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WASTE TO ENERGY

CONSIDERATIONS FOR INFORMED DECISION-MAKING

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Acronyms

CEWEP	Confederation of European Waste-to-Energy Plants
EEA	European Environment Agency
IPCC	Intergovernmental Panel on Climate Change
IRENA	International Renewable Energy Agency
ISWA	International Solid Waste Association
MSW	Municipal Solid Waste
NIMBY	Not In My Back Yard
3Rs	Reuse, Reduce, Recycle
GAIA	Global Alliance for Incineration Alternatives
GIZ	The Deutsche Gesellschaft für Internationale Zusammenarbeit GmbH
PAHO	Pan American Health Organization
SAT	Sustainable Assessment of Technology
OECD	The Organization for Economic Cooperation and Development
UKWIN	United Kingdom Without Incineration Network
UNEP	United Nations Environment Programme
UNSD	United Nations Statistics Department
WtE	Waste-to-Energy

Foreword

Early 2019 marked the fourth United Nations Environmental Assembly, held in Nairobi, Kenya. Delegates discussed and resolved to reduce single use plastics, and better manage waste. Much of the discourse was centred around transitioning to a "green circular economy", sustainability, climate neutrality and "zero" waste. Clearly in an ideal world – one where all these concepts are a reality – there would be no need for waste-to-energy plants.

At the same time, waste collection services in most African countries are inadequate, with an average Municipal Solid Waste collection rate of only 55%, and over 90% of waste generated in Africa disposed of in uncontrolled dumpsites or landfills, often with open burning. Clearly, in the same ideal world, there would also be no open burning, and related toxic emissions, in heavily populated areas.

The Reduce, Reuse, Recycle (3Rs) mantra has been the core of waste management philosophy and strategy for the last several decades. Over the same time period, waste volumes have risen dramatically around the world. Recycling rates, even in some of the wealthiest cities in the world, have recently decreased or plummeted, often with recyclable material being diverted directly to landfill, or in some cases to waste-to-energy plants. In light of these trends, "Reality-check" might be a good fourth R to consider. It is all well and good to talk about circular, green, sustainable economies which don't generate any waste as aspirational targets, but the road from where we are now needs to be paved with sincere efforts to decrease the staggering flow of waste into our environment. At the same time, as this report points out, we cannot blindly implement solutions that we think are necessary, yet which could unfortunately, and ironically, lock us in to waste treatment options that actually remove incentives to reduce our generation of waste.

So, while it is certainly true that waste-to-energy plants don't have a place in a circular economy, neither do open burning and dumpsites. In addition to striving for perfection, decision makers contemplating investing in waste-to-energy solutions must seriously consider the reality on the ground. This report provides a balanced overview of trends in the numbers of municipal solid waste-to-energy plants around the world, and their impacts on people and the environment, including climate. It outlines key considerations to assist decision makers in developing countries when contemplating thermal waste-to-energy plants as a waste management option, while recognizing that it is important to always reduce, reuse and recycle before relying on incineration. Finally, as with every technology, investment and installation are never the end of the story. Integration within the local socio-economic context as well as long-term monitoring and maintenance are the only way to make technology work for us. This report approaches thermal waste-to-energy plants from a holistic perspective, positing that this knowledge-based outlook will lead to the positive and progressive outcomes for people and communities that help them to thrive.

Keith Alverson
Director
International Environmental Technology Centre
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Executive summary

Thermal Waste-to-Energy (WtE), also known as incineration with energy recovery, is a major waste treatment method in some developed countries and the most widely adopted technology that dominates the global WtE market. The European Union, however, which has relied on waste incineration for the past few decades, is now moving away from thermal WtE and other forms of incineration and is focusing on more ecologically acceptable solutions such as waste prevention, reuse and recycling as it shifts towards a circular economy. Though thermal WtE is still used in developing countries as a waste management approach, in particular Asia Pacific countries such as China, India, and Thailand, it is located at the bottom of the waste management hierarchy below reduction, reuse and recycling. These three actions are now increasingly recognized as priorities for governments in terms of policies and investments. All materials have an end-life and eventually become waste, and in these cases thermal WtE is the preferred way of treatment compared to landfilling and open burning. Thermal WtE has received considerable attention in developing countries due to its potential benefits for waste volume reduction and energy generation despite continuing concerns in regard to its applicability and potential health, environment and climate change impacts. Thermal WtE development also remains a challenge in developing countries due to factors such as waste characteristics, social opposition, economic feasibility and noncompliance of environmental standards.

