Disposal of Urban Wastes

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This is an update of Yu-Ting Tang, Chih Huang, Disposal of Urban Wastes, Editor(s): Martin A. Abraham, Encyclopedia of Sustainable Technologies, Elsevier, 2017, Pages 365–377, ISBN 9780128047927, https://doi.org/10.1016/B978-0-12-409548-9.10181-2.

Abstract

The role of solid waste management in sustainable development become increasingly important with the accelerating urbanization worldwide. The urban lifestyles produces waste in larger quantity and diverse quality. This phenomenon stimulates and challenges both the innovation of treatment technologies as well as the development of institutional and legislation instruments in regulating waste sorting at the point of collection, waste transportation and the integration of waste treatment technologies within an urban system. We argue that to achieve urban sustainability, designing a customized integrated waste management plan to suit socio-cultural contexts and economic capacity of a site of a city is the key. The indicators used for evaluating performance of such waste management plan may drive the direction of the waste management approach and should not only focus on one aspect of sustainability such as GHG emission though this environmental issues is shared globally. Further, the public education on waste sorting may be the key factor to optimize the expected outcome of an integrated waste management plan. Developed countries are more advantageous from this aspect of social development than the developing countries in achieving desirable outcome. To improve sustainability in waste management at global scale, some technology transfer from developed countries to developing countries can be helpful. However, affordability and site-specificity need to be taken into account.

Objectives

- Connecting social development and the transition of waste production
- Identifying the challenges in waste management given the ever diversifying content of the waste
- Highlight the needs for both treatment technology and institutional instrument in an integrated waste management plan

 doi:10.1016/B978-0-323-90386-8.00005-X

Introduction - The Scope of the Review

Waste treatment is highly related to sustainable development of human society. Improving solid waste management (SWM) may facilitate achieving sustainable development goals. As part of the effort to eliminate poor living conditions in urban slums and to improve the quality of urban development, a considerable amount of literature has been dedicated to the search of a good practice of SWM to improve the quality of life in countries where the urbanization rate accelerates at unprecedented speed. While, in a more developed countries, improving the quality or waste management is viewed as part of the effort to practice circular economy. By reviewing the current development of disposal and management of urban wastes, this article aims to identify the areas with the potential to improve the urban sustainability.

Background

Defining Municipal Solid Waste

Solid waste has been defined variably by institutions or individuals for management or academic research purposes. It can be regarded as the domestic and industrial refuse, garbage, or any disregarded materials produced in pursue of daily lives and industrial activities; it can be hazardous or nonhazardous. In the United States, the definition of solid wastes according to an important piece of regulation (*i.e.*, the Resource Conservation and Recovery Act, RCRA, title 40 of the Code of Federal Regulations, parts 239–282) (USEPA, 2016) includes not only the solid phase of waste materials but also sludge (from waste treatment plants), manufacturing process wastewaters and non-wastewater sludge, semisolid liquid, or even gases discharged from industrial and commercial activities. This overarching definition may have been for the convenience of regulating solid waste treatment: the wastes produced by human activities usually contain more than one phase; the chemical compositions are variable and the properties of matrixes are diverse.

Chronically, the definition of solid waste has been changing over time to fulfill the contemporary managerial purposes; it may reflect the contemporary opinions of who can be counted as "general public" (Cain, 2011) and what can be treated or needed to be treated as a relatively unseparated materials. For instance, the solid waste in the 1800s in the industrializing United Kingdom would include the human excreta (the so-called "night soil") (Atkinson *et al.*, 2012). By contrast, the World Bank (2012) nowadays considered solid waste as "any waste other than human excreta, urine and wastewater.." The changes of definition and perception of the solid waste affected the composition of the materials collected in the solid waste treatment facilities during different stages of development in a society. Specifically, this review focuses on the management of municipal solid waste (MSW) originated from urbanized areas. The issues in relation to wastewater discharge and treatment will be discussed in separate chapters of this encyclopedia.

What Makes MSW a Problem?

The composition of solid waste in rural area nowadays may approximate the types of the solid waste usually produced before industrialization. Based on the survey of Shah *et al.* (2012) in six villages in Tekanpur, India, the rural waste is composed primarily of street sweeping, grass cutting, agricultural waste, cattle dung, drain, and public toilet cleaning. They mostly are composed of biodegradable materials. Indeed, before the time of industrialization, quantity and quality of solid waste a community produced may not go beyond the natural capacities of biodegradation within a reasonable period of time. However, since the process of urbanization and industrialization, this becomes not the case. The cumulative waste produced by human society started to impact the environment that affects both ecosystem and human society. Some attempts to treat the waste might have created new social and environmental issues.

Urban and rural areas are primarily differentiated by the degree of agglomeration; the population size is a primary indicator of the size of a city or urban district. The density of urban area may affect the performance of a waste treatment plan. The appearing of urban clusters and the urban lifestyle have changed the composition of the quality and quantity of the wastes produced from a settlement, to which the waste treatment and disposal methods may need to be adopted over time.

The density of population, built up areas, or roads may affect the schedules and logistics of waste transportation as well as limit the land spaces used for establishing waste treatment facilities in urbanized areas. By contrast, the waste collection from the lower density urban, peri-urban, or intercity areas can be logistically ineffective because of the limited access of the road (Iriarte *et al.*, 2009; Ojewale, 2014). Furthermore, the effect of density may also interact with various socio-statuses, education levels, and life styles (e.g., Ojewale, 2014). The affluent high-density urban area is facing the challenge of increased quantity of waste partly due to the increasing consumption of imported products, while the poor high-density low-income settlements (could be slums) need immediate attention on the sanitary conditions due to the lack of or no solid waste disposal plans (Marshall and Farahbakhsh, 2013). The survey response rates of several studies indicated that, for the urban fringes or peri-urban areas where the development densities are low, the awareness of the importance of urban waste treatment is relatively low and residents are less than enthusiastic to respond to the questions regarding the urban waste treatment (Ojewale, 2014; Oteng-Ababio *et al.*, 2013). This attitude may also affect the effectiveness of the outreach activities promoting the awareness of waste sorting at the household level and the level of the cooperation to compliant with the waste and recyclables collection plans.

Thus, various urban setting may post different challenges for planning an effective strategy for urban waste disposal. The disposal plan has to be adaptive to the density of urban areas, the life style of the society, and the development status of the city.

Municipal Waste Disposal

Compositing, incinerating, and landfilling are the mainstream municipal waste treatment methods. Recently, additional thermal treatment processes have emerged as promising technologies for recovery energy from waste (Astrup *et al.*, 2015; Ephraim *et al.*, 2018; Pecchi and Baratieri, 2019); some technologies of converting the traditional landfill into a facilities where CH_4 can be harvested also reduce the GHG emission from the waste treatment (e.g., the case of Slovenia described in Malinauskaite *et al.*, 2017). Recycling is sometimes considered one of the "treatment" methods (Yadav and Samadder, 2015) while other time would be categorized as part of waste reduction plan. Aleluia and Ferrão (2016) provided similar classification but added a category of hybrid treatment. Each method suits specific types of the waste and has been applied in urban areas in various development stages and financial capacities. Recent literature has also shown that in addition to treatment method, an integrated plan is also critical for managing the waste in a way to make a city resilient.

