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Waste management developments in the last five decades: Asian perspective

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Abstract

Solid waste management was explored in Asia's last five decades, and the issues and challenges were identified. Waste generation has increased in all nations in the previous 50 years, although more recently, a declining trend has been observed in Japan and Korea. The composition has been predominantly organic, with 45–50% being kitchen waste. Material extraction and productivity to sustain the most populous part of the globe are explained. Waste management technologies have evolved, with more nations slowly transitioning from landfills to using waste-to-energy options. However, landfilling and open dumps are still the major disposal choice in most developing countries in Asia. Thus, the issues of concern include dumpsites management, the informal sector, waste collection, open burning and food waste. Changes (increasing trends) in the recycling technologies and quantum are evident, as seen in several country reports from India, Indonesia, Japan, Malaysia, Singapore, South Korea, Thailand and Vietnam. There are several issues and challenges for recycling, which are explored in the text. Lastly, the drivers that propel the whole scenario of waste management in Asia and the evolution of these drivers over time are discussed. Several recommendations are included to achieve sustainable waste management in Asia.

Keywords

Asian perspective, five decades, solid waste management, sustainable development, waste management issues and challenges, technologies

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Introduction

Previous Reviews on Waste Management in Asia have published focusing on specific material or time period. We attempt to explore the Waste Management in Asia more on the evolutionary status within the last five decades. This review is unique in examining the waste generation quantity and quality changes in the last five decades. Consequently, we also attempted to trace the technologies used and the changes in the last 40–50 years. Changes to the management of waste such as, how the issues and challenges differed over the period of 50 years are examined and causes explained. Informal sector involvement has also evolved over the period, and the evolutions are captured as the economic reasons for change. Basically, the changes observed are based on the differences in the income level of nations in Asia, and this has affected the amount of waste generated, composition of waste and technologies used, involvement of informal sector and future prospects.

Effective solid waste management is critical for the sustainable development of Asian nations. Asia is the most economically dynamic region, with countries like Vietnam, Indonesia, India and China recording enviable growth rates recently. With the rapid urban population growth (close to 3.0 billion in 2050), waste quantity is expected to increase in Asian nations (except Japan and South Korea).

Asian nations have committed to achieving the Sustainable Development Goals (SDGs); several are seriously embarking on these targets. Sustainable consumption of resources is pertinent to reduce waste in the future.

Solid waste management issues, technologies and challenges are dynamic in developing Asian nations. One of the biggest challenges is the availability of reliable data (compared to developed nations) in most Asian countries. The economic issue is another challenge since 80% of the total cost is for waste collection in most developing countries in Asia (except Japan, where the cost of disposal is much higher than collection).

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Waste management in Asia

Waste generation and materials consumption trends

Inhabited by more than 4.56 billion people in 2021, equivalent to 60% of the world population, Asia recorded a huge amount of waste generation (more than 800 million tonnes/year), making it the largest waste-producing continent on Earth. By 2025, it is estimated that 1.8 billion tonnes will be generated by urban cities alone in Asia. Waste generation is directly correlated to material consumption. Generally, an increasing trend is observed globally and in Asia (Figure 1).

Asia has recorded the highest increase (four-fold jump) in material consumption compared to the other continents. This could be translated into waste generation since most Asian nations are developing nations with rapid economic activity. The two potential superpowers in Asia, India and China, generated the highest amount of municipal solid waste (MSW; Figure 2). Indonesia, one of Asia's fastest-growing nations, generates 65 million tonnes annually, followed by Russia and Japan.

MSW generation in Asian countries trend in MSW generation for the 30 years (1995–2025) period shows a decline only for the two developed nations, Japan and Korea (Figure 2).

Waste composition changes in Asia

Typically, Asian nations generate waste with a high organic fraction, as seen in Figure 3. Organic fraction is the most abundant component in Asian countries. Also, the waste composition in Asia varies significantly based on income levels. As income increases, the waste composition tends to shift towards a higher proportion of non-biodegradable materials such as plastics and paper. In low-income countries, the waste composition tends to be dominated by organic materials such as food and agricultural waste (Figure 3), but this fraction decreased with affluent.

Evolution in waste management technologies

The standard technology used in Asian countries is landfills and open dumps, except in developed nations such as Singapore, Japan and Korea (Figure 4).

However, increasing waste-to-energy (WtE) options are being introduced in a few countries. Thailand has gradually introduced incineration in Bangkok, whereas Malaysia has also embarked on changes to use waste to energy plants. China is rapidly constructing WtE plants, and it may overtake Japan regarding the number of plants (Table 1). Composting is not very popular in Asia, although the climate is conducive to biological treatment (Table 1). Only 1–5% of the waste is composted, and up to 27% is managed without any specific method (Kaza et al., 2018).

As shown in Figure 5, about 6.7% of MSW goes to landfill, and 17% in unspecified landfill. This could be dumpsites. Only about 5.5% goes for resource circulation, indicating the loss of resources and materials. It is important to note that 13% of MSW is unaccounted for, which means this portion could be scattered or disposed of into waterways and may become the main source

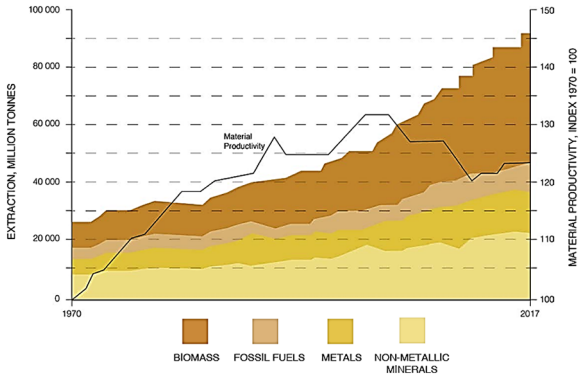

Figure 1. Global material extraction and productivity 1970–2017 (OECD, 2023).

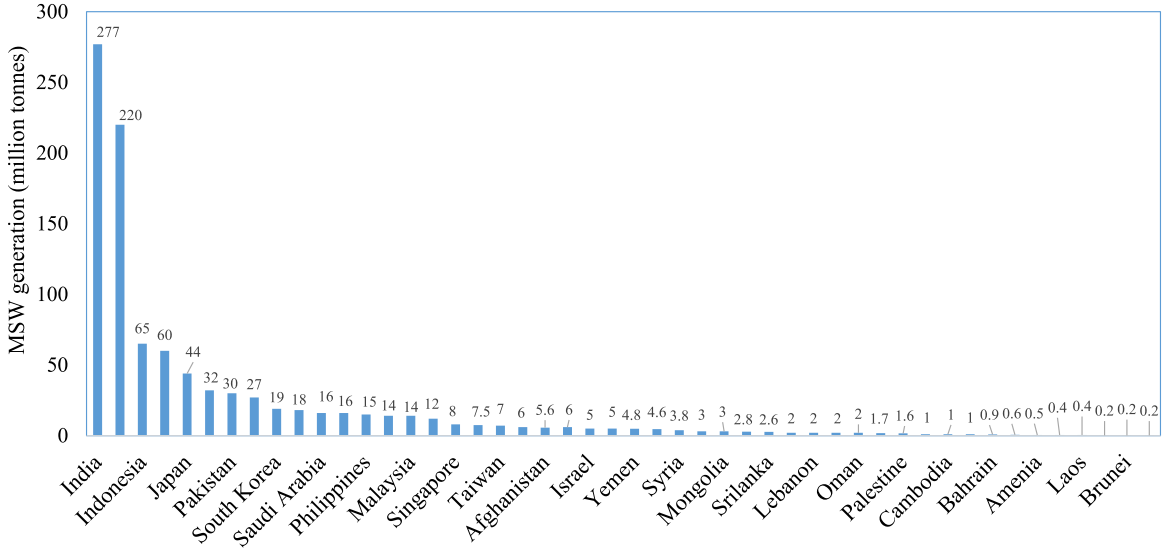

Figure 2. MSW generation in Asian countries (Kaza et al., 2018).
MSW: municipal solid waste.

Figure 3. The average composition of MSW in Asian countries and economic impacts (Modak et al., 2017; UNEP, 2019).
MSW: municipal solid waste.