This report aims to illustrate the key facts and major considerations of thermal WtE implementation for informed decision-making in developing countries, taking into account that it should be the option of last resort. An **overview** of the development and global status and trends that includes a description of thermal WtE technology is presented first, followed by the **challenges** for developing countries in terms of technical, economic, environmental, legal and social aspects. A discussion of thermal WtE **opportunities** under different contexts, including the climate perspective and the context of small island developing states, follows. The last chapter presents key **considerations** for decision makers when implementing thermal WtE in developing countries.

SCOPE OF REPORT

The scope of this report is exclusively on **thermal WtE** in developing countries. The overall objective of this report is to provide key considerations to assist **decision makers in developing countries** when scrutinizing thermal WtE as a waste management option.

KEY FINDINGS AND MESSAGES

1. The **waste management hierarchy should be used** for integrated solid waste management systems. Reduction, reuse and recycling should be prioritized and incorporated into waste management plans that include thermal WtE recovery options.

2. There have been significant improvements in emissions control for modern thermal WtE technologies compared to WtE technologies from the 1970s to the 1990s. Thermal WtE plants with advanced emission control technologies that are well-maintained have **minimum public health impacts**. Nevertheless, mismanaged thermal WtE plants have been shown to produce unsafe emissions, despite advanced emission control technologies.

3. In developing countries, the **low calorific value and high moisture content of waste** remain critical technical challenges for thermal WtE. Low calorific value of waste should average at least 7 MJ/kg, and never fall below 6 MJ/kg.

4. A large scale modern thermal WtE plant requires **at least 100,000 tonnes of MSW per year** over its lifetime. As with all large investment projects, thermal WtE can potentially **create lock-in effects** that may lead to plant overcapacity and hamper efforts to reduce, reuse and recycle.

5. Thermal **WtE requires significant investment for startup, operation and maintenance** A holistic cost benefit analysis should be carried out in the local context to assess the social, legislative and enabling conditions of the plant's life cycle. Income from waste disposal and energy sales is often insufficient to cover full investment and operational costs.

6. A **complete and detailed legislative framework** is a prerequisite for thermal WtE introduction in developing countries. The framework should include strategies for maintenance and plant decommission, a phase out plan, pollution monitoring, guidelines on safe disposal of toxic by-products, medical monitoring and health care for plant workers and the local community, and guidelines for accident management.

7. Thermal WtE **utilizes the energy value in waste to generate electricity and/or heat** The biogenic component of waste overall contributes to approximately one per cent of global renewable energy.

8. Thermal WtE can potentially reduce waste sector greenhouse gas emissions compared to open burning and landfills without methane gas capture and use, but **will not completely abate greenhouse gas emissions.**

9. Thermal WtE can **reduce the volume** of waste entering landfills by 75–90 per cent, but it **does not remove the need for landfills**. In addition, it can produce residues that are hazardous and require safe disposal.

10. **Achieving Integrated Sustainable Waste Management** requires integration of appropriate collection with different technologies and waste treatment methods and governance systems in the local context.