Landfill

In terms of the waste treatment technology development, landfilling is the one step forward from the open dumping, a common method to "treat" MSW in ancient societies when the land resource could be considered almost infinite. Landfilling usually involves compressing and depositing the MSW in low-lying areas outside a city. A better-managed landfill or so-called sanitary landfill would be engineered to accommodate the local geological conditions and to prevent uncontrolled leaching. Upon depositing the waste, the sequence and compartmentalization are planned, and the waste received need to be properly compressed to reduce the spaces the waste occupies. The surface should be capped strategically to reduce the accessibility of waste to the pest and vermin. A proper sanitary and disinfection procedure such as spreading the disinfecting agents regularly may be implemented in a more advanced landfill. Furthermore, to collect the potentially toxic leachate from the landfill and gases discharged from the waste decomposing process, specialized collection systems may be installed (Nanda and Berruti, 2021). In particular, recently, collecting biogas from the landfill has become an alternative energy-generation technology (an example is provided by (Karagiannidis and Perkoulidis, 2009) and was implemented as the primary method to reduce the "landfill" rate among some developing EU member of state to fulfill the Directives related to waste treatment in the EU (Malinauskaite *et al.*, 2017). Arguably, this may potentially convert the landfill into a more sustainable facility with dual functions: waste burials and energy generations.

As landfilling is considered the treatment method with the lowest short-term economic cost, it has been used in developing countries intensively, though environmentally, it is probably the least preferred option. Furthermore, the land resources that could have been planned for other beneficial uses during the urbanization process can be quickly occupied by the wastes. In the developed countries, landfills are usually reserved only for the ashes after the incineration process, or non-biodegradable and non-recyclable materials. By contrast, some of the less-developed countries or cities struggle for establishing sanitary landfill for MSW (Brunner and Fellner, 2007; Aleluia and Ferrão, 2016). This increases the risk for public health affected by an uncontrolled release of toxic substances as well as pathogens spreading contagious disease.

Incineration and thermal processing

Incineration is a process to digest (combust) solid waste under a controlled condition. This is different from the uncontrolled burning or degradation in the open space. For example, an excessive amount of methane, a potent greenhouse gases (20 years GWP 86), together with other sulfurases gases is often produced after decomposition of the biodegradable waste in open dumps.

The temperature of the incinerating process is usually maintained between 1000°C and 2000°C. Under such high temperature, most of the organic compositions may be completely oxidized, and carbon dioxide, a less potent greenhouse gas (1 GWP), would be generated. On the other hand, the air pollutants such as dioxins and PCB may be generated and emitted from the incineration process if the burning process is not well controlled. This is an environmental issue that the neighborhood would rather keep distance from.

The advantages of this method are the reduction of waste volume by 80% to 90% (Cheremisinoff, 2003; Xin-gang *et al.*, 2016); the land resource is conserved, and the ashes produced are absolutely sterile. Further, as the technologies developed, the heat generated from burning also can be harvested as a form of energy (e.g., Spittelau incineration plant in Vienna and (Brunner and Rechberger, 2015; Astrup *et al.*, 2015; Jo *et al.*, 2016). These facilities for incinerating municipal wastes with energy generation capacities or heat supply capacities can be named as waste-to-energy plants. However, the efficiency of thermal processing is greatly affected by the composition of the waste (Brunner and Rechberger, 2015). Organic fractions of the waste with high moisture content or low calorific value will hinder the thermal process; more energy supplies will be needed in order to initiate the burning and to ensure the complete burning and oxidation that prevent the toxic substance generation. The benefits of thermal energy production will then be compromised. Thus, to reduce the risk of toxic gases emission and enhance the waste-to-energy efficiency, sorting and then selecting the waste to be incinerated becomes very important (Wang *et al.*, 2021).

Theoretically, the waste with water content occupied less than 50% of its weight, with combustible fraction higher than 25% as well as ignition residuals (ashes) less than 60%, may be "feasible for combustion without auxiliary fuel" (Rand *et al.*, 2000, p. 12). In this case, the organic waste such as garden waste and food waste cannot fulfill the criteria to be the fuel for thermal energy generation.

Furthermore, the calorific values of the combustible portion dictate the burning efficiency. In general, the burning efficiencies of plastics, leather and rubber, and textile may be better than wood and paper despite that they all fulfill the earlier-mentioned criteria for combustion without auxiliary fuel (Wang *et al.*, 2021).

Recently, thermal processes named pyrolysis and gasification were recommended to be commercially applied in the waste treatment process (Kothari *et al.*, 2010). Different from the concept of recovering energy directly during the incineration process, these thermal processes carried out under relatively anaerobic conditions and at lower temperatures (several hundred Celsius degrees) may yield a storable and transportable fuel (char, oil, or gases) (e.g., Dobele *et al.*, 2007). The processes are claimed to be more environmentally friendly for lower energy consumption, lower emission of greenhouse gases, or toxic substances (e.g., dioxin or PCB) (Samolada and Zabaniotou, 2014). However, the process required more refined raw materials for quality end products (Bridgewater, 1980; Astrup *et al.*, 2015; Brunner and Rechberger, 2015). Some pretreatment of the wet biomass such as hydrothermal carbonization or modified process such as steam gasification has been developed for reducing the threshold of applying the technologies (Lin *et al.*, 2016).

Biological treatment

The kitchen (food) waste or to some extent, the garden waste, is more suitable to be subjected to a biological process named anaerobic digestion. Namely, the organic content rich materials are undergone a process of biodegradation under an anaerobic condition. The process generates methane rich biogas that can be used as fuel and the digestants that can be applied to soil as fertilizers or soil conditioners after maturation. This biological treatment may harvest both energy and resources from the waste materials. However, the process take much longer in comparison to the anaerobic thermal processes mentioned above (Potts and Martin, 2009). A recent development is to couple anaerobic digestion with those physical/chemical thermal process to hopefully extract more energy rich materials (mainly biogas) from the waste materials as part of the effort to produce renewable energy (Pecchi and Baratieri, 2019). The design of this combination of process, is also affected by the composition of the wastes.

Composting is a traditional treatment for organic waste that has been practiced for the longest time in human society since agricultural stage of civilization. The power of decomposers and natural fermentation processes under appropriate conditions may be utilized to transform waste with high organic content into fertilizer of high agricultural values (Onwosi *et al.*, 2017). The issues of applying composting to treat urban solid waste would be the increasing amount of non-biodegradable components in the mixture of the waste as described in the later section (Sustainability Challenges).

Overall, using waste as substrates to be biologically metabolized is a promising methods for resources and energy recovery. However, sorting before treating the urban solid waste becomes critical for improving the quality of the product. A "quality control" becomes important during the waste collection and pre-treatment.

Recycling

Recycling is not a new concept in human history. People looked for valuable resources and materials from used items (such as scrap metals, empty bottles, or used paper) when the raw materials in demand were scarce. Thus, initially and historically, the motivation of recycling is rather economically driven. Until today, the economic incentives are still playing important roles in the development of curtain recycling businesses specializing in recovery materials such as electronic devices. For example, despite increasing amount of used mobile annually in the markets, the profit margin of recovering the precious metals such as gold from the abandoned mobiles had been decreasing during early 2000s (Geyer and Blass, 2010). Thus, it was believed that the recycling industry of the mobiles in the United States may have been better supported by the profit margin produced by consumers buying the refurbished second-hand mobiles.