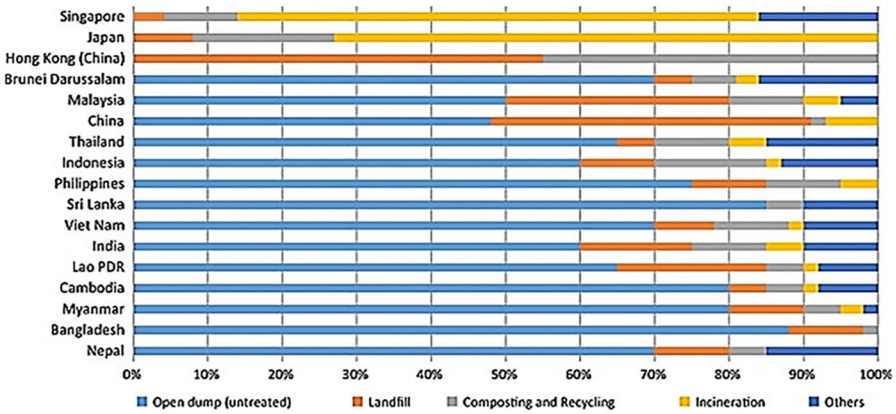

Figure 4. MSW treatment technologies in Asian countries (Aleluia and Ferrão, 2016).
MSW: municipal solid waste.

Table 1. Waste generation and treatment in Asia (Kaza et al., 2018).

Region	MSW generation rate (tonnes/cap/year)[a]	Percentage of MSW disposed at disposal sites (%)	Percentage of MSW incinerated (%)	Percentage of MSW composted (%)	Percentage of other MSW management unspecified (%)
Eastern Asia	0.37	55	26	1	18
South-Central Asia	0.21	74	–	5	21
Southeast Asia	0.27	59	9	5	27

[a]MSW: municipal solid waste.

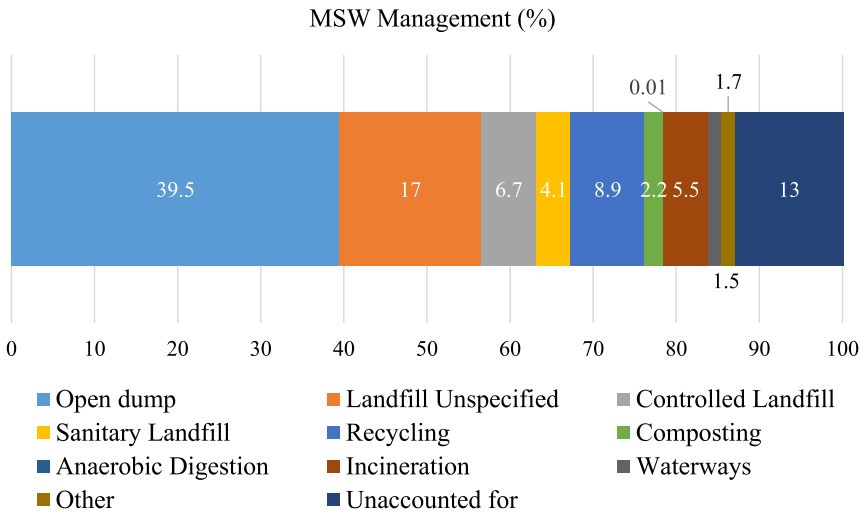

Figure 5. Waste management technologies used in Asia (Visvanathan and Tränkler, 2003).

of plastic pollution in rivers and microplastics eventually (Ta and Babel, 2023, Visvanathan and Tränkler, 2003).

Issues of concern in Asian (developing) nations

1. The highly comingled waste composition makes managing the MSW challenging, especially with about 45% food waste.
2. The lack of formalized waste diversion sector hinders reduce, reuse and recycle (3Rs) practice and wastes resources.
3. Generally, there is a lack of enforcement of waste management legislation in most Asian nations.
4. Multiple government departments are involved in the waste management hierarchy; hence, there are overlapping responsibilities that sometimes no one takes the job.
5. Public participation is lacking in most Asian nations. This will reduce 3R practices since source separation is not being practiced (Pariatamby et al., 2014).

Challenges in waste management

Dumpsites

Disposal sites of MSW can be open dumps or landfills. Open waste dumping has become the most prevalent method in Asian low- and middle-income countries, including 79% in South Asia, 64% in Southeast Asia and 51.1% in South and Central Asia (Kaza et al., 2018). Open dumps are poorly managed by either local authorities or other landfill operators (Idris et al., 2004). Besides financial resources, a lack of awareness of environmental and health issues is the root cause of low-quality waste management (Hogland et al., 2005).

Table 2 shows that open dumps and sanitary landfills are practiced in every ASEAN country (Jain, 2017). There are about 212 dumpsites in Malaysia, and 81.5% of the waste generated goes to landfills. The country spends 7.2 million USD in capital expenditure on landfills (Pariatamby and Bhatti, 2020). In Vietnam, about 76–82% of MSW is disposed of by dumping or landfilling. Currently, 98 open dumpsites and landfills are operating in Vietnam. However, only 16 sites have proper practices on solid waste management and handling (Truong, 2018). The other open dumpsites are operating in an unhygienic manner. Thailand has a large number of open dumps, of which 1670 are under state control, whereas the other 32 are taken care of by the private sector (PCD, 2022). On the other hand, there are 70 disposal sites with proper practices, such as sanitary landfills, engineered landfills and semi-aerobic landfills (PCD, 2022). As Southeast Asia's largest MSW producer, Indonesia also relies on open dumping as the main landfilling method. The major landfill in Jakarta, Indonesia, receiving 6000 tonnes of waste daily, is almost full (Aprilia, 2021). This indicated that proper solid waste management by landfilling is still lacking in many Asian countries (Agamuthu and Khidzir, 2008).

Figure 6 illustrates the percentage distribution of waste disposal methods based on income levels. More than 90% of low-income countries deploy open dumping for waste disposal (Kaza et al., 2018). The proportion of open dumps is descending in countries with higher income levels, and landfilling is the most prevalent disposal method. However, due to the increasing rate of waste generation and limited available space for landfills, many countries face the problem of space for waste disposal facilities (Joseph and Nagendran, 2007). Large metropolitan cities in middle-income countries are shifting to WtE incineration instead. However, implementing WtE schemes faces some challenges in middle-income countries due to high operation costs and the high organic composition of the waste (Kaza et al., 2018). The recovery and reintegration rate of material is higher in high-income than low-income countries due to an emphasis on recycling and the productive use of organic waste. Moreover, high-income countries in Asia, particularly Japan and Korea, have almost completely terminated landfilling while reducing incineration by maximizing waste reduction and recycling (Kaza et al., 2018).

Open dumps have no precautionary measures and rely on only natural lining such as clay layer with no leachate collection/treatment and thus can cause various environmental and health problems (Yadav et al., 2019). A high concentration of organics, heavy metals and toxicity was found in the leachate from the

Table 2. Treatment/disposal technology for MSW in ASEAN countries adapted from Jain (2017).

Country	Treatment/disposal				
	Composting	Incineration	Sanitary landfill	Open dump	Open burning
Brunei Darussalam			✓	✓	
Cambodia	✓		✓	✓	✓
Indonesia	✓	✓	✓	✓	✓
Lao PDR	✓		✓	✓	✓
Malaysia		✓	✓	✓	
Myanmar		✓	✓	✓	
Philippines	✓		✓	✓	
Singapore		✓	✓	✓	
Thailand	✓	✓	✓	✓	
Vietnam	✓		✓	✓	

MSW: municipal solid waste.

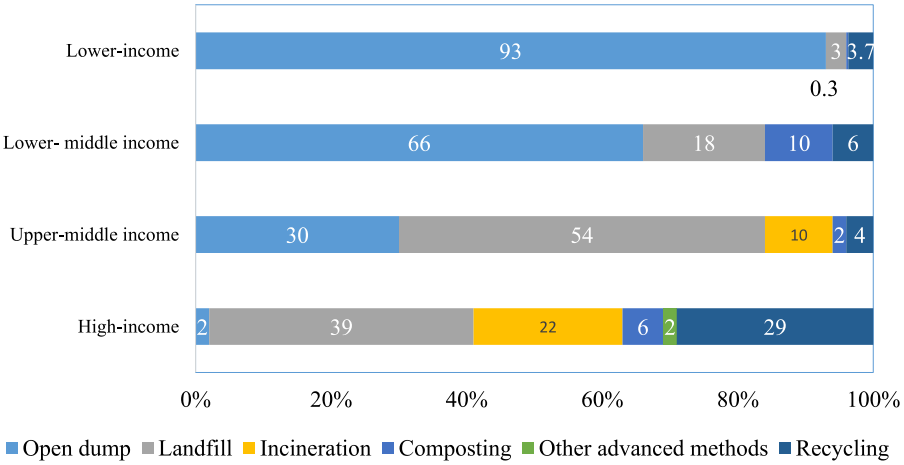

Figure 6. Percentage distribution of waste disposal method by income level (Kaza et al., 2018).