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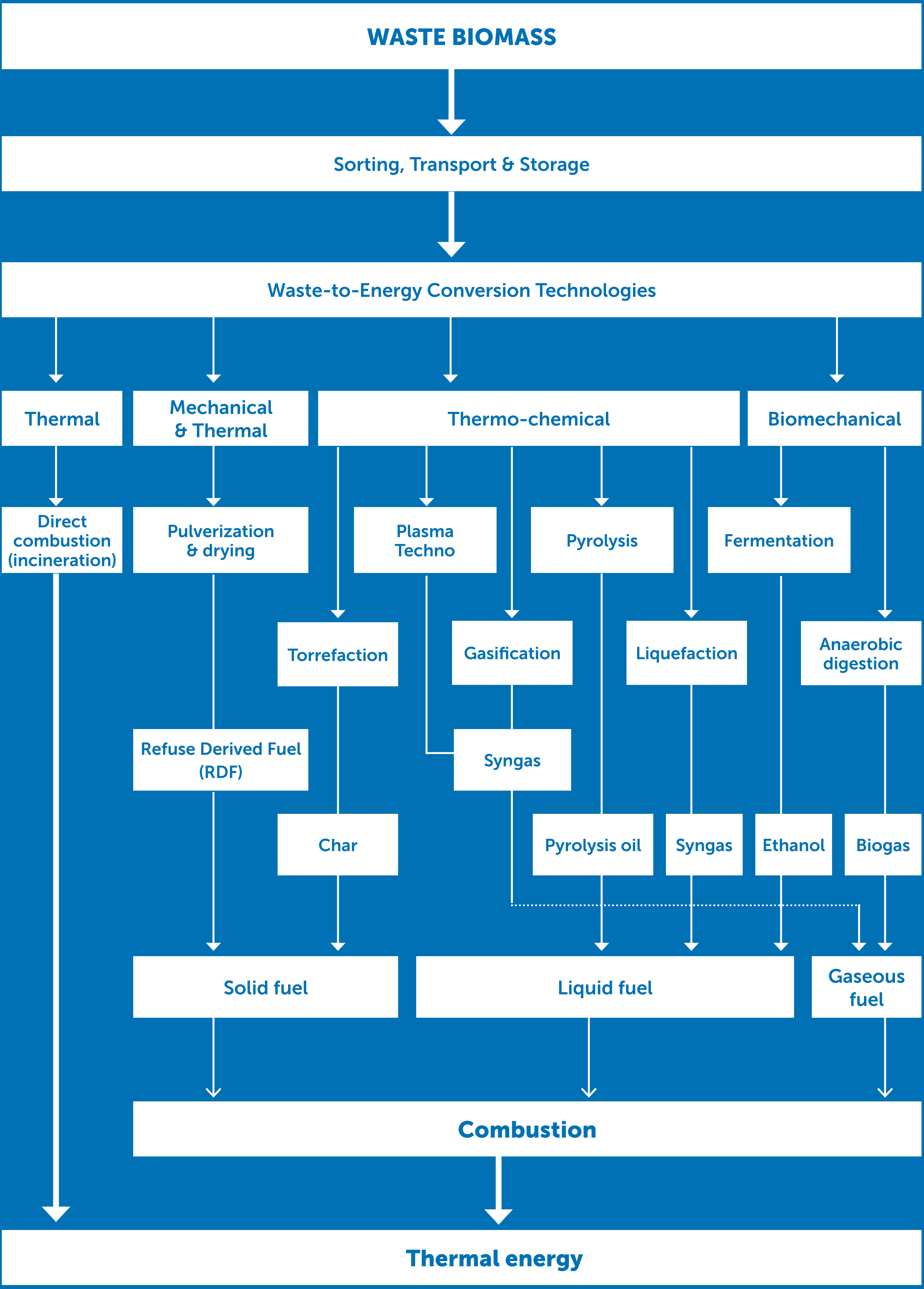
Background

Waste-to-energy (WtE) refers to a variety of treatment technologies that convert waste to electricity, heat, fuel, or other usable materials, as well as a range of residues including fly ash, sludge, slag, boiler ash, wastewater and emissions, including greenhouse gases. Based on its energy conversion processes (Figure 1.1), WtE is classified into four categories: thermal, mechanical and thermal, thermo-chemical and biochemical. In the waste management hierarchy, it can also be classified into disposal, other recovery or recycling operations, according to the energy products produced and recovery level (Figure 1.2).

Figure 1.1 Types of WtE technologies (Gumisiriza et al. 2017)



1.1 DEFINITION

This report focuses on **thermal WtE** (i.e. incineration with energy recovery) due to its recent emergence in developing countries and wide global application. WtE facilities are often known as **WtE plants**. In the following chapters, plants adopting incineration with energy recovery are referred to as **thermal WtE plants**.

Municipal Solid Waste (MSW) is a common waste source used in the thermal WtE process. Definitions of MSW vary among countries due to different legal frameworks. In general, however, **MSW must include waste items collected from households. In some countries, the definition will include commercial waste, hospital waste, and construction and demolition waste** (World Bank 2018; OECD 2019; UNSD 2019; IPCC 2006). The variation in MSW definitions leads to inconsistency of waste data, which makes direct comparison between countries difficult.

1.2 ANALYTICAL FRAMEWORK

This report examines waste-to-energy in the context of the circular economy and follows the framework of Integrated Sustainable Waste Management. A **circular economy** is an industrial system that is restorative by design (**Figure 1.3)**, which replaces the “end-of-life” concept with restoration (Ellen Macarthur Foundation 2013). It preserves resources, reducing the reliance on energy extraction and disposal that characterizes a linear economy. In a circular economy, resource and waste management follow the waste management hierarchy in order to preserve the value of materials as long as possible. Users should minimize, reuse, and recycle before discarding materials and products. Incinerating materials, regardless of the amount of energy that may be recovered, constitutes a leakage from a circular economy. **Figure 1.3** shows the role of thermal WtE in resource management in a circular economy.

Thermal WtE captures a portion of the energy embedded in waste as heat and/or electricity. In order of preference in the waste management hierarchy, thermal WtE is placed after prevention, minimization, reuse and recycling (**Figure 1.2)**. To follow the hierarchy, the diversion of waste from landfill or open dumps should go hand-in-hand with the creation of increased collection and recycling capacity and the implementation of waste prevention policies and programmes. It is equally important to avoid creating infrastructural barriers to the development of these upstream systems. WtE should always be considered in concert with the order of preference, and based on the context of each locality and how advanced its waste prevention and material recovery systems are (Ellen Macarthur Foundation 2013; UKWIN 2018; EEA 2016; European Commission 2017).