Indeed, the review by Tonjes and Mallikarjun (2013) on the economic models run for evaluating the cost-effectiveness of recycling indicates that it is more possible to consider recycling the MSW "profitable" when adding the consideration of the cost saving for landfilling those recycled materials if they were not recycled. The major private companies for waste management in the United States claimed that the profit of recycling is uncertain and strongly depends on the price of commodities (Kanellos, 2013). If the business model of a private manufacturing is considered, recycling business is hardly the profitable industry.

Therefore, a comprehensive recycling program in a municipality usually has to be regulated or run by local governments alongside with the municipal waste collection. From the position of the government, it is easier to see the benefit of recycling, taking into account the externalized environmental cost by not recycling the resources from the municipal waste. Other recycling programs that incentivize the recycling behaviors include offering subsidies for recycling. For example, in recent years, the Chinese government has set up a system to officially subsidize consumers who turn in the e-waste while buying new electronic devices, the e-waste collectors, as well as the e-waste dismantling enterprises, to facilitate the recycling as well as resources recovery (Cao *et al.*, 2016). However, the amount of the subsidies is disproportionally higher than the tax revenue collected from the e-product manufactures. Thus, general taxpayers have been sharing the financial burden of the subsidies through Chinese government. Though subsidies may incentivize recycling and resource recovering from the e-waste, and thus it is worthwhile for the government to invest taxpayers' money to initiate and promote the development of the recycling industry, a more self-sustained business model may be needed for the recycling business from the long-term perspectives.

The review and additional modeling work conducted by Tonjes and Mallikarjun (2013) also indicated that the quality of sorting work done prior to the waste collection as well as the arrangement of waste collection affected the results of the cost-effectiveness of the ensuing recycling activities significantly. The ill-sorted waste will increase the cost of pretreatment in the recycling facilities and potentially reduce the quality of the end products that can be used for manufacturing new products. In developed countries, a variety of separation techniques are being developed or already commercially available to identify the recyclable materials based on their chemical–physical properties (e.g., magneticity, density, shape, or size). The performance of these techniques still relies on the degrees of the presorting work (Gundupalli *et al.*, 2017). The solid wastes collected in the developing countries are not usually well-sorted. Thus these technologies are not yet very helpful to improve the effectiveness of recycling of the developing countries. This somewhat implies that the education and policy incentives to encourage people to sort the waste at household level may be one of the keys to the improvement of the economic sustainability for the recycling. On the other hand, an effective logistic plan can also reduce the energy cost and environmental impact of transporting waste.

Thus, technology development for designing a more efficient waste collection system, resource recovery process, as well as the auditing procedure for the good practice of recycling industry may be helpful to reduce the cost (environmental and economic) of recycling. This may indirectly promote the recycling business.

Behaviors/Institutional control

The performances of treatment technologies described above does not only rely on the technological sophistication of the treatment facilities but also depends on the quality of the raw waste. Thus, the effort and efficiency in waste classification at sources may be considered important for the sustainability of the waste management.

Apart from industrial recycling process, gradually, many municipalities are now developing a waste collection system to facilitate waste sorting at the point of collection (more than likely, the households). This requires quite a comprehensive promotion and public education regarding the method of waste classification and schedule of waste collection (Moustairas *et al.*, 2022). The waste classification depends on waste treatment plan by the municipality. For example, in some cities, plastic is considered a materially recyclable product while others, this is the type of waste to be incinerated for producing energy because of its high heater value. Thus, the public communication regarding how the waste can be sorted and collected may be quite specialized.

In the experience of Nottingham city in England, the recycling plan of the city starting from fewer types to more detail classification and from smaller metropolitan to wider areas over the 20 years of the study (Wang *et al.*, 2022). The recycling plan still needs further improvement to separate the food waste from the waste to be incinerated from energy. Even for the developed country, nurturing the habit of conducting household recycling takes time. The difficulties of encouraging recycling may be increasingly difficult; researches indicated that the factors related to economic status and social development affected the willingness and feasibility of individual to perform recycling (Strydom, 2018; Knickmeyer, 2020; Moustairas *et al.*, 2022). Even in some states in the United States as a developed country, the waste separation only happens after the waste collection in the waste processing process; there is no federal law to enforce waste classification.

Integrating methods

Considering the ever-expanding urban areas, especially in the developing countries, dumping the municipal waste outside of the city boundary and waiting for biodegradation and weathering to do their wonders are not practical any longer. The peri-urban areas or rural areas adjacent to the fringe of the city may become part of the urban settlement in the foreseeable future. Furthermore, characteristics and quantity of the urban waste have been changing as residents adapt to urban lifestyles. The proportions of natural and biodegradable waste are decreasing and the weathered chemical leaching from the artificial materials may pose environmental and health threats (Joint UNEP/OCHA Environment Unit, 2011), especially for those newly urbanized areas that used to be the dumping ground of the wastes.

As the type of the waste is increasingly diversified, especially in the emerging economy and developed countries (see section "Sustainability Challenges"), combination treatment methods may be needed if each types of the MSW is to be properly treated with minimized environmental impact. The population density and the ever expending metropolitan in developing countries make the logistic and waste collection a serious issue (Kundariya *et al.*, 2021). While, some of the cities in developed countries have been shrinking and aging, the compositions of the waste is also changing as the demography changing (Sun *et al.*, 2018). Thus, gradually, planning an integrated waste management process becomes an important part of managing a sustainable city (Santibañez-Aguilar *et al.*, 2013; Kůdela *et al.*, 2020). The treatment methods of the waste, through the most symbolic and intuitive subject in the center of waste treatment challenges, the logistics and public education regarding waste sorting and waste collection affect considerably the actual performance of a waste management system.

The integrated waste management system can be understood as combining several waste treatment methods to treat the MSW so that the waste with the complex compositions can all be treated with suitable methods for reducing cost as well as secondary pollution.

In the case of Nottingham in the UK, the waste treatment methods have evolved from mostly landfilling to waste to energy, in combination to waste valorization for fuel as well as recycling (Wang *et al.*, 2020). Sorting food waste from general waste has now become an important next step to improve the performance for waste to energy (Wang *et al.*, 2021). It is also noted that the range of waste collection of the city increase, the carbon emission from the vehicles that collect waste from household and transport waste between treatment facilities reach similar scale of that of the major treatment methods applied in the city (Wang *et al.*, 2022).

In the city of developing countries like Kuala Lumpur, Malaysia, based on the chronological statistics of the waste composition, waste treatment methods, are suggested to be transformed from landfill only to the combination of landfill, thermal treatment, biological treatment, and recycling (Xiang *et al.*, 2013). The promotion of this concept of integration has facilitated the evolution of the assessment models on the sustainability of waste treatment strategy to expand the boundary of assessment to before (e.g., collection and sorting), and after (e.g., energy recovery) the actual treatment of the waste (Morrissey and Browne, 2004). The relevant literature on the integrated waste treatment concept, again, has shown that to achieve the efficiency and effectiveness of solid waste treatment, and resources and energy recovery, the education of sorting and recycling in combination of well-designed collection regiment and system should be further integrated into waste management system (e.g., Song *et al.*, 2013; Sukholthaman and Sharp, 2016). The waste management should include collection, transportation, processing, recycling, or disposal (Ezebilo and Animasaum, 2011). Understanding local geography and demography is rather essential for designing an effective collection plan with high compliance. From this aspect, designing a sustainable SWM plan goes far beyond balancing environmental and economic benefit and cost. The social policy and spatial analyses in relation to waste collection may all play a part.