Okhla landfill in Delhi located in floodplains, and it was pointed out as a potential source of pollution in the Yamuna River (Yadav et al., 2019).

Odour is another major problem associated with open dumps. The operation of open dumps poses a safety hazard to waste scavengers and dumpsite employees (Joseph and Visvanathan, 2008). Methane is released from the dumpsites by decomposing waste under anaerobic conditions contributing to global warming and generating fires and explosion at the open dumps (Sridevi et al., 2012). Furthermore, organic waste generates heat from chemical and biological degradation, which may cause a spontaneous fire (Chavan et al., 2022). Open waste burning leads to air pollution, loss of lives of dumpsite workers, lower leachate quality and long-term health effects on surrounding communities (Chavan et al., 2022). Fine particles released from the uncontrolled burning at dumpsites can cause respiratory diseases and smog (Sridevi et al., 2012).

Moreover, in dumping sites in developing Asian countries, dioxins and dibenzofurans are likely to be formed by the uncontrolled burning of solid waste, generation of methane gas, lack of advanced waste incineration technology and natural low burning temperature (Minh et al., 2003). Toxic chemicals like polychlorinated dibenzo-*p*-dioxins (PCDDs) and polychlorinated dibenzofurans (PCDFs) were found in soils from dumping sites in the Philippines, Cambodia, India and Vietnam (Minh et al., 2003).

Therefore, developing countries need to shift from open dumping to sanitary landfill, which is operated scientifically. However, some developing countries in Asia lack resources, funds and technical expertise for operating sanitary landfills. Poorly managed landfills can cause landfill slides or collapse, leading to injury or fatality. For example, the collapse of landfills in Shenzhen, China, in 2015 caused 73 deaths (Yang et al., 2016, 2017). Another landfill failure occurred in Bandung, Java, Indonesia, in 2005, killing 140 people (Lavigne et al., 2014).

A progressive improvement over open dumping can be achieved by a step-by-step approach, from open dumps to controlled dumps, engineered landfills and sustainable landfills (Figure 7; Joseph and Nagendran, 2007, Joseph and Visvanathan, 2008). A sustainable landfill can be described as a landfill with minimal environmental risk, and waste materials are eventually assimilated into surrounding environments (Luo et al., 2022, Westlake, 1997).

Landfill mining can be attempted subsequently when waste is physically, chemically and biologically stable. It is a strategy towards sustainable development and can extend the landfill's life. This technique benefits from the recovery of valuable

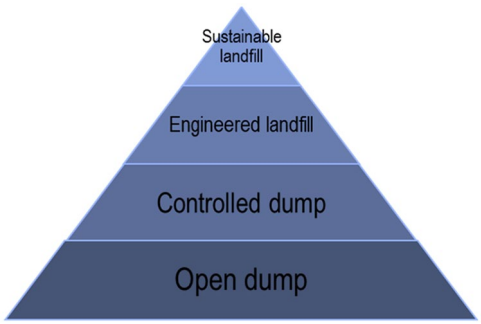

Figure 7. Phased approach to dumpsite rehabilitation in Asia (Joseph and Nagendram, 2007).

material from landfills and reduces greenhouse gas emissions from landfills and dumpsites (Calderón Márquez et al., 2019). Dumpsites can be converted into revenue-generating assets rather than a source of environmental pollution (Dubey et al., 2016). In Asia, countries that have implemented landfill mining are India, China, Thailand, Taiwan, South Korea, Sri Lanka and Pakistan (Calderón Márquez et al., 2019). India was the first country in Asia where 'bio-mining' was carried out using biological treatment for dumpsite remediation (Patel, 2016). Another landfill mining project was in Taipei, Taiwan, at Neihu landfill between 2006 and 2013 (Weng et al., 2015). The project aimed for environmental rehabilitation, and the site was later reclaimed as a park. Excavated material was used for construction and energy production.

Another alternative is to convert waste into useful resources such as refuse-derived fuel (RDF). RDF is produced from a solid combustible waste fraction of MSW such as plastic, wood, pulp and organic waste by mechanical-biological treatment (Bhatt et al., 2021, Mustia et al., 2021). RDF can be used in industries and WtE power plants. Public buses also use waste-derived energy (Kaza et al., 2018).

Dubey et al. (2016) conducted a study on dumpsites in 32 cities in India. Waste disposed of in dumpsites in one city is higher than 20 million tonnes, and the land area occupied is as high as 250 hectares. After landfill mining, these cities gained revenue not only from valuable land reclaimed but also from recyclables and combustibles acquired.

Uncontrolled open dumps create environmental and health problems. Thus, waste disposal practices must move from open dumping to sustainable landfills or WtE incineration. Public awareness of waste disposal should be raised through educational campaigns, which can be carried out at various levels based on the target group to create awareness of environmental issues from open dumping. Moreover, the authorities should take care of market incentives and penalties and appropriate allocation of financial resources for the waste management sector (Hogland et al., 2005). Regional waste management or inter-municipal cooperation can be initiated to use shared resources such as landfills and collection trucks (Kojima, 2020). Public–private partnership programmes can be established to manage the government budget efficiently. The formal private sector is responsible for developing and operating waste facilities, while the government pays for the treatment cost to the private sector (Kojima, 2020). Moreover, sustainable landfills can be an alternative for developing countries to replace open dumps, and landfill mining would help them benefit from the reclaimed material.

Informal sector

With the rapid urbanization and population growth, the waste generation rate is increasing especially in low-income and middle-income countries, and the formal sector cannot handle the increasing amount. Thus, in some regions, the informal sector collaborates with municipalities to manage waste collection, processing and disposal (Tong et al., 2021). Additionally, the informal sector is often responsible for the collection of recyclable materials (Yang et al., 2018). The informal sector is defined by Scheinberg (2011) as individuals or enterprises that are involved in recycling and waste management activities that are not sponsored, financed, recognized, supported, organized or acknowledged by the formal solid waste authorities or which operate in violation of, or competition with, formal authorities. The informal sector collects, transports and trades recyclables (Yang et al., 2018). They collect recyclable material from households, the commercial and service sector, landfills and imported waste and send it to a transfer station for processing. The individuals or groups involved in informal recycling activities are women, children and the elderly.

About 1% of the urban population, or at least 15 million people in developing countries, scavenge recyclables from waste for their livelihood (Medina, 2008). China has the largest number of people working in informal recycling activities, or about 6 million waste pickers and dealers (WorldBank, 2019). However, the number of informal recyclers in China has been declining in recent years due to higher living standards and lower prices of recyclables.

The informal sector mainly contributes to the recycling rate in many developing countries. The proportion of the total generated waste can be recycled by up to 45% by informal waste recyclers (Linzner and Lange, 2013). The most frequently recycled materials by the informal sector are paper and cardboard, scrap metal, glass, plastic bottles (polyethylene terephthalate (PET)), rubber, wood, textiles and food waste (Ezeah et al., 2013). They prefer metal, paper and PET due to their recycling potential and long life span (Ezeah et al., 2013).

In 2011, the recycling rate of China was 15.8% of the total waste generation because of the informal sector (Kaza et al., 2018). China reached a total amount of waste recycling of 282 million tonnes in 2017, comprising 52.85 million tonnes of paper, 6.93 million tonnes of plastics, 3.74 million tonnes of E-waste, 3.5 million tonnes of textile and 10.7 million tonnes of glass. The recycling rate in China in 2017 reached 27.8% from the informal sector's contribution (WorldBank, 2019). In Jakarta, Indonesia, about 37,000 waste pickers recover 25% of the city's waste (378,000 tonnes a year) and reduce the volume of waste by