As over 80 per cent of global MSW is comprised of dry recyclables or organics, investment in prevention, recycling and composting can greatly reduce waste disposal, while providing opportunities to formalize the work of informal recyclers and strengthening local economies. Moreover, high-income countries are increasingly moving away from landfilling and incineration (including thermal WtE) and are increasing recycling and waste reduction to shift towards a circular economy (Zero Waste Europe 2018a; World Bank 2018).

Integrated Sustainable Waste Management provides a useful analytical framework for structuring thermal WtE considerations and decisions in developing countries. This report follows the Integrated Sustainable Waste Management system framework, which integrates all **physical elements**, related **stakeholders** and **strategic aspects** throughout the life cycle of thermal WtE implementation.

The integration of physical elements, stakeholders and strategies is known as the concept of **Integrated Sustainable Waste Management**, which has become the norm in discussions of solid waste management in developing countries (UNEP 2015)[1]. **Figure 1.4** below shows the basic schematic framework of Integrated Sustainable Waste Management. The first triangle’s three primary **physical elements** – waste collection, waste treatment and disposal, and the 3Rs – provide the necessary infrastructure for solid waste management. The second triangle focuses on **governance strategies**, including stakeholder inclusivity, financial sustainability and legislative framework.

Thermal WtE, as an energy recovery option among waste treatment methods, falls in the second category of physical elements in Integrated Sustainable Waste Management. Yet it is also closely related to other physical elements as it requires a well-developed waste collection system and existing recycling infrastructure for different waste streams. Thermal WtE is also associated with a cross section of stakeholders and includes strategic health, environmental, social, economic, technical and legal aspects. All strategic aspects, stakeholders and physical elements must be addressed when considering the introduction of thermal WtE into a waste management system.

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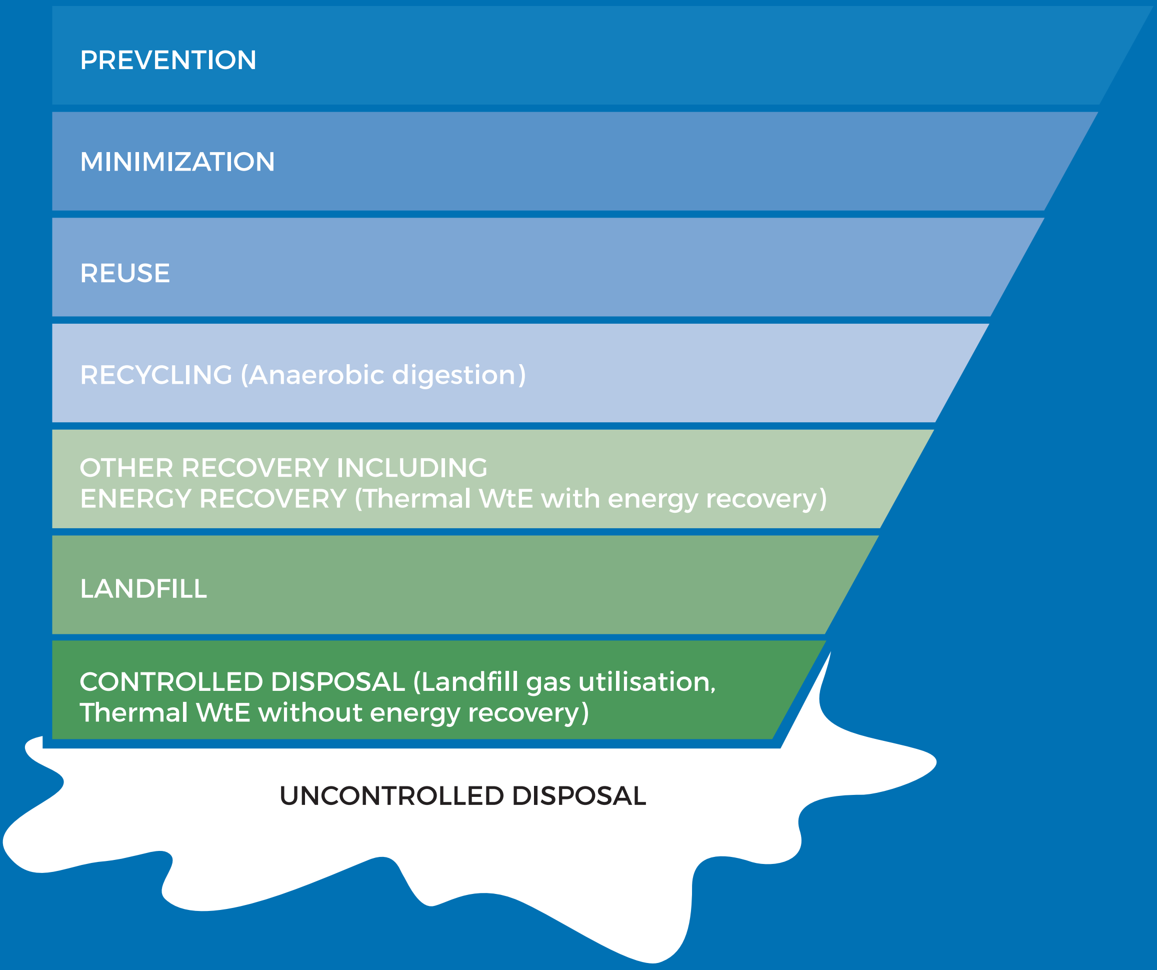
[1] The Integrated Sustainable Waste Management framework was first developed for the UN-Habitat “Solid Waste Management in the World’s Cities” (2010) publication, and later adopted by the Global Waste Management Outlook (UNEP 2015).