Sustainability Challenges

Compositions and Quantities of the MSW in Various Development Stages

As mentioned previously, the composition of MSW has been changing as the urban lifestyle encouraging mass consumption of manufacturing products emerged. For example, the use and dispose of nappies become a concern in developed countries much earlier than the developing countries (Reese *et al.*, 2015). In general, the areas with higher urban concentration or at an advanced development stage in a continent produced lower percentages of food wastes (Zhongming *et al.*, 2019; Kaza *et al.*, 2018) and higher percentages of plastics (e.g., 17.5% and 20.5% in Western Asia which cover Israel and Qatar, and Western Europe, respectively) (**Fig. 1**). These statistics reflect the increase in non-biodegradable composition in the waste as urbanization progressed. Further, the countries with higher gross domestic product per capita tend to produce larger amounts of solid waste per capita (Gundupalli *et al.*, 2017). Based on the dataset describing the MSW generation globally during 2010s, one person in high income countries on average generated slightly over 1.5 kg of waste per day, more than three times of that in low income courtiers (0.47 kg/capital per day) (Kaza *et al.*, 2018). At the municipality level, the amount of the waste produced per capita in the cities of a developed country (540 kg/year in Vienna 2002) is much larger than that of in the developing countries (240 kg/year in Damascus 2003 and 150 kg/year in Dhaka City, 2002) (Brunner and Fellner, 2007). Although some modern commercial products such as plastic bags now are also being widely used in the countryside and become the source of wastes, the proportion may be much less than that in the urban areas.

Similarly, at community levels, the economic development played a determining role in the changes in waste composition and quantity: wealthier urban residents "have more consumer goods in quick to dispose packages (as canned food and bottled drinks), thus have higher tendency to generate more solid waste materials than people who has less money (Ezebilo and Animasaum, 2011, p. 682). Within a demographically homogeneous area, region, or society, waste compositions also vary as the consequences of seasonal changes (Katsamaki *et al.*, 1998; Singhal *et al.*, 2021). The composition of the waste types may be differed among cities based on the dominant types of industry and this will also affect the effectiveness and the selection of waste management methods (Guerrero *et al.*, 2013).

Currently, the most significant changes in waste composition may be brought by the mass production of household appliances and IT products. In the early 2000s, already 8% of composition in the global MSW is considered e-waste (Widmer *et al.*, 2005); the estimation of 20–50 million metric tons of e-waste produced annually at the beginning of the millennium by (UNEP, 2005) has been exceeded before 2019 (Forti *et al.*, 2020; Shittu *et al.*, 2021). Since the trend of e-products sold, in-use as well as being disposed of have been increasing, the amount of e-waste is projected to further increase (Widmer *et al.*, 2005; Robinson, 2009; Islam *et al.*, 2021). Geographically, these e-wastes were produced primarily richer, more developed countries and they are composed of large household appliances and IT telecommunication equipment (Widmer *et al.*, 2005; Forti *et al.*, 2020). On the other hand, the growth of PC ownership per capital during the 1990s among the developing countries, such as China, have been skyrocketing and the increasing trend continued as IT technology and commerce advances in the region, especially in cities (Widmer *et al.*, 2005; Forti *et al.*, 2020). Although the e-waste production per capital in Asia (5.6 kg per capital) is still lower than that produced in Americas and Europe (13.3 kg and 16.2 kg per capital, respectively), the much larger population make Asia the region that produced highest amount of total e-waste. The continuously accumulated amount of e-wastes of the emerging economies may not be avoidable. Thus, the proper disposal, treatment and resource recovery of e-waste are the current issues for municipal waste management (Ikhlayel, 2018; Boubellouta and Kusch-Brandt, 2021).

In summary, the quantity and the characteristics of the MSW have been changing concurrently with the evolving human living style and social development. The alteration of the ratio between biodegradable and non-biodegradable wastes and the increasing fractions of e-waste both pose challenges to the selection of municipal waste treatment technologies. Moreover, the levels of urbanization may be diverse for a specific region or city, partly due to urban sprawl. A good understanding of the urban transition becomes critical in designing a suitable waste management system as part of sustainable urban metabolism.

What Makes a Waste Disposal Technology Sustainable?

Sustainable waste management

The most often referenced definition of sustainable development is from the Brundtland Report (World Commission on Environment and Development, 1987, Chapter 2 Section I).

The development meets the needs of the present without compromising the ability of future generation to meet their own needs.

The concept was proposed in response to the limited and uneven distribution of resources continuously being consumed by human society (Kates *et al.*, 2005). This often cited definition is vague and open to interpretation (Hopwood *et al.*, 2005); translating the definition in Brundtland Report into a feasible technical definition for practicing in specific areas are needed and could be quite diverse (Gibbs *et al.*, 1998; Eisner, 2007; Smardon, 2008).

In discussing how urban waste disposal technologies may promote sustainable development, it is recognized that one solution may not fit all, due to the complexity and variability of municipal wastes composition resulting from the geographical differences and development stages of communities. An adaptive and integrated management system to fulfill the needs of the society may be a more desirable solution.

Society, economy, and environment are collectively referred to as "sustainable triangle" (Munasinghe, 2002); balancing the three aspects of sustainability during the development is one of the criteria of sustainable development. In practicing SWM, during the 1990s, the consideration of sustainability was initially based on environmental benefit and economic cost of an integrated waste