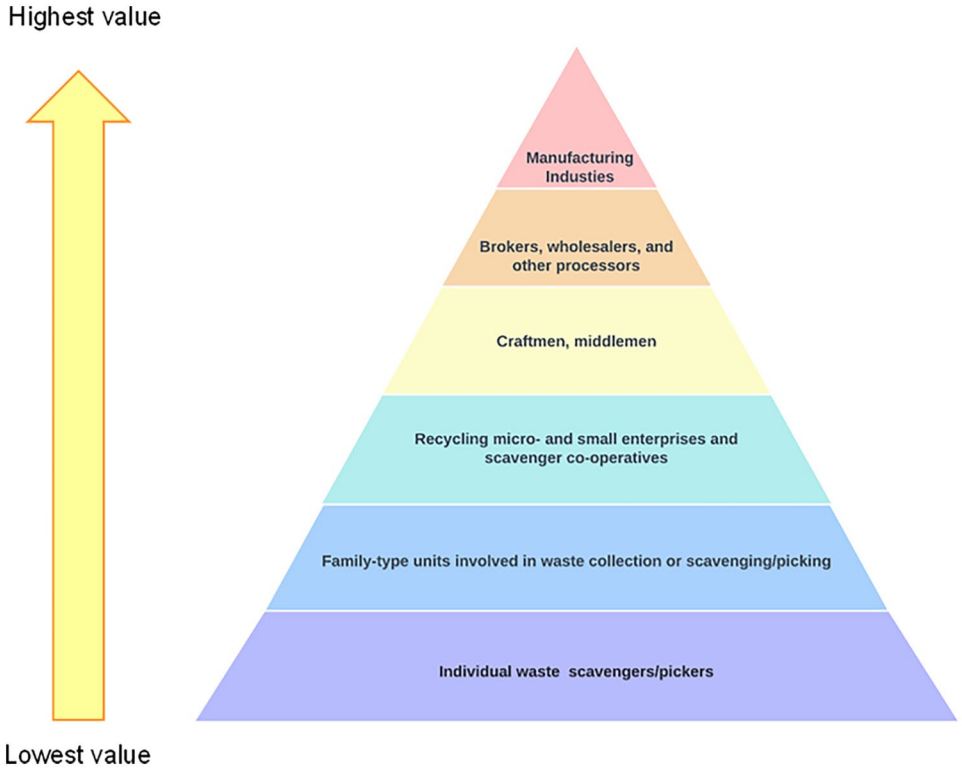

Figure 8. The pyramid of the informal waste recycling system (Wilson et al., 2006).

30% (Medina, 2008). The informal waste activities save the cost of the municipality 300,000 USD a month and produce an economic benefit of more than 50 million USD a year (Medina, 2008).

Even though waste pickers in the informal sector provide societal benefits regarding waste management and reclamation of high-value resources from waste, they are not legally recognized in many Asian countries (Kashyap and Visvanathan, 2014). The informal waste recyclers receive low income and are driven by the revenues from selling the recovered waste (Fei et al., 2016). Low income is the result of the lowest position in the pyramid (Figure 8; Wilson et al., 2006). The competition for waste scavenging and middlemen also affect the price of recyclables (Kashyap and Visvanathan, 2014). There is no control over the price the informal waste workers get paid per kilogram of material (Ojeda-Benitez et al., 2002). The fees paid to the informal waste recyclers by small and large merchants and the industry also fluctuate in different countries (Gutberlet, 2008). For example, waste pickers working at the Bantar Gebang landfill in West Java, Indonesia, have income below the legal minimum wage and lower than occupations in other industries (Sasaki et al., 2022).

Environmental, social and health issues from an informal recycling. There are several environmental, social and health problems related to waste scavenging. The informal waste workers rely solely on primitive technologies, and the existing non-standard recycling and processing activities create waste materials (Troschinetz and Mihelcic, 2009). The contamination of environmental pollution from recycling activities occurs in the air, water and soil, and the level of contamination can be highly high near informal recycling sites (Yang et al., 2018). For example, the metal scrap industry can be a potential source of air and water pollution due to simple recycling techniques without pollution control mechanisms (Kashyap and Visvanathan, 2014).

In addition, social issues associated with informal waste activities are poor working and living conditions, child labour and the lack of schooling and poor education (Aparcana, 2017). The main factors driving child labour in the informal waste sector are economic contribution, poverty, lack of skills and educational opportunities, and high cost of schooling (Aparcana, 2017). Waste pickers in many countries are perceived as having a negative social stigma of being associated with waste. The marginalization of informal waste workers can potentially cause harassment by the authorities or police (Wilson et al., 2006). Informal workers are often excluded from protective legislation because they are not under labour laws.

The informal waste workers are at risk of health problems and are likely to be injured by using bare hands to collect sharp objects. They are in contact with toxic, corrosive, flammable or explosive garbage. Furthermore, biomedical waste can cause respiratory, skin and other lethal diseases to rag pickers (Kumari and Kiran, 2022). A study has reported an increased risk of musculoskeletal problems from waste picking (Cointreau, 2006). There is also an increasing number of waste electrical and electronic equipment, which releases toxins to which informal waste recyclers are exposed by direct contact (Yang et al., 2018). Workers in the informal sector live and work in filthy and vulnerable conditions. However, they do not receive government support, for example, social security and labour rights (Kumari and Kiran,

2022). Thus, improving workers' health in the informal sector is a major challenge.

Informal sectors are facing conflict with local authorities. In countries with a negative perception of the informal sector, public policies towards the informal sector are negative, such as repression, neglect or collusion (Medina, 2000, Wilson et al., 2006). The informal waste workers are arrested or fined in some countries (Aparcana, 2017). Scheinberg et al. (2015) defined the relationship between the formal and informal sectors as mistrust and competition. There is high competition for waste scavenging. Thus, the informal waste pickers are subject to bribery to access the waste (Baud et al., 2001, Ezeah et al., 2013, Katusiimeh et al., 2013). Local authorities in Chennai (India) and Manila (the Philippines) prefer cooperation with non-governmental organizations (NGOs) or large-sized waste management enterprises instead of local waste pickers, and the authorities communicate with the informal sector through the mediation of NGOs and community-based organizations (CBOs; Baud et al., 2001).

Formalization and integration of the informal sector. In developing countries of Asia, formalizing the informal sector could increase recycling rates, improve the well-being of informal waste workers and reduce waste management costs (Yang et al., 2018). The inclusion of the informal sector can also promote employment, protect the livelihood of the disenfranchised groups of society, provide a steady supply of secondary raw materials and provide environmental protection (Ezeah et al., 2013). The integration needs to consider a particular area's political, climatic, economic, religious, legal, cultural and social conditions (Gunsilius, 2012). National regulations and guidelines are encouraged to provide recognition and societal benefits to waste workers, such as legal identification, housing, health and education (Kaza et al., 2018).

Due to the negative perception of waste scavengers, positive public and political attitudes towards waste pickers can be created through civil society campaigns to promote integration (Gerdes and Gunsilius, 2010). For instance, the Indian media has played a significant role in disseminating information on waste pickers, solid waste management issues and the informal sector integration to the public (Gunsilius, 2012). Public attention stimulates social recognition and acceptance of informal recycling activities.

NGOs play an important role in the process of informal sector integration. NGOs can act as initiators, advocates and intermediates by becoming partners, participating in official decision-making processes, and formally acknowledging a specific project (Gerdes and Gunsilius, 2010). NGOs may provide technical, financial and social assistance to informal waste workers through social aid projects (Aparcana, 2017). Networking and collaborating with NGOs and CBOs adds credibility to the rag pickers and allows communication channels with the government, formal stakeholders, decision-makers, industry and the community (Ezeah et al., 2013).

For example, in Quezon City (Philippines), formal identification is provided to approximately 3000 waste pickers working at the Payatasau landfill (Gupta, 2012). The workers also work in shifts to earn income from recreating valuable materials. Moreover, child labour was banned in this area. Another example is in Pune, India, where waste pickers are granted the right to collect waste and service fees from households (Gupta, 2012). They also get trained to work professionally in occupational safety. Pune can reduce the waste disposal rate to more than 20% by integrating the informal sector (Gupta, 2012).

Formalization initiatives depend on social acceptance, financial support from the government and institutional elements such as stakeholders and legal and institutional arrangements (Zurbrügg et al., 2012). However, there are some common barriers to formalizing the informal sector. The absence of adequate policies, clear legislation and strong regulations on formalization have been reported (Guerrero et al., 2013). Funding limitation is one of the barriers to MSW management (Ezeah and Roberts, 2012). Furthermore, the use of technology and the human workforce is not effective or unavailable (Troschinetz and Mihelcic, 2009). Aparcana (2017) has reported that the most frequently observed barrier in the policy/legal category is a lack of empowerment. Even after formalization, waste workers lack empowerment because they are considered a socially vulnerable group. The barriers mentioned above related to policies, finance, social acceptance and technology need to be considered by decision-makers when designing formalization strategies.

