-organic waste; (2) improving resource recovery through recycling system; (3) enacting a complete legislation on MSWM; (4) incorporating digitization technology into MSWM; (5) involving public participation in waste collection and its classification; and (6) establishing standards and definitions for recycled products and/or recyclable materials.

Overall, this study has demonstrated that the 'One Country, Two Systems' framework has enabled Xiamen and Hong Kong SAR not only to cooperate in MSWM and strengthen regional coordination in the area of environmental protection, but also to formulate their environmental regulations according to real conditions, while simultaneously maintaining their own political and economic systems.

## Credit author statements

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## Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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## Appendix A. Supplementary data

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## References

Abdallah, M., Talib, M.A., Feroz, S., Nasir, Q., Abdalla, H., Mahfood, B., 2020. Artificial intelligence applications in solid waste management: a systematic research review. Waste Manag. 109, 231–246. https://doi.org/10.1016/j.wasman.2020.04.057.

Allegrini, E., Vadenbo, C., Boldrin, A., Astruop, T.F., 2015. Life cycle assessment of resource recovery from municipal solid waste incineration bottom ash. J. Environ. Manag. 151, 132–143. https://doi.org/10.1016/j.jenvman.2014.11.032.

Bai, R.B., Sutanto, M., 2002. The practice and challenges of solid waste management. Waste Manag. 22, 557–567. https://doi.org/10.1016/S0956-053X(02)00014-4.

Burgess, M., Holmes, H., Shaver, M.P., Sharmina, M., 2021. The future of UK plastics recycling: one bin to rule them all. Res. Conserv. Recyl. 164, 105191 https://doi.org/10.1016/j.resconrec.2020.105191.

Chauhan, A., Jakhar, S.K., Chauhan, C., 2021. The interplay of circular economy with industry 4.0 enabled smart city drivers of healthcare waste disposal. J. Clean. Prod. 279, 123854 https://doi.org/10.1016/j.jclepro.2020.123854.

Chen, X.D., Geng, Y., Fujita, T., 2010. An overview of municipal solid waste management in China. Waste Manag. 30, 716–724. https://doi.org/10.1016/j.wasman.2009.10.011.

Chen, X., Huang, G., Zhao, S., Cheng, G., Wu, Y., Zhu, H., 2017a. Municipal solid waste management planning for Xiamen City, China: a stochastic fractional inventory-theory-based approach. Environ. Sci. Pollut. Res. 24, 24243–24260. https://doi.org/10.1007/s11356-017-0027-x.

Chen, X., Huang, G., Zhao, S., Cheng, G. Wu Y., Zhu, H., 2017b. Municipal solid waste management planning for Xiamen, China: a stochastic fractional inventory-theory-based approach. Environ. Sci. Pollut. Res. 24, 24243–24260. https://doi.org/10.1007/s11356-017-0027-x.

Chen, D.M., Bodirsky, B.L., Krueger, T., Mishra, A., Popp, A., 2020. The world's growing municipal solid waste: trends and impacts. Environ. Res. Lett. 15, 074021 https://doi.org/10.1088/1748-9326/ab8659.

Cheng, Z.H.K., 2017. Study of Policies and Regulations for Waste Management in China and Potential for Application in the US (MSc. Thesis). Columbia University (US).

Chung, S.S., Poon, C.S., 1998. A comparison of waste management in Guangzhou and Hong Kong. Resour. Conserv. Recycl. 22, 203–216. https://doi.org/10.1016/S0921-3449(98)00013-5.

Cloirec, P.L., 2012. Treatments of polluted emissions from incinerator gases: a succinct review. Rev. Environ. Sci. Technol. 11, 381–392. https://doi.org/10.1007/s11157-012-9265-z.

Dan, C., Han, M.S., Chen, W., 2021. Power generation from municipal solid waste landfilled in the Beijing-Tianjin-Hebei region. Energy 217, 119393. https://doi.org/10.1016/j.energy.2020.119393.

Fabian, N., Lou, L.I.T., 2019. The struggle for sustainable waste management in Hong Kong: 1950s–2010s. World Waste.: J. Interdiscipl. Stud. 2, 10. https://doi.org/10.5334/wwwj.40.