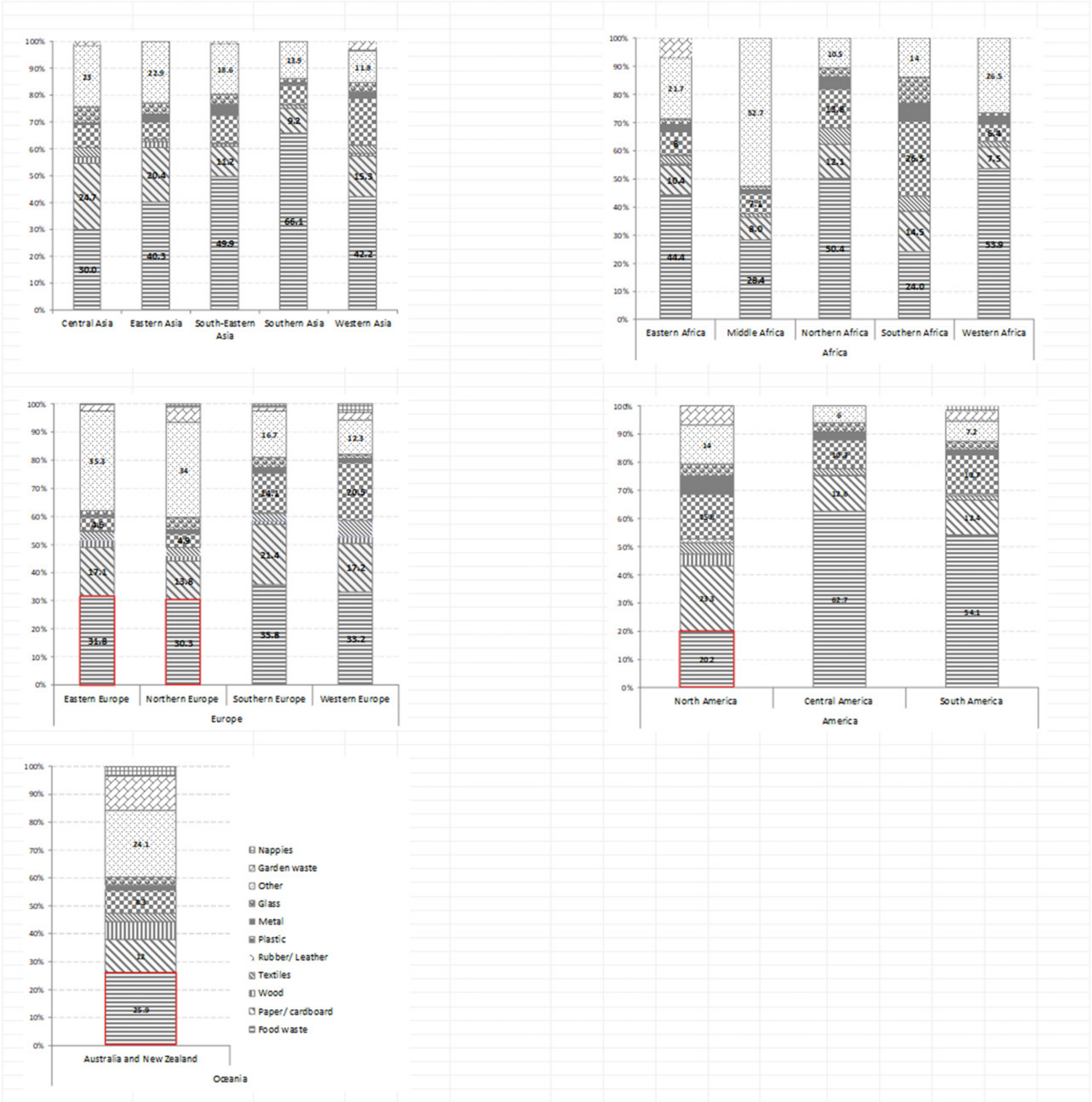

Fig. 1 Composition of solid waste from regions of the world during 2010s. Updated from IPCC, 2006. Chapter 2 Waste generation, composition and management data. In: Eggleston, H.S., Buendia, L., Miwa, K., Ngara, T., Tanabe, K. (eds.), IPCC Guidelines for National Greenhouse Gas 5, IGES. Zhongming, Z., Linong, L., Xiaona, Y., Wangqiang, Z., Wei, L., 2019. Refinement to the 2006 IPCC Guidelines for National Greenhouse Gas Inventories, Intergovernmental Panel on Climate Change.

management package including waste collection, waste treatment, as well as recycling; the social aspect of sustainability started to get noticed after 2000s (Morrissey and Browne, 2004). It is now suggested that adopting a strongly participatory, contextually grounded, complex, and adaptive system may help achieve a more sustainable strategy to manage solid waste; the appropriate solutions for handling waste greatly depend on the understanding of the interfaces and interactions between societies and environment (Marshall and Farahbakhsh, 2013). Because of the ever-evolving definition of sustainability as well as the development of society, the SWM plan initially considered as a sustainable waste management plan may later become undesirable (e.g., Corvellec *et al.*, 2013).

Yet, an institution capable of "mediating between the different sustainability dimensions" is essential to achieve the objectives of sustainable development (Thornton *et al.*, 2007, p. 51). From this line of thoughts, policy makers and planners, who usually have authority to design and dictating the implementation of the service package of a waste management plan, may be perceived as "the institution" which affects the degree of urban sustainability by designing and implementing the solid waste treatment plan.

On the other hand, recent case studies on solid waste treatment revealed that not only policy makers and planners but also other stakeholders such as generators of waste (e.g., households in the communities) and Non-Governmental Organizations (NGOs) can all be considered important, because their behavior and operation may affect the compositions of the solid waste as well as the efficiency of the waste collection and the performance of the ensuing treatment. In this way, they directly or indirectly influence the results of the implemented policy in relation to waste treatment (Guerrero *et al*., 2013; Soltani *et al*., 2015).

The conditions of the three aspects after implementing waste management plan reflect the performance of institutions in pursuing sustainable development. Often, techniques that do not seem directly relate to the waste treatment methods, but relate to the waste collection and resources recovery will affect the overall sustainability. The policy instrument (e.g., EPR, reviewed by Widmer *et al*., 2005), planning design, and even computer and remote sensing techniques (e.g., the logistic planning for waste treatment presented by de Oliveira Simonetto and Borenstein, 2007) may help make urban solid wastes management more efficient.

Based on the definition of sustainable development, the sustainable waste disposal should support an urban environment that is suitable for its citizen to live (current generation) and the impact of its treatment should not be externalized so that other groups living on earth suffered. Furthermore, the waste disposal should not sacrifice social, economic, and environmental resources for the future generation.

The ultimate answer to the sustainable waste management may therefore be the 100% circular economy. By practicing circular economy, the waste will no longer be stigmatized as useless and harmful substances. The treatment of the waste is always under the consideration of extracting as much resources as possible. Therefore, the final waste to be disposed may be minimized, and added economic values may be derived from the waste treatment process. The idea sounds straightforward but many need to be done in terms of technology development, institutional control, and waste transportation.

Waste management issues in three components in sustainable development

Sustainability cannot be evaluated without considering the background conditions of a society. However, the development status of a society continuously evolves. These dynamic conditions affect the types of the waste generated from the urban households as well as the applicability of the technology in response to the composition of the waste as well as the geographical conditions of the local environment.

Clift *et al*. (2000) recommend the life cycle assessment for evaluating integrated approaches for the waste treatment: the life cycle assessment is suitable for evaluating the applicability of various technologies in a specific location by evaluating the potential impact of inventoried materials (including emission) and energy flows in the foreground system (waste collection and treatment facilities) as well as background system (the surrounding urban setting, such as the characteristics of household, and types of energy supply of each technology). Indeed, in the past decades, life cycle assessment has been widely applied in evaluating the sustainability of waste management methods. In some cases, the economic benefits associated with the technologies were also presented (e.g., Mu *et al*., 2016; Ahamed *et al*., 2016). However, it is difficult to use this methodology for evaluating some of the important intangible factors considered important in the social sustainability. As our knowledge on waste management based mostly on the analytical results from the life cycle approaches (the entire cycle or part of the cycle). The limitation of the analyses in social sustainability for this section needs to be recognized.

(1) Environment

Patel *et al*. (2016) pointed out the current emphasis of LCA on waste treatment method comparisons:

Among the environmental effect categories, global warming potential is most stressed by different authors. But a complete LCA analysis should consider all three impact assessment categories (human health, ecosystem, and resource depletion).