Waste workers can exemplify the formalization of informal waste recycling in Gianyar, Indonesia (Zurbrügg et al., 2012). They were formalized as workers in the composting plant. The involvement of local stakeholders in this formalization scheme reduced social conflict in the area. In addition, the municipality of Iloilo city in the Philippines established recycler's associations (Paul et al., 2012). It is a pilot project for testing new options for material recovery in which stakeholders are involved in identifying market demand. The economic impact of the informal sector can be seen in Mumbai, India. More than 30,000 waste pickers have formed more than 400 microenterprises that process waste material and consumer products from the reusable and recyclables collected by them (Medina, 2008). This activity yields an estimated 650 million–1 billion USD annually (Medina, 2008). There are currently 24 officially recognized waste picker organizations in many cities in India (Gerdes and Gunsilius, 2010). Cooperatives or associations of waste pickers are involved in local source segregation schemes such as door-to-door garbage collection (Gerdes and Gunsilius, 2010). The formalization of the informal sector has been implemented in many areas, but it should be extended on a larger scale to achieve the goals of sustainable solid waste management.

Waste collection efficiency and coverage. The maximum collection in the Asian nation is only 74%, as shown in Figure 9. In some cities, the collection rate can vary from 18% to 100% (Figure 10).

Open burning and dumping are the consequences of a low waste collection rate. Poor collection coverage leads to open waste burning since 40% of the population lacks minimum

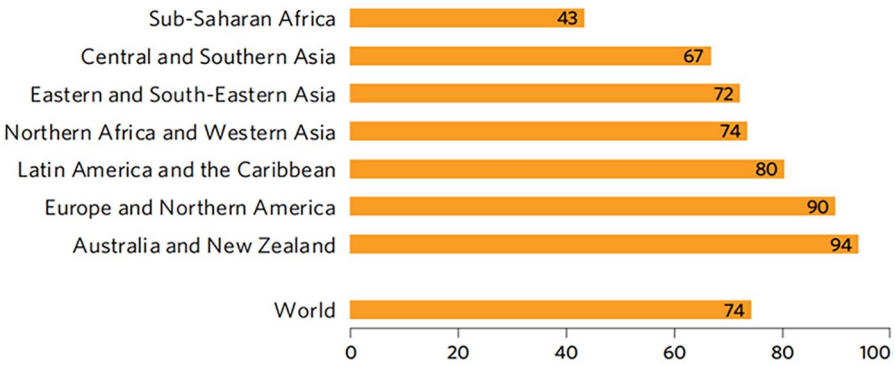

Figure 9. Waste collection efficiency in Asia compared to other parts of the world (Department of Economic and Social Affairs, 2018).

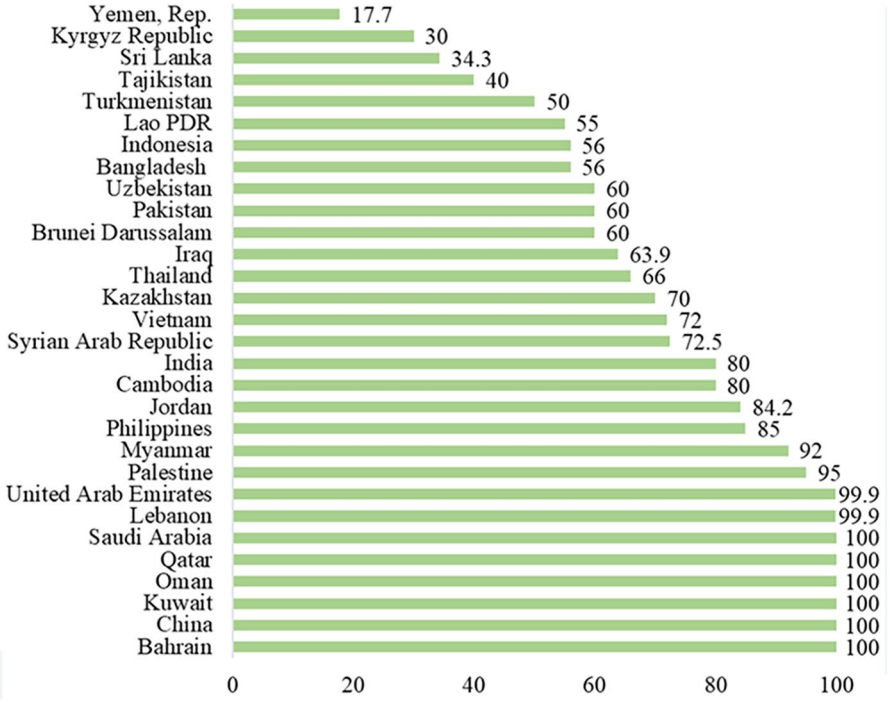

Figure 10. Waste collection rates (%) in Asian cities (Agamuthu et al., 2020; Modak et al., 2017; UNEP, 2019).

collection service. Open burning is rampant in many Asian countries. About 562 million tonnes of waste per year are burned openly. Mostly occurs in landfill/dumpsites that have been filled far beyond their maximum capacity. The global open burning scenario is captured in Figure 11. Most waste burning occurs in Asia, articulately in China, India, Russia and Southeast Asia.

Another consequence of the low rate of waste collection is open dumping. This illegal waste disposal causes soil contamination, attracts pests and vermin and causes severe river pollution in many Asian countries. Scavenging by human and animals are the norm since there is no control in the dumpsites. Illegal squatters are typical in some countries like the Philippines and Indonesia. The slums are a cause of concern from a health point of view. Slums rarely have a waste collection schedule.

Open dumping is usually associated with the passive release of Green House Gases (GHG). These GHG are the main contributors to global warming from the waste sector.

Food waste. Food waste or organic fraction is the main component of MSW in Asia. It can compost or be sent for anaerobic treatment to produce biogas if properly treated. However, both these biological treatments are not common in most Asian nations. One of the reasons for this situation is the lack of source separation and the contamination caused by 1–2% hazardous waste in the MSW.

- The food sector accounts for 30% of the world's total energy consumption while emitting 22% of total GHG.
- 1.3 billion tonnes of food produced (~$1 trillion) are wasted yearly due to poor transportation and harvesting practices, while ~1 billion people go undernourished, and another ~1 billion are hungry.
- Food security is at risk due to land degradation, declining soil fertility, unsustainable water use, overfishing and marine environment degradation.