Figure 1.2 **Waste management hierarchy[2] (UNEP 2015; European Commission 2017).**



The waste management hierarchy is an order of preference for waste management options. Reduce, Reuse and Recycle (3Rs) are prioritized over other recovery and disposal options. The generally accepted principle is to move waste management up the hierarchy and take into account life-cycle thinking to reduce the environmental impacts of waste.

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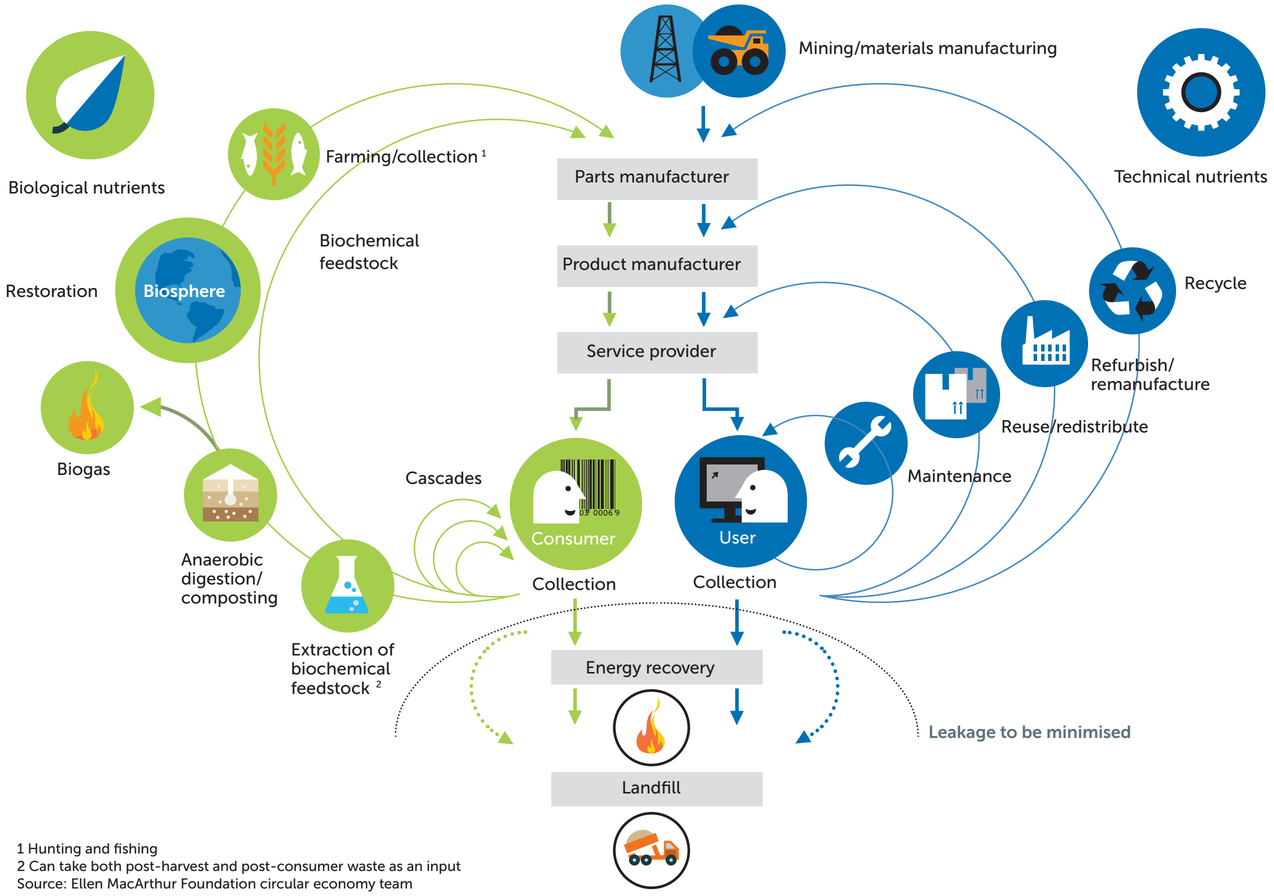
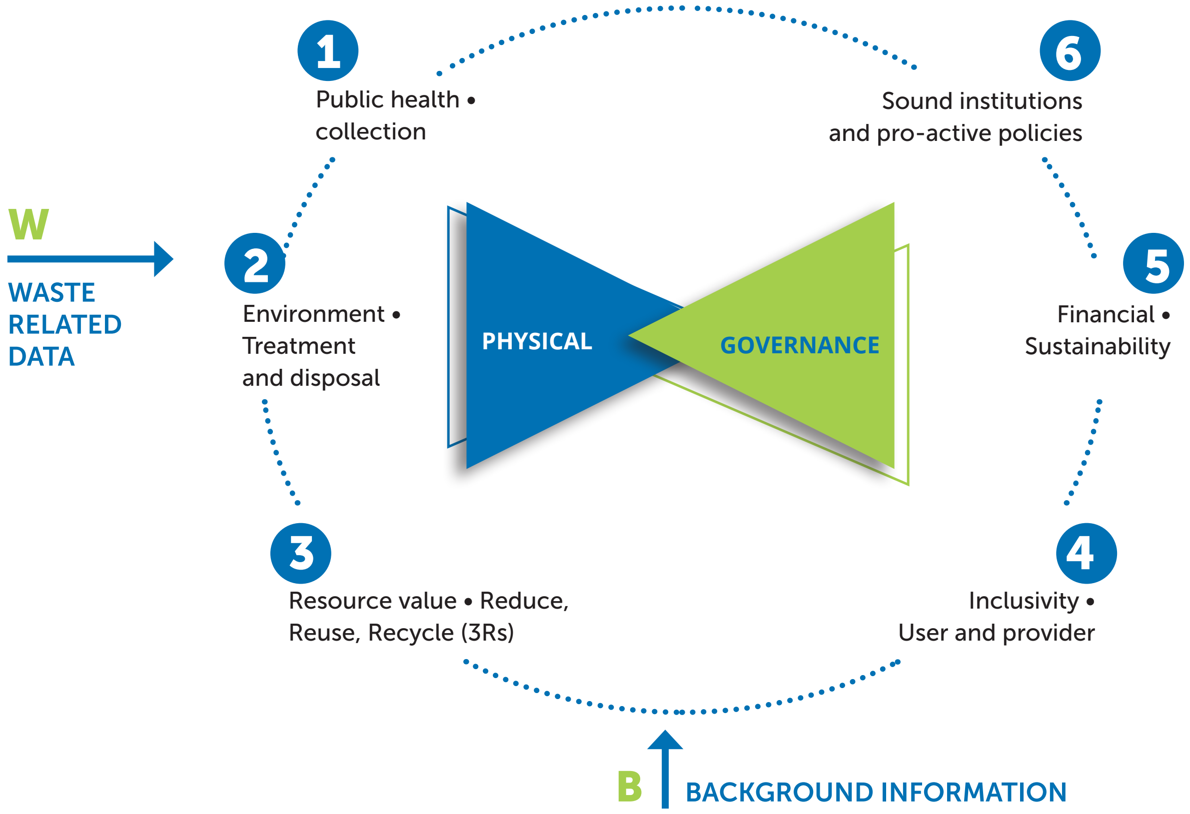
[2] Thermal WtE with energy recovery refers to an energy efficiency that meets the R1 formula as established by the European Commission Waste Directive 2008/98/EC, which suggests that only thermal WtE plants with energy efficiency equal to or higher than 0.60 (for installations in operation before 2009) or 0.65 (for installations permitted after 2009) are regarded as an energy recovery operation (European Commission 2017).

Figure 1.3 Resource management within a circular economy



1 Hunting and fishing
2 Can take both post-harvest and post-consumer waste as an input
Source: Ellen MacArthur Foundation circular economy team

Figure 1.4 Schematic framework of Integrated Sustainable Waste Management (UNEP 2015)