Cleary (2009) also noted that acidification and global warming potential are the most often evaluated impacts in the life cycle assessment of MSW management system (19 out of 20 literatures reviewed by Cleary), while fewer than half of the literature has mentioned factors such as the toxicity of emissions or leachate to human or ecological systems. Further, direct land use change has been studied by a few authors, while indirect land use change is not a consideration in any of the reviewed papers.

From the aspect of comparability, it is reasonable to use GHG emission as the indicator, because the GHG emission concerns many of the international agreements. Thus, there is a regulatory need internationally for such evaluation. It is likely also because of this, the related data on the GHG emission are more available.

However, evaluating only one indicator for representing environmental sustainability may cause bias since different indicators may produce contrasting results as demonstrated by Cleary (2009). Thus, although LCA may be a suitable methodology, the current trend of using LCA may not be comprehensive enough for evaluating the overall environmental sustainability of integrated waste management strategy (Patel *et al*., 2016; Cleary, 2009).

Overall, even within the realm of environmental sustainability, to be comprehensive, considering a varieties of impacts at scale of sites, cities, and nations may be required. The uncertainty and site-specificity need to be recognized. As such, we almost need a matrix of evaluation to integrate a variety of aspects in environmental sustainability for a comprehensive understanding of the impacts. Within this matrix, multiple life cycle assessment (or life cycle impact assessment) will need to be conducted. Some life cycle software packages have provided the mechanisms of doing so. However, using them without understanding the default scenarios or underline assumptions will make the evaluation result unrealistic and even ungrounded. Further, the issues of data availability for evaluating life cycle based on other impacts than GHG emission made performing a comprehensive and integrated evaluation challenging.

(2) Social

Social sustainability emphasized by communities may vary (Muga and Mihelcic, 2008) depending on the current status of the society. Two mainstream aspects can be considered in the social sustainability of urban waste treatment technology. The first is the issue of maintaining public health. In quite a few developing countries, the open (or even illegal) dumping is still the primary method of urban waste disposal (Kaza *et al.*, 2018). This low-cost method cannot contain or stop the spreading of infectious diseases. The social and economic cost of human lives suffered from contracting the infectious diseases, however, is externalized and has not been properly quantified. Some of the waste treatment facilities may not be properly constructed, operated, or maintained. Thus, the emissions (air or leachate) pollute the environment which further impact public health. In this aspect, the social sustainability is interlinked with that of the environmental sustainability. In developed countries or a relatively affluent community, for the sake of amenities, the residents usually would prefer the waste treatment facilities to be far away from their residence (Marshall and Farahbakhsh, 2013). The degree of opposition to having a waste treatment facility nearby may be differed depending on the types of the treatment technologies (Lober and Green, 1994), but it was not necessarily consistent with the scientific understanding of the economic and environmental benefit of the technology. For example, the waste to energy plant (incinerator) was being rejected at higher percentages than the ash landfill (Lober and Green, 1994). This also echoes the point mentioned previously that investing in enhancing public understanding of the waste treatment is needed in order to improve the sustainability of SWM strategies (see section Behaviors/Institutional Control). The public engagement is also important for enhancing their cooperation in waste sorting or recycling at households or points of collections for ensuring optimizing outcome of ensuing waste treatment procedures.

(3) Economic
Economic sustainability or economic benefit of waste treatment technologies have been evaluated either via the idea of cost reduction in the form of energy consumption, land space acquiring and facility construction or the idea of revenue generation if the waste treatment process managed to generate energy (e.g., Woon and Lo, 2016), or recover resources (e.g., Mu *et al.*, 2016). In life cycle assessment, if the economic values are of concern, life cycle cost may be calculated, which may provide a more comprehensive view (Menikpura *et al.*, 2016).
Recently, the term "circular economy" becomes popular in the field of waste management. It is suggested that the economic value generated via options of treatments should be evaluated before the treatment plan is implemented. For example, both approaches of recycling and incinerating for energy may generate economic benefit while reducing landfill rate (e.g. Bergeron, 2017; Wang *et al.*, 2022). However, different municipality may maximizing the economic benefit by adapting either of the approaches. In some cases, importing waste from external to incinerate for energy in place of burning the coal can be considered more economical.

Therefore, it is recognized that the design of an integrated disposal plan that may contribute to urban sustainability highly depends on the geographic characteristics, resources availability, lifestyle, and development status of the areas. **Table 1** summarises, in general, the technical practicality for waste treatments. The comparison only points to a general direction but not a universal conclusion. Rather, this may direct attentions toward certain areas that can be considered innovatively improving the treatment methods for reducing the impact and even increasing the added value of the end products (materials or energy). Given the complexity of the aspects that can be considered in the sustainability, any technological improvements that may enhance the sustainability and reduce any controversy in the three components in sustainable development.

Technological Alternatives

Current Trends and Future Perspectives

Waste treatment hierarchy

(1) The Hierarchy
Current rule of thumb in evaluating how successful a waste treatment is and a disposal system would involve a concept or a model named waste treatment hierarchy (**Fig. 2**). The model places the management approaches and treatment methods considered more superior in terms of achieving sustainability on the top of a reverse triangle and least favored at the bottom. It is aspired that most of the waste can be handled using the methods at the upper layer of the hierarchy while only the trace of the residual needs to be handled using the least sustainable treatment methods. Usually, waste prevention is placed on the top of the triangle followed by recycling and reusing the second hand products. At the very end of the triangle is most certainly landfill. In between, a variety of treatment methods (such as those discussed in section "Municipal Waste Disposal") can be ranked based on how sustainable they are. Usually, the raw material extraction may come before the energy extraction. Only when both materials and energy s from the waste materials are exhausted, the residuals are disposed in the landfill.

(2) Alternative Considerations
The idea of hierarchy sounds quite logical. However, the ranking of the waste disposal methods regarding their levels of sustainability can depend on the indicators used in the evaluation as some methods may produce more GHG but leach very little into the groundwater while the other methods do the opposite (Tang, 2020). Their ranks on the triangle may vary. Currently, most of the hierarchy are based on the GHG emission.
The impacts a waste treatment method produced also are affected by the type of waste to be treated. This can be quite obviously demonstrated by a few types of food wastes or comparing the food waste and plastic (Department for Environment, Food and Rural Affairs, 2011). Thus, the generalized waste management hierarchy may not fit all.