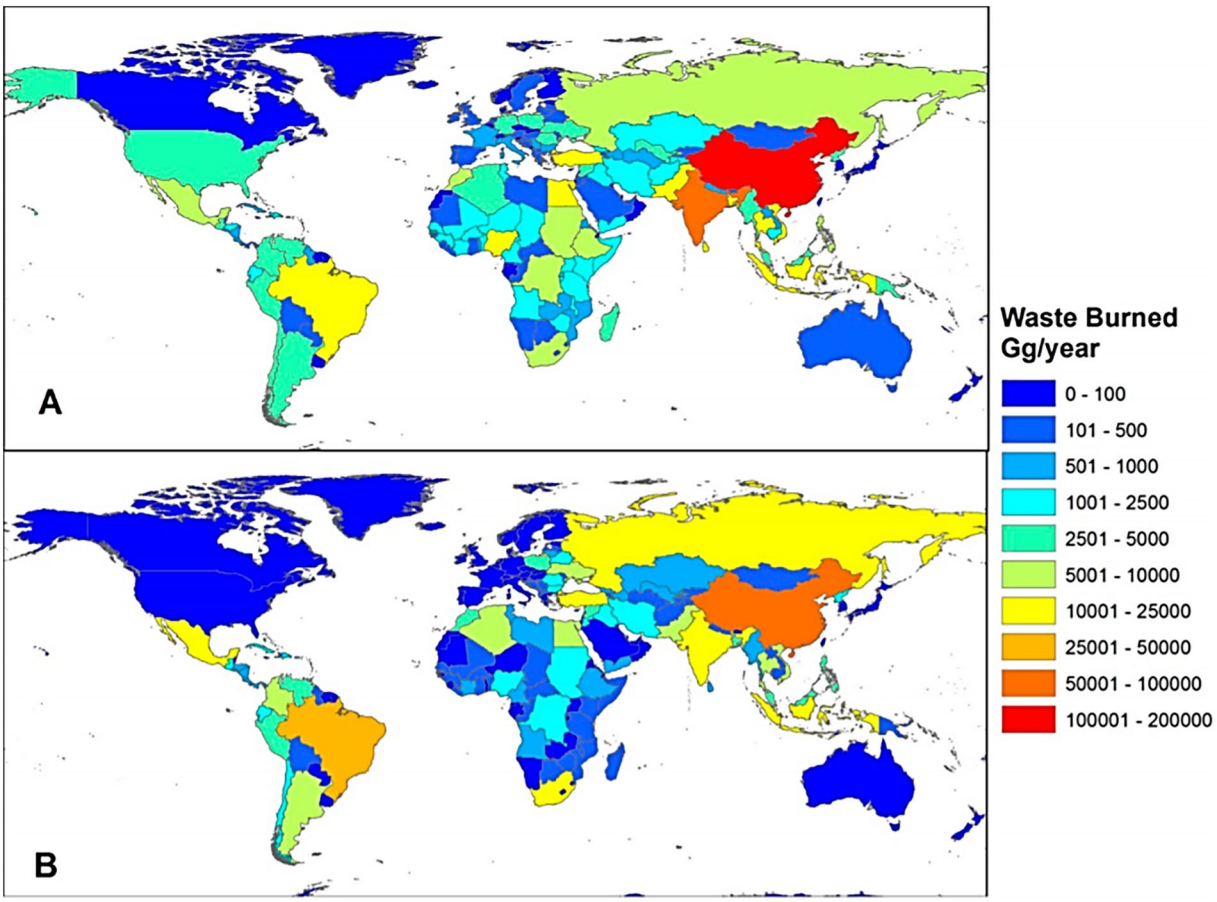

Figure 11. Estimated quantity of waste burned by country, residentially (A) and in dumpsites (B) (Wiedinmyer et al., 2014).

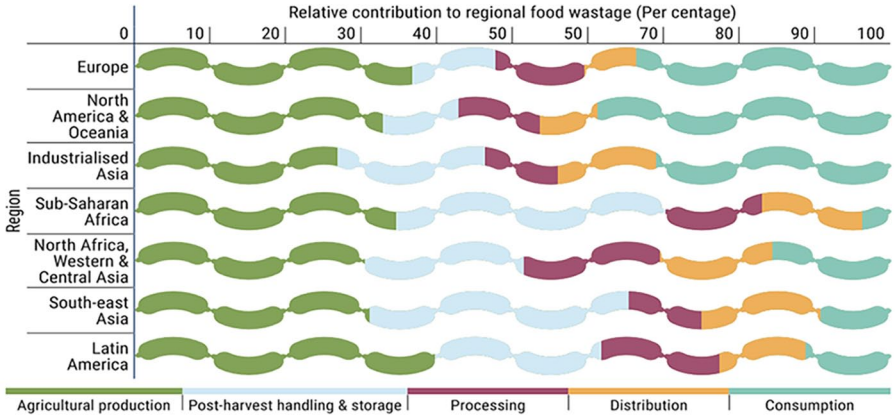

Figure 12. Food wastage in Asia compared to global countries (FAO and Food Waste Footprint, 2013).

Southeast Asia loses 30% of the food in production, whereas another 35% is lost in post-harvest handling and storage (Figure 12).

Transition of MSW management in Asia: Case examples of India and Japan

Across the diverse landscapes of Asia, nations have embarked on distinct trajectories in their efforts to grapple with the growing complexities of waste management. This section focuses on the transition of MSW management, particularly in Asia, using case examples from India and Japan. These two countries were chosen for their varying economic development levels, waste generation patterns and management strategies. India (developing nation) and Japan (developed nation) offer a different perspective on waste management approaches. Despite rapid urbanization, Japan maintains stable or decreasing waste generation per capita due to advanced waste reduction and recycling technologies. In contrast, India with rapid population growth employs decentralized waste management to tackle its increasing waste generation.

India (developing nation)

The economic changes in India over the last 50 years have significantly impacted solid waste generation and management practices in India. As the country's economy has grown and urbanized, the volume of waste generated has increased, leading to significant challenges in waste management. However, economic changes have also created new opportunities for innovative solutions to address these challenges (Balasubramanian, 2015). According to the Ministry of Housing and Urban Affairs, the total MSW generated in India increased from around 26,000 tonnes per day (TPD) in 1961 to around 39,031 TPD in 2001 (Shahab and Anjum, 2022). In the following two decades, the quantity of MSW generated has increased even further. In 2021, this had increased to approximately 160,038 TPD (Shahab and Anjum, 2022).

Also, India has significantly changed waste management practices over the last five decades. Prior to the 1970s, waste management was mainly limited to the disposal of solid waste in open dumps or landfills, which often led to uncontrolled pollution of land, water and air (Chattopadhyay et al., 2009). However, several initiatives have been taken at the national and state level to manage the growing volume of waste produced in the country.

In the 1970s, the Indian government passed the Water (Prevention and Control of Pollution) Act and the Air (Prevention and Control of Pollution) Act, which marked the beginning of environmental regulation in the country. These Acts led to the establishment of the Central Pollution Control Board and State Pollution Control Boards to enforce the regulations (Joshi and Ahmed, 2016).

In the 1980s and 1990s, the focus shifted to decentralized waste management by introducing the 'garbage to compost' programme, which aimed at promoting composting of biodegradable waste at the household level. This programme was implemented in several cities across the country, including Bangalore, Chennai and Delhi (Joseph, 2014).

In the early 2000s, the concept of integrated solid waste management (ISWM) was introduced, which focused on the segregation of waste at the source, followed by collection, transportation, treatment and disposal. The MSW (Management and Handling) Rules, 2000 provided the legal framework for ISWM in India (Rules, 2000).

More recently, India has also been focusing on the circular economy approach to waste management, which aims to minimize waste generation and promote the reuse, recycling and recovery of materials. The Solid Waste Management Rules (2016) were revised to encourage waste minimization and recycling and to introduce extended producer responsibility (EPR) for plastic waste. Waste generators are required to segregate waste into three streams: wet (biodegradable), dry (plastic, paper, metal, wood) and domestic hazardous wastes and hand over segregated wastes to authorized ragpickers or waste collectors or local bodies. State governments or any other group are required to integrate waste pickers/ragpickers and dealers into the formal system (Javadekar, 2016).

A successful case study on the management of MSW in India is the Indore city. The city has improved its ranking in the Swachh Survekshan survey for cleanliness, going from 149th in 2016 to 1st in 2018 (Chauhan et al., 2020). This was achieved through efforts to make the city waste-free and open-defecation-free. Efforts include implementing door-to-door waste collection services, achieving 100% waste segregation, distributing waste bins and setting up disposal units for organic waste compost and material recovery. The local government also employed waste pickers to segregate dry and wet waste, classified waste generators as domestic, semi-bulk or bulk, and constructed eight garbage transfer stations to improve its secondary collection system. The city also converted a former dumping site into a garden (Paul and Paul, 2021).

In conclusion, India has come a long way in terms of waste management over the last five decades, from introducing environmental regulation to adopting integrated waste management approaches and the circular economy model. However, there is still a long way to go in improving waste management practices, particularly in smaller cities and rural areas.

Japan (developed nation)

Over the last 50 years, Japan has undergone significant economic changes that have profoundly impacted solid waste management in the country. According to the Ministry of the Environment in Japan, the total amount of waste generated in Japan has increased significantly over the last 50 years. In 1970, Japan generated approximately 28 million tonnes of waste, but by 2020, this had increased to about 41 million tonnes (Hiratsuka-Sasaki and Akiko Kojima, 2020). This represents an increase of almost 100% over the last 50 years. However, it should be noted that while the total amount of waste generated in Japan has increased, the per capita amount of waste has decreased over the last 20 years. In 2000, the per capita amount of waste generated in Japan was approximately 1.22 kg day^{-1}, but by 2019, this had decreased to approximately 0.94 kg day^{-1} (Saitoh et al., 2022). This can be attributed to Japan's focus on waste reduction/recycling and improvements in waste management technologies.

In the 1960s and 1970s, Japan's waste management system focused on landfilling, and waste was typically dumped in open areas. The government responded by implementing the Basic Law for Environmental Pollution Control in 1970, which aimed to reduce waste generation and promote recycling (Honma and Hu, 2021). In 1971, the government also established the Waste Management and Public Cleansing Act, which required municipalities to develop waste management plans and promote recycling (Tanaka, 2014).

During the 1980s and 1990s, Japan focused on improving its waste management infrastructure and implementing new technologies. One notable development was the introduction of the 3Rs (reduce, reuse and recycle) and Japan's EPR system in the late 1980s. The introduction of this law led to a significant increase in recycling rates in Japan, as manufacturers began to design easier packaging and invest in recycling infrastructure.

Japan also implemented a pay-as-you-throw system, where households are charged based on the amount of waste they generate, to encourage waste reduction (Weng et al., 2012).