1.3 CURRENT WTE TECHNOLOGY

Table 1.1 Overview of WtE technologies

Type of technology	Incineration with energy recovery	Gasification	Pyrolysis
TECHNOLOGY DESCRIPTION	Direct combustion of waste between 750 and 1100°C in the presence of oxygen.	Partial oxidation of waste between 800 and 1200°C in the presence of a controlled amount of oxygen.	Thermal degradation of waste between 300 and 1300°C in the absence of oxygen.
MAJOR PRODUCTS	Produces steam for electricity and/ or heat generation in a boiler or steam turbine. Can generate heat or electricity, or combined heat and power.	Produces synthetic gas for further combustion or conversion to chemical feedstock.	Produces liquid fuel for further combustion or conversion to chemical feedstock.
WASTE INPUT	Mixed MSW or refuse-derived fuel.	Only suitable for relatively homogeneous waste streams, such as wood waste, agricultural residues, sewage sludge, and plastic waste.	
VOLUME REDUCTION*	75–90%	75–90%	50–90%
POLLUTION CONTROL REQUIREMENT	High	Medium	Medium
COST PER TONNE (IN US DOLLARS)*	95–190 For centralized facilities on a moderately large scale.	95–190 For centralized facilities on a moderately large scale.	95–190 For centralized facilities on a moderately large scale.
SCALE OF PLANT	Available from small to large scales. A centralized large scale plant is more common.	Available from small to large scales.	Available from small to large scales.
EXTENT OF USE	Widely applied in Europe, Japan and the United States. Increasing application in developing countries.	Not widely applied and only available at small scales. Commercial gasification plants are established in Japan and the Republic of Korea for 20 years with pre-treated waste as input.	Not widely established for MSW.
GENERAL APPLICABILITY	Suitable for mixed MSW but the waste quality and composition in developing countries may not be suitable without specific pre-treatment such as pre-drying. A district heating system is not common in low-income countries.	Potential for wood gasification technology.	Not established yet in developed or developing countries.

Composting	Anaerobic digestion
Aerobic bioconversion of organic wastes.	Biodegradation of (readily degradable) organic wastes in the absence of oxygen, with anaerobic microorganisms.
Produces compost which can serve as a soil conditioner, mitigate erosion, sequester carbon in soil, be used in land reclamation and as a final cover for landfills.	Produces biogas and digestate. Digestate can be composted for use as a soil conditioner or dewatered and used as a low calorific value refuse-derived fuel.
Separated organic fraction of MSW, food waste, or other solid organic waste. Suitable to treat material high in lignin (woody).	Separated organic fraction of MSW, food waste, animal/human excreta, or liquids and sludges. Less suitable for high in lignin (woody) material.
95–100%	45–50%
Low	Low-medium
0 –70 For small scale composting. At a pilot site running in Phnom Penh, Cambodia, for example, the cost can be made-up by the value of the end product.	65–120 For centralized facilities on a moderately large scale. Cost depends on subsidies for renewable energy.
Available at the household scale (home composting), community scale (backyard, vermicomposting), or at a centralized, large scale (window, aerated static pile, in-vessel).	Available in decentralized small scale digesters (including on-farm), and large scale digesters for the organic fraction of MSW.
Widespread in high-income countries. Asia has a long tradition of making and using compost.	Widespread use for non-MSW, and increasing use for clean organics from separate collection of MSW, including using anaerobic digestion followed by composting.
High potential, particularly in developing countries with a high organic fraction of MSW. Not yet widespread due to operating costs and need for source separation. Severe environmental impacts such as methane emissions, odour, leachate, bioaerosols, particulate matter, etc have to be assessed and kept technologically under control during operation.	Small scale anaerobic digesters are used to meet the heating and cooking needs of individual rural communities.

Note: The volume of waste reduction depends on its composition, the specific type of technology used, and the amount of bottom ash recycled. For incineration with energy recovery, gasification, and pyrolysis, the typical volume reduction is 75 per cent, while higher volume reduction can be attained through recycling of bottom ashes.
* Cost per tonne (in US dollars) refers to the estimated net operation and investment costs minus revenues from resource recovery. The estimated cost depends on the income level of the country. The term “refuse-derived fuel” is used in this table to designate all processed fuel outputs.
Source: Moya et al. 2017; Beyene et al. 2018; World Energy Council 2016a; UNEP 2015.

1.4 THERMAL WTE DEVELOPMENT

Thermal WtE was first developed in Europe, with the earliest plant dating back to 1874 in Nottingham, England. In the early and mid-twentieth century, thermal WtE was extensively applied in developed countries such as Japan and the United States, as well as in European countries, as a part of the waste management system. The development of thermal WtE in Japan is illustrated below.