Table 1 The Three aspects of sustainability for solid waste treatment technologies

Aspects in sustainability	*Technical consideration*	*Treatment*					*Alternative technology*	
		Open landfill	*Sanitary landfill*	*Composting*	*Incineration/Thermal process*	*Recycling*	*Spatial technology*	*Policy instrument*
Economic	Montary cost	Low	Relatively low	Relatively low	Relatively high	Could be a profitable business	Reduce cost during collection phase	Integrating technologies to reduce the direct and indirect cost
	Resources recovery	Little	Little	Good (agriculture values)	Little	High	NA	NA
	Energy recovery	Less possible	Potential (biogas collection)	Potential (biogas collection)	Potential (a.k.a waste-to-energy)	Little	Reduce energy consumption at waste collection	NA
Environment	Land resources demand	High	High	High	Relatively low	Medium	NA	NA
	Green house gass emission	Relatively high	Relatively high (if methane is not captured)	Relatively high	Relatively low (waste-to-energy can further reduce the impact)	Low	Reduce emmission during transpotation	As the indicator of the long term performance
	Rain acidification (SO_2 emission)	Relatively high	Relatively high	Relatively high	Relatively low	Low	Reduce emmission during transpotation	As the indicator of the long term performance
	Health effect on toxic substance	High risk	Controllable risk	Controllable risk	Controllable risk	To specific occupation	NA	NA
Social	Contagious disease	High risk	Controllable risk	Controllable risk	Low risk (sterilized end product)	Controllable risk	NA	NA
	Requirement of education on sorting	Low	Some	Relatively high	Relatively high	High	High	Can the be action point for the policy implementation
	Not In My Back Yard (NIMBY)	High	High	High	High	Could be low	NA	NA

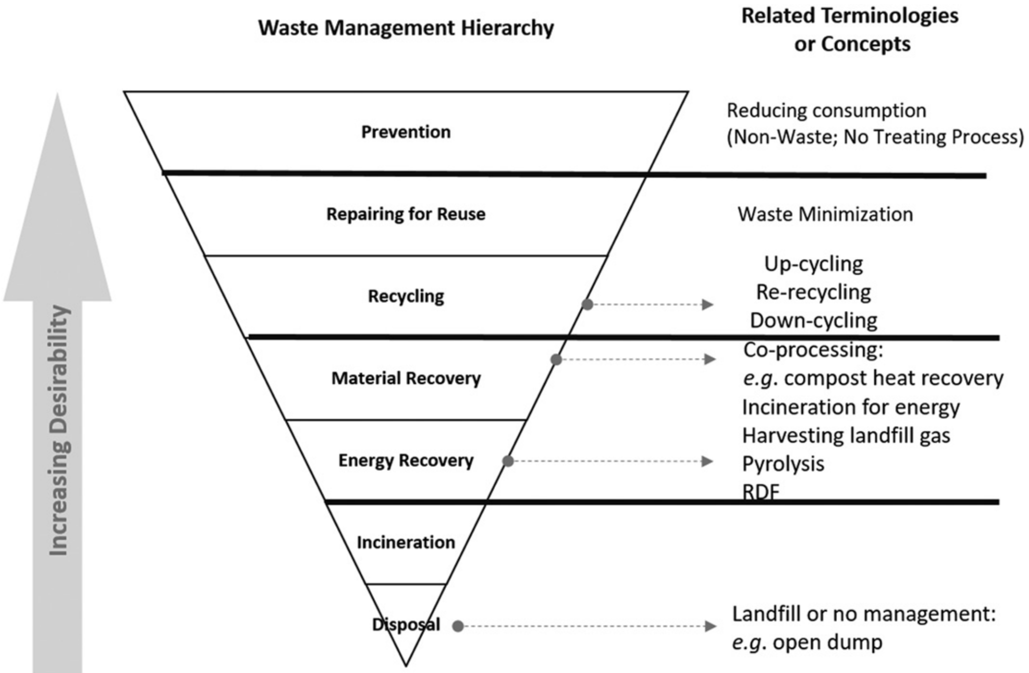

Fig. 2 Waste management hierarchy.

Waste as resources (recycle and the challenges for developing countries)

The idea of circular economy is straightforward and easy to understand: if the materials can be used multiple times within a city (viewed as a system), the economic values derived from the materials increased. Hence, the city can be more independent and resilient from the external disturbance. However, similar to the waste management hierarchy, implementing the idea to the real practice of waste management is not as straightforward as expected. This is especially true for the developing countries and low to middle income countries (Kaza *et al.*, 2018).

The technologies of waste treatment have been advancing; even for the landfill, the least favorite waste disposal methods, can be used as a mean for energy recovery, anaerobic composting and so on (Nanda and Berruti, 2021). Nowadays, the incineration is not necessarily the only choice of waste-to-energy; a variety of technologies has been developed to increase the efficiency of converting energy from different types and compositions of waste (Astrup, *et al.*, 2015). Treatment sequences have also been developed to extract valuable metals, plastics and so on from e- waste (Ilankoon *et al.*, 2018).

For developing and low-income countries, the challenges are not the availability of the technologies but the affordability of them. Further, the institutional controls (waste collection and sorting) require collaboration from the citizens, and this is more problematic for the developing countries. Some of them may even still deal with the issues of literacy of the disadvantageous groups in the society; the environmental education on waste management would be a luxury for them.

Circular economy and resilient cities (for developed countries)

For some metropolitan areas, the concept of "circular economy" in waste treatment has been implemented even before the terminology become popular. The cities consider waste as their resources equipped either as raw materials or fuels for energy so that they can be more resilient and sustainable (Rushbrook and Krol, 1990). Sometimes, they do not follow the logic of reducing environmental impact based on waste management hierarchy mentioned above. The reduction of the landfill can be economically incentivized than regulatory driven, such as to release land resource for more beneficial uses. Further, if the valuable resources can be extracted in the cost equivalent or lower than obtaining the primary raw materials, the waste treatment become a means of resource generation that derives financial benefit. Similarly, extracting the surplus heat or chemical (e.g. biogas) as the sources of energy generation can either compensate the costs of the waste management or reduce the costs and uncertainties of purchasing energy source externally. As early as 1990, under the encouragement of International Energy Agency Bioenergy Agreement, countries, manufactures, and related research institutes have already investigated the feasibility and been developing a variety of advanced waste to energy technologies, such as RDF production, mass combustion (for excavating the heat from incineration), thermal processing (pyrolysis/gasification/liquefaction), landfill gas and anaerobic digestion. Nowadays, the economic incentive can be strong enough for developing and applying those MSW treatment technologies (Rushbrook and Krol, 1990) to the commercial scales.

The legislation on waste management is linked more strongly with the climate change and GHG emission control around later 1990s, roughly concurrent with a series of international agreements starting to take effects (Fischer, 2011). It appears, the regulation started to prioritize the technologies that may reduce GHG emission. Hence a hierarchy that favors resource recovery over energy recovery (such as incineration) was constructed; based on which the regulation such as Landfill Directives & Waste management Framework of the EU were made.

We saw cities or EU members of state that have surpassed the target of landfill rate requirement in the directives plan for their waste management strategies are not necessarily based on the hierarchy. Rather whether to shift the waste treatment from recycling to energy recovery really depends on the long-term needs of the cities. Some cities, such as Genova, has reallocated the treatment capacity slightly towards the material recovery-based style from the energy recovery-based style, only to reduce the dependency of importing mixed bulky waste from outside of the city for energy production purpose (Bergeron, 2017); this has further improved the autonomous of the city based on a conceptual model built by Bergeron (2017) to evaluate the city resilience. For cities like this, waste reduction may be desirable but not necessary as the right kind of treatment will turn the waste back into resource. In this way, the concept of circular economy is realized without the legislative incentive. Another example would be the Spittelau incineration plant located in the center of the city, rebuilt in 1991 (Jo *et al*., 2016). Electricity produced in incinerator via the heat it produced by itself can support the operation of the facility. The surplus of the energy can be used for warming up the water to be supplied to 334,000 households of Vienna and cooling water to be provided for 6500 places like City Hall, hospitals, and department stores. In this way, the incinerator is a power generation plant, not only the stigmatized waste treatment facilities.