In the 2000s, Japan shifted its focus to developing a circular economy and promoting the use of renewable energy (Herrador et al., 2022). In 2001, the government introduced the Basic Law for the Promotion of the Recycling-Oriented Society, which set targets for reducing waste and increasing recycling (Hara and Yabar, 2012). These laws require manufacturers, retailers, wholesalers and importers to recycle. Municipalities oversee the sorted collection of materials. A designated organization handles recycling operations for commercial companies, and consumers typically bear the cost of recycling. These laws have greatly improved the collection of recyclable items in Japan.

In recent years, Japan has continued innovating in waste management, particularly plastic waste. In 2018, Japan launched the 'Plastic Smart' campaign to reduce plastic waste and promote sustainable plastic use. Japan has also developed advanced recycling technologies, such as the chemical recycling of plastic waste (Kuan et al., 2022).

Overall, Japan's waste management developments over the past five decades have focused on reducing waste generation, promoting recycling and developing new technologies. These efforts have made Japan a waste management leader and helped minimize waste's environmental impact.

In comparing the progress of the MSW management between Asian developing and developed countries, it becomes evident that each category faces distinct challenges and opportunities. Developing countries often grapple with building adequate infrastructure and managing increasing waste volumes, while developed countries focus on optimizing waste reduction, recycling and advanced technologies. Nonetheless, knowledge-sharing and collaboration between countries at different stages of development can foster innovation and facilitate the adoption of best practices. In developing countries like India, rapid urbanization, population growth and limited resources often amplify waste management challenges. These countries face significant hurdles in establishing effective waste management systems due to infrastructure gaps, funding constraints and the need for capacity building. However, there have been notable advancements in waste management practices in many developing Asian countries. Efforts to promote decentralized waste management, integrated approaches and adopting circular economy principles demonstrate a commitment to addressing waste management challenges and moving towards sustainable practices. On the other hand, developed countries like Japan have made significant progress in waste management over the years. With greater financial resources and established infrastructure, these countries have been able to invest in advanced technologies, implement stringent regulations and promote waste reduction and recycling. Japan's focus on the 3Rs and its EPR system have contributed to high recycling rates and efficient waste management.

In addition, many Asian countries are taking proactive steps to prioritize waste prevention, reduction and reuse. They are implementing awareness campaigns, educational programmes and policies like plastic bag bans or fees to reduce waste generation (Hermawan and Astuti, 2021). These countries are also promoting concepts like 'zero waste' and organizing initiatives like repair programmes and community swap events to encourage product reuse and extend lifespan (Babel et al., 2020, Kurniawan et al., 2021). By adopting these integrated approaches, Asian countries demonstrate a comprehensive commitment to transitioning from a linear economy to a circular economy model. This shift emphasizes resource conservation, waste minimization and a more environmentally conscious future.

Current situation, issues and challenges of waste recycling in Asia

Current situation of waste recycling in Asian countries

Recycling is an effective way to address the growing waste problem in Asian countries (Kashyap and Visvanathan, 2014). By putting the waste products into the production chain, recycling makes it feasible to convert a linear resource extraction pattern into a cyclic cycle.

Implementing fundamental waste management practices, source separation and efficient garbage collection are necessary for recycling to become a reality. As shown in Figure 6, a significant fraction of recyclables is found in solid waste in Asian countries. Thus, the potential for recycling in each nation is enormous. While developed economies like Japan, South Korea and Singapore have achieved high recycling rates, many developing countries still face structural and systemic difficulties when implementing recycling (Table 3).

Currently, there are two primary recycling flows in developing Asian countries. In the first flow, recyclers, especially informal economy, collect recyclable materials at the source. In the second flow, municipalities separate and recycle materials after MSW collection.

Moreover, informal sectors are more likely to collect the materials if they have a specific economic value.

Issues and challenges of waste recycling in Asian countries

Except for a few developed countries, implementing recycling in most Asian countries has faced many problems in the last few decades. The issues and challenges in implementing recycling practices in Asia can be summarized as follows.

Lack of a clear policy and necessary enforcement. The absence of a clear policy and necessary enforcement is a significant challenge for implementing recycling in Asian countries. While the success of recycling implementation in Singapore, Japan and Korea is driven by appropriate legislation and policy, its lack in many developing countries is viewed as a crucial issue that must be considered (Pariatamby and Fauziah, 2014). The efficiency of recycling activities is hampered by 'ambiguous' recycling

Table 3. Current situation of recycling rates (formal and informal) in major Asian countries.

Country	Recycling rate (%)				
	2000	2005	2010	2015	2020
India (Hoornweg and Bhada-Tata, 2012)	–	5.0–15.0	–	27.0	–
Indonesia	1.6 (Meidiana and Gamse, 2010)	–	5.9 (2008) (MOE, 2008)	10.0	14.6 (UNDP, 2022)
Japan (Harada, 2019)	14.3	19.0	20.8	20.4	21.7
Malaysia (DOSM, 2020)	3.0	5.0	12	15.7	28.1
Singapore (NEA, 2021)	40.0	47.0	58.0	61.0	52.0
South Korea (Park, 2018)	41.3	53.1	59.0	57.2	59.7
Thailand (PCD, 2021)	14	21.9	16.1	18.4	32.9
Vietnam (Hoornweg and Bhada-Tata, 2012)	–	–	8–12	8–15	10–15

policies in many Asian countries and by a lack of enforcement and unhelpful facilities. Enforcement of several components of recycling laws has been low or non-existent in many countries in Asia.

Other challenges include insufficient data and a lack of experts to counsel the government (Gunarathne et al., 2019). Accurate waste generation and composition information is a prerequisite for a successful recycling programme. However, the systematic documentation of waste generation and composition is lacking in many Asian countries. Since recycling mainly exists as a private transaction between waste generators and private enterprises, there is no comprehensive data and information on the amount, composition, waste sources and waste characteristics within municipalities. Asian governments rely on relevant concessionaires and local agencies for the solid waste management database, especially when formulating and enforcing legislation. Municipal authorities provide data on waste minimization, and recycling is much more variable in terms of accuracy and consistency since surveys are not standardized. This results in inaccurate policies on recycling practices, particularly in home solid waste, despite ongoing efforts to increase awareness, such as source separation and recycling in sustainable waste management (Berglund, 2006). To further enhance present policy tactics and meet public needs, policymakers should be aware of the relationship between policy measures and current behavioural intentions (Wan et al., 2014).

Lack of funding and appropriate infrastructure. Lack of funding and proper infrastructure is another major challenge for recycling practices in Asian countries. Due to a lack of funding, many Asian countries either lack the necessary trucks for waste collection or have an insufficient number. Additionally, the lack of funds implies that these trucks are rarely fixed, which impacts the collecting system since they frequently break down. Additionally, a lack of funds prevents local councils from having the staff or resources necessary to manage the growing amount of waste effectively and prevents homes from getting appropriate waste bins. Further, the recyclers have not received any government support to make the industry profitable, such as tax breaks, VAT exemptions, or capital allowances for industry investment (Gunarathne et al., 2019).

Lack of infrastructure and knowledge of practices and technologies can also hamper recycling practices. The limited availability of technology or methods for properly processing or treating existing and new wastes is another hamper on developing recycling practices in Asian countries. Lack of information, such as on the chemical makeup of recycling products and country-adaptive technology; insufficient infrastructure or testing capabilities to classify and separate wastes according to their nature and hazardous material content, also affects the level of recycling. As a result, it might not be possible to ensure the required level of quality for the recycled output to be tradeable (Ezeah et al., 2013, World Bank, 2007).

Lack of stakeholder involvement. Although central/local municipal governments in Asian countries oversee solid waste systems, there is still a lack of capacity and focus on managing solid waste systems at all levels. The communication and links between trash producers, collection service providers, waste pickers, traders, recycling centre owners, NGOs and end users are also limited. Proper coordination and connection between the stakeholders are required to provide adequate separation of reusable and recyclable materials at sources, establish collection stations and enable effective transportation by collectors. Lack of cooperation and inconsistent operating procedures restrict prospects of improving the efficiency of recyclables collection, which would prevent recycling from being as effective as possible (Tarmudi et al., 2012). Municipalities, different governmental levels, private concessionaires and the general public should work together to fill each other's gaps, which occasionally could be impossible to handle individually.

Moreover, a traditional top-down approach by related authorities and organizations in implementing recycling programmes is usually imposed without involving the public in decision-making. For example, the types of waste materials people are willing to recycle, the collecting methods that are convenient for them, or the financial resources needed to support these recycling programmes. The top-down method of governance creates passive residents who rely on local authorities to resolve issues and justifies shifting the burden of problem-solving to these government representatives (Ho, 2002). Since they pay taxes to the local governments, households in most Asian countries frequently rely on

local authorities and municipal garbage collectors to handle waste concerns, including source separation and recycling.