Ferronato, N., Torretta, V., 2019. Waste mismanagement in developing countries: a review of global issues. Int. J. Environ. Res. Publ. Health 16, 1060. https://doi.org/10.3390/ijerph16061060.

Fu, D., Kurniawan, T.A., Avtar, R., Xu, P., Othman, M.H.D., 2021. Recovering heavy metals from electroplating wastewater and their conversion into $Zn_2Cr$-layered double hydroxide (LDH) for pyrophosphate removal from industrial wastewater. Chemosphere 271, 129861. https://doi.org/10.1016/j.chemosphere.2021.129861.

Gosh, S.K., 2016. Sustainable SWM in developing countries focusing on faster growing economies, India and China. Proc. Environ. Sci. 35, 176–184. https://doi.org/10.1016/j.proenv.2016.07.073.

Gu, Y., Zhou, G., Wu, Y., Xu, M., Chang, T., Gong, Y., Zuo, T., 2020. Environmental performance analysis on resource multiple-life-cycle recycling system: evidence from waste pet bottles in China. Resour. Conserv. Recycl., 104821 https://doi.org/10.1016/j.resconrec.2020.104821.

He, C., Fu, Y., 2021. Why does waste separation policy vary across different Chinese cities? A configurational analysis of the pilot scheme. J. Clean. Prod. 283, 124613 https://doi.org/10.1016/j.jclepro.2020.124613.

Hong Kong Environmental Protection Department, 1998. Monitoring of Solid Waste in Hong Kong, Waste Statistics for 1997. Available from: https://www.wastereduction.gov.hk/en/assistance.wizard/waste_red_sat.htm. (Accessed 20 August 2015).

Hong Kong Environmental Protection Department, 2005a. A Policy Framework for the Management of Municipal Solid Waste (2005-2014). Available from: http://www.epd.gov.hk/epd/msw/htm.en/content.htm. (Accessed 23 August 2020).

Hong Kong Environmental Protection Department, 2005b. Monitoring of Solid Waste in Hong Kong, Waste Statistics for 2004. Available from: https://www.wastereduction.gov.hk/en/assistance wizard/waste_red_sat.htm. (Accessed 20 August 2015).

Hong Kong Environmental Protection Department, 2019. Monitoring of Solid Waste in Hong Kong, Waste Statistics for 2018. Available from: https://www.wastereduction.gov.hk/en/assistance.wizard/waste_red_sat.htm. (Accessed 23 August 2020).

Hong Kong Environmental Protection Department, 2011. Monitoring of Solid Waste in Hong Kong, Waste Statistics for 2010. Available from: https://www.wastereduction.gov.hk/en/assistance wizard/waste_red_sat.htm. (Accessed 23 August 2020).

Hong Kong Environmental Protection Department, 2013. Hong Kong Blueprint for Sustainable Use of Resources 2013-2022.

Hong Kong Environmental Protection Department, 2020a. Hong Kong Waste Treatment and Disposal Statistics. Available from: http://www.epd.gov.hk/epd/tc_chi/environmentinhk/waste/data/stat_treat.html. (Accessed 23 August 2020).

Hong Kong Environmental Protection Department, 2020b. Monitoring of Solid Waste in Hong Kong, Waste Statistics for 2020. Available from: https://www.wastereduction.gov.hk/en/assistance wizard/waste_red_sat.htm. (Accessed 20