Education more important than technology development? (for developing countries)

Thus, from the development of waste management strategies either following the hierarchy or the principle of circular economy, it is clear the technology development is meaningful and useful for cities with diverse life styles, development stages, and geographical characteristics. As the compositions of the municipal waste vary, the availability of technologies to mix and match in an integrated management plan can significantly aid to tackle the issues related to sustainability such as GHG emission reduction. For example, incinerating for energy seems to be preferred by the northern and western European countries while extracting CH_4 from landfill to produce energy become a more popular types of waste management methods for energy production while reduce the potency of GHG that was emitted from the process (Malinauskaite *et al*., 2017; Wang *et al*., 2022).

The advantage of for diverse options for waste treatment is even more obvious when the waste management strategies were designed based on circular economy. As the effective implementation of the circular economy in waste management relies on effectively extraction of the secodary raw materials and energy from the wastes, the customized combination of technologies fulfilling the aims of extracting as much resources as possible from specific types of waste mixture is vital to turn waste treatment a profitable industry.

From the cases reviewed, it also become quite clear that planning and being able to constantly adapt to the changing demand for waste treatment is increasingly critical for a city to catch up with the social development. How to manage the material flows to be sent to the suitable treatment facilities, and design the waste collection routine have emerged as influential factors for the performance of waste management of a city. During the transition of the waste management in Nottingham, the GHG emission from the logistic part of the operation only became visible (though still small) during the latter period when the GHG emission from the GHG from the major contributors, landfill, was reduced (Wang *et al*., 2022). The effort of implementing this complex and perhaps longer mileages transportation plan, from the GHG emission aspect, is worth while.

Technological transfer and geographical appropriateness

Transferring waste treatment technology from the developed countries to developing countries may be desirable as the environmental issues derived from the waste disposal may be transboundary and even shared globally (such as climate extreme resulted from warming effect). However, provided the waste compositions in the developing countries may be quite different from that of developed countries, exactly which technologies to be transferred may be a good research question in itself. For example, we observed a huge proportion of food waste in the waste composition from South Asia, a few regions in Africa as well as central and South America (**Fig. 1**). Most of the countries in these regions are emerging economies or developing countries. The food waste is usually high in organic and moisture content. It is not suitable for the incinerating for energy methods that are prevalent in western and northern European countries. On the other hand, the emerging anaerobic digestion technologies applied that turns the residual wastes into fuel (RFD), compost heating recovery or anaerobic digestion may be a suitable technology to be adapted to treat food waste (Tang, 2020).

Research and Development Needs

Overall, we saw the thoughts on solving the urban waste disposal issues moving from single engineering or technological means towards a more integrated approaches in response to the increasingly complex material combinations of the urban waste. Usually, to reduce the environmental impacts of the urban waste disposal, a metropolitan or a country needs to diversify its waste treatment methods; the added waste treatment methods are moving upwards of the waste treatment hierarchy. Following the now popular concept of the circular economy, in a waste disposal plan, multiple treatment methods are integrated and customized with the regulatory and institutional control as well as economic benefits in mind. For example, a convenient collection schedule (institutional control) may encourage the sorting behavior that improves resources and energy extraction efficiencies for the corresponding waste treatment methods (integrated plan). The solutions for urban waste disposal evolved from emphasizing engineering and technology development to incorporating institutional and social development issues with the technology progression to fit the needs for diverse lifestyles under socio-economic contexts.

Therefore, the multi-disciplinary research is valuable on how to develop a well-structured management plan that integrates institutional control, environmental education and the suitable treatment technologies. The management plan may optimize the resources and energy recovery while minimizing the environmental impacts. This type of research may rely on the methods such as

Fig. 3 Effect of social development on solid waste disposal.

material flow analyses and life cycle assessment. The former may assist the overall understanding of the characteristics of the waste generated for an urban area with its unique socio-economic and geographical traits. This can then aid to set the realistic goals for waste management such as the target of waste reduction, diversion or reallocation of the waste material flows to reduce the landfill rate or to facilitate recycling or resources extraction. The lifecycle assessment may be good at evaluating the environmental impact at unit waste treated based on the available or planned waste treatment methods in a waste management plan. This is a better way to look at the overall performance of waste management. Still, caution is needed to the uncertainty and variability of the assessment results.

Under the situation where a suitable integrated waste treatment plan is in place, the waste collection may be planned to effectively transport the properly sorted waste to the corresponding locations to be further treated. Considering waste collection part of the waste management, the energy and human resources used in the logistic plan need also to be optimized together with the consideration to maximize the cooperation from the citizens or institution at the point of collection. For this, the expertize in the transportation and spatial simulation techniques (for example ArcGIS or sensing technologies such as remote sensing or GPS that can trace the vehicle movements) may be used in the research and development. Further, as the urban areas in the emerging economies and developing countries are ever expanding with population growth, the waste collection may need to be adopted and optimized every several years. Thus, developing a good algorithm to spatially and temporally manage the waste collection and transportation may also be beneficial.

Conclusions

Globally, the urbanized and industrialized areas are expanding at an unprecedented speed. Because of the change of social and household compositions during the urbanization process, in the foreseeable future, it is expected the growth rate of nonorganic waste production (e.g. e-waste or plastics) will further accelerate; the inappropriately disposed wastes could have exacerbated some devastating environmental consequences.

Provided the changes are not only in the compositions of the municipal wastes but also in the socio-economic conditions as urbanization progress in various forms both in developed and developing countries, the engineering solutions for solid waste treatment are no longer the sole focus of modern urban/municipal waste management to achieve urban sustainability; the education of waste sorting and collection, the planning of waste collection, and the locations of facilities also need to be considered in an integrated waste-management packages (Fig. 3). This way, not only economic cost and benefit may be balanced, but also social acceptability for the waste management plan can be incorporated to significantly increase the feasibility and the efficiency of implementing the plan.

Furthermore, the application of the concept of circular economy is expected to play an increasing important role in the urban waste disposal. "Wastes are the misplaced resources" may become a universal thought. The techniques of resources recovery and purification from the various types of waste will become economically incentivized. This will enhance the economic viability of industries related to waste treatment. Of course, the policy instruments may also facilitate reinventing the waste treatment facilities. The development of waste-to-energy technologies has potential to turn the solid waste treatment facilities into a profit-making business by selling the net positive energy generated from the treatment process. Both recycling and energy recovery can improve the economic sustainability as well as environmental sustainability.

The integrated solid waste treatment service packages can be tailored to suit the local conditions (Fig. 3). The consideration behind the design will always need to include the social and geographic factors that will affect the composition of the waste and the level of collaboration for sorting the waste at the household level as well as the level of compliance on waste collection schedule.

Overall, there will be no one solution that can be considered the most sustainable urban waste disposal. The current trend is to use integrated waste management strategies combining several waste treatment methods in response to the changing composition of urban waste during urbanization process and social development. Applying spatial technologies to optimize the efficiency of waste collection, as well as enhancing the awareness of the importance of waste sorting at the household level also aid to the performance of the integrated strategies. The combination of waste treatment technologies with a detailed survey on the composition of the urban waste and the consumption behavior may further optimize the planning of building waste treatment facilities. Together, the sustainability of the waste treatment can then be realized.

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