Little regard for waste pickers and the informal sector. Another ongoing challenge is the lack of recognition for the contribution of informal sectors. This may be due to the adoption of almost Western-style recycling systems in many Asian nations. In Western countries, due to intrinsic and effective waste separation and management systems, scavenging waste is illegal, and the roles of scavengers are insignificant (Pariatamby and Fauziah, 2014). However, in Asia's developing countries, waste pickers fill a niche by manually sorting, cleaning and selling recyclable wastes. Waste pickers in Asia exist due to the lack of waste separation programmes and the possibility of making a living by manually handling waste. Although there is generally legislation in place to prohibit or restrict scavenging activities, enforcement is often slack. This allows waste pickers to continue their work despite their status as unrecognized, trespassers on landfills or illegal collectors of waste. As a result, their misery and physical condition are not monitored despite their contribution to recycling. Since waste pickers frequently come from severely underprivileged backgrounds and are on the periphery of society, they should receive the proper respect and protection. Incorporating existing informal recycling systems into formal MSWM can bring significant benefits to Asian countries (Ezeah et al., 2013).

Drivers towards the success of waste management changes

The concept of 'System Drivers' is defined as an event that changes the status quo of an existing waste management system (in either a positive or negative direction), be it legislation that encourages an integrated approach to waste management or a change of public perception of a MSW management system (Agamuthu et al., 2009). In this review, four groups of drivers of sustainable waste management, specifically in Asia, are explained. The four groups of drivers consist of three human elements (human, economic and institutional) and the environment as a single driving group.

Wilson et al. (2006) studied sustainable waste management in several European cities and defined drivers as factors that positively (termed facilitators) or negatively (termed constraints) alter an existing waste management system. Wilson (2007) elucidated the history of waste management and its drivers in the European Union and North America.

As more countries in Asia realized their annual economic goals, there will be an increase in the standards of living. With increased affluence comes increased consumption and increased waste generation. Increased waste generation is a major driver catalysing the growth of the waste management industry. Other drivers that affect the paradigms, policies/strategies and waste management trends are often subtle and poorly elucidated. There have been few attempts to identify the groups of waste management drivers and none for Asia's general waste management scenario. The academic effort has been concentrated mainly on technical/operational aspects, namely improving current practices/techniques and innovating new ones. Policy research and trend studies are often seen as a governmental domain and have only recently received participation from scientific researchers (Gemechu et al., 2022).

Group of human drivers

The increase in human population with increase in human activities has caused an increase in the volume of waste generated. The presence of waste creates the basic need for sustainable waste management operations. The need has a ripple effect – it drives legislation, action by the authorities, technical and technological innovation, etc. A quantitative and logical connection exists between an increasing population and increasing waste generation. Human activity inevitably generates waste materials, which is the quintessential waste management driver (Agamuthu and Law, 2020).

Health and well-being

The mandate of proper sanitary management and healthcare spurs the construction of drains, reservoirs, water treatment plants or landfills and the implementation of solid waste collection and recycling. This is the health driver in the group of human drivers. Effectiveness between governments can be informally compared by the availability and effectiveness of public amenities, cleanliness of the constituency, percentage of the urban population or low-income communities provided with waste collection services or the percentage of wastes properly disposed and recycled (Agamuthu et al., 2009).

Education and awareness

Education of the public and awareness of current environmental issues are important drivers in the group of human drivers. Education will influence the way humans respond and cooperate on waste management issues. Any waste management policy requires cooperation from all sides, especially from the general public. Abbreviations like NIMBY (not in my backyard), LULU (locally unacceptable land use; Wilson et al., 2006) and NOTE (not over there either) are frequently used to describe resistance from the public towards new waste management or disposal programmes. Education and awareness can soften this resistance. Waste management campaigns must begin with the dissemination of information to secure the public's agreement or cooperation. When information is disseminated, the public becomes better informed of the campaigns' objectives, strengths and weaknesses and can participate accordingly. This promotes creative responses to any shortcomings (Debrah et al., 2021).

Group of economic drivers

The group of economic drivers is divided into two: the availability of funds, socioeconomics and the profit from waste. A waste management policy can only be deemed effective when waste

materials are consistently managed (which is heavily dependent on the availability of funds) for a period of time. This requires waste management administrators to have sufficient funds for that period or the necessary infrastructure to collect revenue or earn profits from investments. Planners must examine their organization's financial health before deciding if and how wastes in their region can be managed. On the other hand, scavenging wastes for items that are salvageable to be sold is also a major economic driver for the 3Rs (reduction–reutilization–recycling; Agamuthu and Law, 2020).

Availability of funds and socioeconomics

It requires a lot of money to run waste management operations, so the availability of funds is the most influential driver of all. There is a persistent legislative problem of funding sources for solid waste management. The problem is serious in the cities of developing countries in Asia. Waste administrators do not see eye to eye with the public and its lawmakers. For example, MSW management funds for cities in India are obtained by revenue and other taxes but are generally insufficient (Agamuthu et al., 2009).

Group of institutional drivers

The group of institutional drivers can be considered human activity *en masse* – at the research, governmental or business level. It has great potential for change but is ultimately dependent on the efforts of many people, scientific research and development. The vision of academic research does not always contribute to industrial or applied activities but new and innovative research is changing waste materials' perception, utilization and management policies. In Malaysia, compost production was reported on rural/sub-urban MSW (Blaise and Agamuthu, 2004), and compost derived from agricultural waste has been used as a low-cost cover on closed landfills in tropical conditions to reduce methane emissions (Agamuthu et al., 2020).

The environment as a driver

1. Economically developed Asian countries (e.g. Japan, Singapore and the South Korea) have waste management practices that are environmentally sustainable, but historically, this has not been the case in developing countries. Environmental issues – global warming, increasing carbon emissions and the lack of potable water – drive current trends in science, education, waste management, disposal and research. This is also reflected in governance; policies are now formulated or amended to include environmental considerations. Thus, only recently has the environment become a major waste management and disposal driver in greater Asia. The availability of a country's environmental resources drives individual waste management procedures. The need to use the land for residential or commercial purposes precludes the establishment of waste disposal methods such as landfills or incinerators. Other natural factors (geological/ geographic suitability, safety, etc.) also affect the type of waste disposal (Agamuthu et al., 2009).
2. Sustainable waste disposal programmes require significant financial investment in education, technology and equipment that renders it too expensive when people's basic needs (food subsidies, budget for housing and education, etc.) are considered. Thus, people use the methods previously explained.
3. Ineffective policies or planners who react slowly to change. The environment is now increasingly prominent as a waste management policy driver. Several types of institutional drivers (worldwide environmental protocols, the push from worldwide CDM initiatives, more effective communication of scientific research, and a greater willingness to adopt evidence-based policies) have contributed to the environmental driver being given greater consideration in policy formulation. Aside from the institutional drivers, the economic/ human drivers, through financial contributions and technical advice from United Nations Environment Programme (UNEP), the World Bank and individually developed countries, have also augmented the effect of the environmental driver (Giulia et al., 2021).

Conclusions and recommendations

The authors believe that in Asia, especially in developing countries, the economic driver historically has the highest impact. Recently, environmental and political trends have increased the impact of the environmental driver. Still the developing Nations in Asia are influenced by economic drivers, whereas developed nations such as Japan, Korea and Singapore are influenced by environmental drivers more than economic drivers. Success of integrated waste management lies on source separation and adopting the concept of circular economy. Indore city in India is a successful example of good solid waste management. Japan through its strict regulations and enforcement is also able to achieve its goal in implementation of 3R and public participation.

Funds are not always available for waste management, which drives community initiatives for waste collection and disposal. Many people in Asia benefit from sorting solid wastes and selling recyclable materials. This trend has somewhat continued in the last five decades. Formalization of informal recyclers are recommended.

The authors support the notion that the effectiveness, enforcement and practicality of laws related to sustainable waste management often make the difference between success and failure, especially when the public's attitude is concerned. It is hoped that the groups of drivers elucidated are seen as conceptual signposts for waste management planners or as a checklist of factors to be investigated at the local level when making decisions, especially in Asia.

Lastly, lack of reliable data and transparency have hindered waste management over the years in developing nations in Asia. Positive changes are evident in some countries, but serious integrated efforts are necessary to see real improvement in Asia as a whole.

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