August 2020).
Huang, C.L., Yu, C.P., Lin, T., Ye, Z., 2016. Water conservation significance of municipal solid waste management: a case of Xiamen in China. J. Clean. Prod. 129 https://doi.org/10.1016/j.jclepro.2016.03.062, 693-303.
Huang, L., Zhen, L., Yin, L., 2020. Waste material recycling and exchanging decisions for industrial symbiosis network optimization. J. Clean. Prod. 276, 124073. https://doi.org/10.1016/j.jclepro.2020.124073.
Ibrahim, M.A., 2020. Modeling of risk for improper sorting of waste at Recycling Centers. Waste Manag. 102, 550–560. https://doi.org/10.1016/j.wasman.2019.11.017.
Jain, S., Singhal, S., Pandey, S., 2020. Environmental life cycle assessment of construction and demolition waste recycling: a case of urban India. Resour. Conserv. Recycl. 155, 104642 https://doi.org/10.1016/j.resconrec.2019.104642.
Kaza, S., Lisa, Y., Bhada-Tata, P., Van Woerden, F., 2018. What a Waste 2.0: A Global Snapshot of Solid Waste Management to 2050. Urban Development Series, Washington DC. https://doi.org/10.1596/978-1-4648-1329-0.
Kurniawan, T.A., de Oliveira, J.P., 2014. Technology adaptation and assimilation of Takakura for promoting environmental protection in Surabaya (Indonesia) through city level cooperation. In: Brust, D.V., Sarkis, J., Cordeiro, J.J. (Eds.), Collaboration for Sustainability and Innovation: A Role for Sustainability Driven by the Global South? Springer Verlag, ISBN 978-94-007-7632-6, pp. 177–192. https://doi.org/10.1007/978-94-007-7633-3_9.
Kurniawan, T.A., Lo, W.H.L., Repo, E., Sillanpaa, M., 2010. Removal of 4-chlorophenol from contaminated water using coconut shell waste pretreated with chemical agents. J. Chem. Technol. Biotechnol. 85, 1616–1627. https://doi.org/10.1002/jctb.2473.
Kurniawan, T.A., Lo, W.H., Sillanpaa, M., 2011. Treatment of contaminated water laden with 4-chlorophenol using coconut shell waste-based activated carbon modified with chemical agents. Separ. Sci. Technol. 46, 460–472. https://doi.org/10.1080/01496395.2010.512030.
Kurniawan, T.A., de Oliveira, J.P., Premakumara, D.G.J., Nagaishi, M., 2013. City-to-city level cooperation for generation urban co-benefits: the case of technological cooperation in waste sector between Surabaya (Indonesia) and Kitakyushu (Japan). J. Clean. Prod. 58, 43–50. https://doi.org/10.1016/j.jclepro.2013.08.002.
Kurniawan, T.A., Avtar, R., Singh, D., Xue, W., Othman, M.H.D., Goh, H.H., Iswanto, I., Kern, A.O., Albadarin, A.B., 2021a. Reforming MSWM in Sukunan (Yogjakarta, Indonesia): a case-study of applying a zero-waste approach based on circular economy paradigm. J. Clean. Prod. 284, 124775 https://doi.org/10.1016/j.jclepro.2020.124775.
Kurniawan, T.A., Singh, D., Avtar, R., Othman, M.H.D., Hwang, G.H., Albadarin, A.B., Rezakazemi, M., Setiadi, T., Shirazian, S., 2021b. Resource recovery from landfill leachate: An experimental investigation and perspectives. Chemosphere 274, 129986. https://doi.org/10.1016/j.chemosphere.2021.
Lam, P.T.I., Yang, H.X., Yu, J.S., 2017. Critical success factors for integrating renewable energy development in a country with 2 systems: the case of Pearl River Delta and Hong Kong SAR in China. Energy Pol. 107, 480–487. https://doi.org/10.1016/j.enpol.2017.05.024.
Lebreton, L., Andrady, A., 2019. Future scenarios of global plastic waste generation and disposal. Palgrave Commun 5, 6. https://doi.org/10.1057/s41599-018-0212-7.
Li, W., Lin, W., 2016. Circular economy policies in China. In: Anbumozhi, V., Kim, J. (Eds.), *Towards a Circular Economy: Corporate Management And Policy Pathways.* ERIA Research Project Report 2014-2044. ERIA, Jakarta, pp. 95–111.
Li, Y.W., Homburg, V., Jong, M., Koppenjan, J., 2016. Government responses to environmental conflicts in urban China: the case of the Panyu waste incineration power plant in Guangzhou. J. Clean. Prod. 134, 354–361. https://doi.org/10.1016/j.jclepro.2015.10.123.
Liu, M., Tan, S., Zhang, M., He, G., Chen, Z., Fu, Z., Luan, C., 2020. Waste paper recycling decision system based on material flow analysis and life cycle assessment: a case study of waste paper recycling from China. J. Environ. Manag. 255, 109859 https://doi.org/10.1016/j.jenvman.2019.109859.
Luttenberger, L.R., 2020. Waste management challenges in transition to circular economy – case of Croatia. J. Clean. Prod. 256, 120495 https://doi.org/10.1016/j.jclepro.2020.120495.
Matthew, J.A., Tan, H., 2016. Circular economy: lessons from China. Nature 531, 440–442. https://doi.org/10.1038/531440a.
Meys, R., Frick, F., Westhues, S., Sternberg, A., Klankermayer, J., Bardow, A., 2020. Towards a circular economy for plastic packaging wastes – the environmental potential of chemical recycling. Resour. Conserv. Recycl. 162, 105010 https://doi.org/10.1016/j.resconrec.2020.105010.
Mian, M.M., Zeng, X., Nasry Al-Hamadani, S.M.Z.F., 2016. Municipal solid waste management in China: a comparative analysis. J. Mater. Cycles Waste Manag. 19, 1127–1135. https://doi.org/10.1007/s10163-016-0509-9.
Ministry of Environmental Protection of PR China, 2019. The annual municipal solid waste pollution prevention report in large and medium city. Available from: http://zls.mep.gov.cn/hjtj/nb/2013tjnb/201411/t20141124_291866. (Accessed 23 August 2020).
National Bureau of Statistics of China (NBS), 2020. The national economic and social development statistical bulletin in 2020. Available from: http://www.stats.gov.cn/tjsj/zxfb/201502/t20150226_685799.html. (Accessed 22 August 2020).
Nizetic, S., Solic, P., Artaza, D.L.G., Patrono, L., 2020. Internet of Things (IoT): opportunities, issues and challenges towards a smart and sustainable future. J. Clean. Prod. 274, 122877. https://doi.org/10.1016/j.jclepro.2020.122877.
National People's Congress of PR China (NPC), 2005. Law on solid waste pollution and its prevention of people's Republic of China. Available from: http://www.npc.gov.cn/wxzl/wxzl/2003-08/12/content_318892.htm. (Accessed 22 August 2020).
National People's Congress of PR China (NPC), 2008. Law of people's Republic of China on circular economy promotion. Available from: http://www.gov.cn/flfg/2008-08/29/content_1084355.htm. (Accessed 22 August 2020).
National People's Congress of PR China (NPC), 2013. Law on solid waste pollution and its prevention of the people's Republic of China. Available from: http://www.npc.gov.cn/wxzl/gongbao/2013-10/22/content_1811015.htm. (Accessed 28 July 2015).
Planning, Environment & Lands Branch (PELB), 1989. Waste Disposal Plan for Hong Kong. Government Secretariat, Hong Kong.
Pan, S.Y., Du, M.A., Huang, I.T., Chang, E.E., Chiang, P.C., 2021. Strategies on implementation of waste-to-energy (WTE) supply chain for circular economy system: a review. J. Clean. Prod. 108, 409–421. https://doi.org/10.1016/j.jclepro.2015.06.124.
Pesce, M., Tamai, I., Guo, D., Critto, A., Brombal, D., Wang, X., Cheng, H., Marcomini, A., 2020. Circular economy in China: translating principles into practice. Sustainability 12, 832. https://doi.org/10.3390/su12030832.
Peters, B., Kiratli, N., Semeijn, J., 2019. A barrier analysis for distributed recycling of 3D printing waste: taking the maker movement perspective. J. Clean. Prod. 241, 118313. https://doi.org/10.1016/j.jclepro.2019.118313.
Premakumara, D.G.J., Canete, A.M.L., Nagaishi, M., Kurniawan, T.A., 2014. Policy implementation of the republic act (RA) No. 9003 in the Philippines: a case study of cebu city. Waste Manag. 34, 971–979. https://doi.org/10.1016/j.wasman.2013.10.040.
Qiao, L., Liu, D., Yuan, X., Wang, Q., Ma, Q., 2020. Generation and prediction of construction and demolition waste using exponential smoothing method: a case study of Shandong province, China. Sustainability 12, 5094. https://doi.org/10.3390/su12125094.
Qu, C., Shao, J., Cheng, Z., 2020. Can embedding in global value chain drive green growth in China's manufacturing industry? J. Clean. Prod. 268, 121962. https://doi.org/10.1016/j.jclepro.2020.121962.
Roberts, R.J., Chen, M., 2006. Waste incineration—how big is the health risk? A quantitative method to allow comparison with other health risks. J. Public Health 28, 261–266. https://doi.org/10.1093/pubmed/fdl037.
Rodic, L., Wilson, D.C., 2017. Resolving governance issues to achieve priority sustainable development goals related to solid waste management in developing countries. Sustainability 9, 404. https://doi.org/10.3390/su9030404.
Romanelli, A.M., Bianchi, F., Curzio, O., Minichilli, F., 2019. Mortality and morbidity in a population exposed to emission from a municipal waste incinerator. A retrospective cohort study. Int. J. Environ. Res. Publ. Health 16, 2863. https://doi.org/10.3390/ijerph16162863.
Sarc, R., Curtis, A., Kandlbauer, L., Khodier, K., Lorber, K.E., Pomberger, R., 2019. Digitalization and intelligent robotics in value chain of circular economy oriented waste management – a review. Waste Manag. 95, 476–492. https://doi.org/10.1016/j.wasman.2019.06.035.
State Environmental Protection Association (SEPA), 2014. The publicity of final accounts of ministry of environmental protection department in 2014. Available from: http://www.mep.gov.cn/zwgk/czzj/zhxx/. (Accessed 23 August 2020).
Shittu, O.S., Williams, I.D., Shawm, P.J., 2021. Global E-waste management: can WEEE make a difference? A review of e-waste trends, legislation, contemporary issues and future challenges. Waste Manag. 120, 549–563. https://doi.org/10.1016/j.wasman.2020.10.016.
Singh, J., Laurenti, R., Sinha, R., Frostell, B., 2014. Progress and challenges to the global waste management system. Waste Manag. Res. 32, 800–812. https://doi.org/10.1177/0734242X14537868.
Singh, N., Tang, Y., Zhang, Z., Zheng, C., 2020. COVID-19 waste management: effective and successful measures in Wuhan, China. Resource, Conserv. Recyl. 163, 105071. https://doi.org/10.1016/j.resconrec.2020.105071.
Sun, L., Zhu, D., Chan, H.W., 2016. Public participation impact on environment NIMBY conflict and environmental conflict management: comparative analysis in Shanghai and Hong Kong. Land Use Pol. 58, 208–217. https://doi.org/10.1016/j.landusepol.2016.07.025.
Tao, H., Wu, Y.P., Zhang, L.Y., 2006. Environmental governance analysis of China's solid wastes management. Res. Environ. Res. 19, 33–39. https://doi.org/10.1007/s11783-007-0066-5.
Taveres, G., Zsgraiova, Z., Semiao, V., Carvalho, M.G., 2009. Optimization of MSW collection routes for minimum fuel consumption using 3D GIS modelling. Waste Manag. 29, 1176–1185. https://doi.org/10.1016/j.wasman.2008.07.013.
Titto, E., Savino, A., 2019. Environmental and health risks related to waste incineration. Waste Manag. Res. 1–11. https://doi.org/10.1177/0734242X19859700.
Troschinetz, A.M., Mihelcic, J.R., 2009. Sustainable recycling of municipal solid waste in developing countries. Waste Manag. 29, 915–931. https://doi.org/10.1016/j.wasman.2008.04.016.
Vause, J., Gao, L.J., Shi, L.Y., 2013. Production and consumption accounting of $CO_2$ emissions for Xiamen, China. Energy Pol. 60, 697–704. https://doi.org/10.1016/j.enpol.2013.04.069.
Xiamen Bureau of Environmental Protection, 2014a. Environmental Quality Bulletin 1996-2014.
Xiamen Bureau of Environmental Protection (XMEPB), 2014b. Environment quality bulletin in 2014. Available from: http://www.xm.gov.cn/zwgk/hjbfxx/hjzlgb/201506/t20150608_1128062.htm. (Accessed 12 July 2020).
Xiamen Bureau of Environmental Protection, Xiamen Municipal Government, 2014. Xiamen Municipal Solid Waste Pollution Prevention in 2013. Available from:

http://www.xmepb.gov.cn/sj/Content.View.aspx?CmsList=256&CmsID=1. (Accessed 12 July 2020).
Xiamen Bureau of Statistics, 2013. The SAR Year Book for Xiamen 2013.
Xiamen Bureau of Statistics, 2014. The SAR Year Book for Xiamen 2014.
Xiamen Statistics Press, 2014. Yearbook of Xiamen Special Economic Zone 2014.
Xiao, S., Dong, H., Geng, Y., Fransisco, M.J., Pan, H., Wu, F., 2020. An overview of the municipal solid waste management modes and innovations in Shanghai, China. Environ. Sci. Pollut. Res. 27, 29943–29953. https://doi.org/10.1007/s11356-020-09398-5.
Xiamen Bureau of Environmental Protection (XMEPB), 2008. Function of institutions: solid waste management administration. Available from: http://www.xmepb.gov.cn/sj/ContentView2.aspx?CmsList=63&CmsID=10. (Accessed 12 July 2020).
Standing Committee of the Fujian People's Congress, XMEPB, 2019. Certain rules for the prevention and control of environmental pollution by solid waste in fujian province. Available from: http://www.xmepb.gov.cn/sj/ContentView.aspx?CmsList=142&CmsID=6. (Accessed 12 July 2020).
Xue, W.J., Cao, K., Li, W.W., 2015. Municipal solid waste collection optimization in Singapore. Appl. Geogr. 2015 (62), 182–190. https://doi.org/10.1016/j.apgeog.2015.04.002.
Yang, Q., Fu, L., Li, X., Cheng, M., 2018. Evaluating the efficiency of municipal solid waste management in China. Int. J. Environ. Res. Publ. Health 15, 2448. https://doi.org/10.3390/ijerph15112448.
Yu, S., Dong, H., 2020. Uncover cost-benefit disparity of municipal solid waste incineration in Chinese provinces. Sustainability 12, 697. https://doi.org/10.3390/su12020697.
Yu, Y., Cui, S.H., Lin, J.Y., Li, F., 2012. Study on greenhouse gas emissions from urban waste disposal System: a case study in Xiamen. Huanjing Kexue 33, 3288–3294.
Zhang, L., 2019. China: new waste-sorting rules to take effect in Shanghai. Available from: https://www.loc.gov/law/foreign-news/article/china-new-waste-sorting-rules-to-take-effect-in-shanghai/. (Accessed 12 February 2021).
Zhang, D.Q., Tan, S.K., Richard, M.G., 2010. Municipal solid waste management in China: status, problems and challenges. J. Environ. Manag. 91, 1623–1633. https://doi.org/10.1016/j.jenvman.2010.03.012.
Zhang, Z., Luo, X., Liu, C., Zhao, L., Jing, H., 2020a. Single stream or dual stream? A game-theoretic approach to the sustainable evolution in waste recycling systems. J. Clean. Prod. 269, 121847 https://doi.org/10.1016/j.jclepro.2020.121847.
Zhang, R., Ma, X., Shen, X., Zhai, Y., Zhang, T., Ji, C., Hong, J., 2020b. PET bottles recycling in China: an LCA coupled with LCC case study of blanket production made of waste PET bottles. J. Environ. Manag. 260, 110062 https://doi.org/10.1016/j.jenvman.2019.110062.
Zhou, B., Sun, C., Yi, H., 2017. Solid waste disposal in Chinese cities: an evaluation of local performance. Sustainability 9, 2234. https://doi.org/10.3390/su9122234.
Zhou, M.H., Shen, S.L., Xu, Y.S., Zhou, A.N., 2019. New policy and implementation of municipal solid waste classification in Shanghai, China. Int. J. Environ. Res. Publ. Health 16, 3099. https://doi.org/10.3390/ijerph16173099.
Zhu, J., Fan, C., Shi, H., Shi, L., 2019a. Efforts for a circular economy in China: a comprehensive review of policies. J. Ind. Ecol. 23, 110–118. https://doi.org/10.1111/jiec.12754.
Zhu, M., Kurniawan, T.A., Fei, S., Ouyang, T., Othman, M.H.D., Rezakazemi, M., Shirazian, S., 2019b. Applicability of BaTiO3/graphene oxide composite for enhanced photodegradation of methylene blue in synthetic wastewater under UV–vis irradiation. Environ. Pollut. 255, 113182 https://doi.org/10.1016/j.envpol.2019.113182.
Zhu, M., Kurniawan, T.A., Avtar, R., Othman, M.H.D., Ouyang, T., Yujia, H., Xueting, Z., Setiadi, T., Iswanto, 2021. Applicability of $TiO_2$(B) nanosheets@hydrochar composites for adsorption of tetracycline from contaminated water. J. Hazard Mater. 405, 123999 https://doi.org/10.1016/j.jhazmat.2020.123999.