THERMAL WTE DEVELOPMENT IN JAPAN

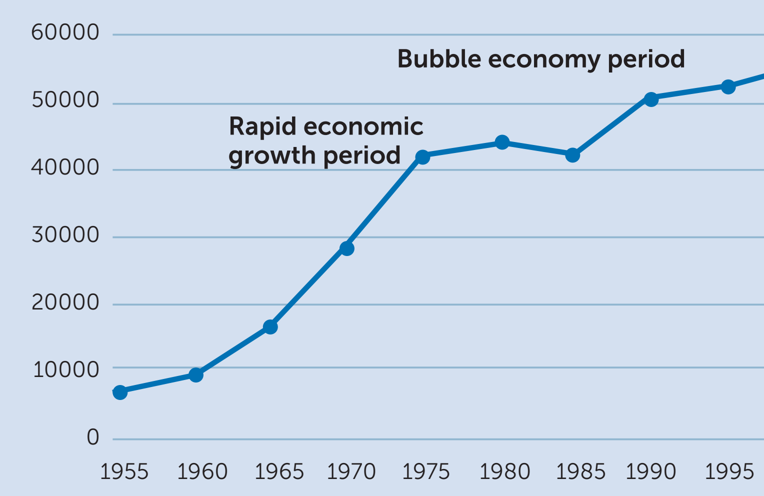
1960s–1970s:
Thermal WtE plant pollution problems

In the 1950s, waste incineration plants were introduced in Japan. From the 1960s onwards, a period of rapid economic growth led to extensive urban development and an increase in income that changed consumption behaviour, leading to an abrupt increase in municipal and industrial waste generation (Ministry of the Environment, Government of Japan 2014). To solve its growing waste problem, a large number of incinerators were built in Japan.

1980s–1990s:
Technological development

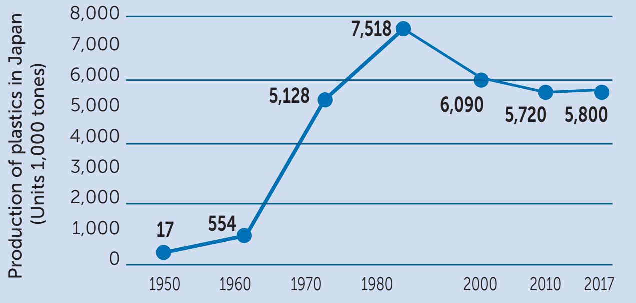
Dioxin emissions from incinerators were first reported in Japan in 1983, drawing attention from the public to the emissions of these and other acidic gases, as well as other hazardous materials from incineration, that caused serious air, water and soil pollution, as well as public health concerns. Incinerators emitting high concentrations of dioxin were forced to close down due to public opposition, for example the incinerator in Nose Town in Osaka Prefecture (Ministry of the Environment, Government of Japan 2014). To tackle the dioxin problem, the development of dioxin and pollution control technology escalated quickly during this period. In 1997, the Government of Japan revised its Guidelines for Reduction of Dioxin from 1990. At the same time, the Waste Management Act was revised to reinforce the structure and maintenance standards for waste incinerators. In 1999, the Act on Special Measures Against Dioxins was implemented to manage dioxin emissions. Dioxin emission standards were reinforced for existing plants (1 to 10 ng-TEQ/Nm^3) and new plants (0.1 to 5 ng-TEQ/Nm^3).

Figure 1.5 MSW generation in Japan[23]



MSW generation in Japan has been gradually decreasing in recent years
packaging during this time, and is now generates the second largest am

Figure 1.6 Plastic production in Japan



Source: Japan Plastics Industry Federation 2019

The production of plastic waste increased by more than 13-fold from 1960 to 1980 in Japan.

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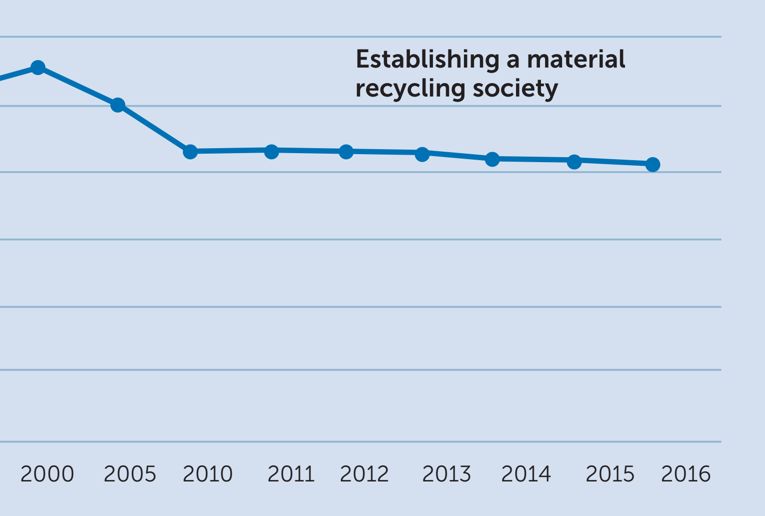
3 Data retrieved in Oct 2018 from the waste database of the Ministry of Environment, Government of Japan

2000–Present: Prioritizing the 3Rs

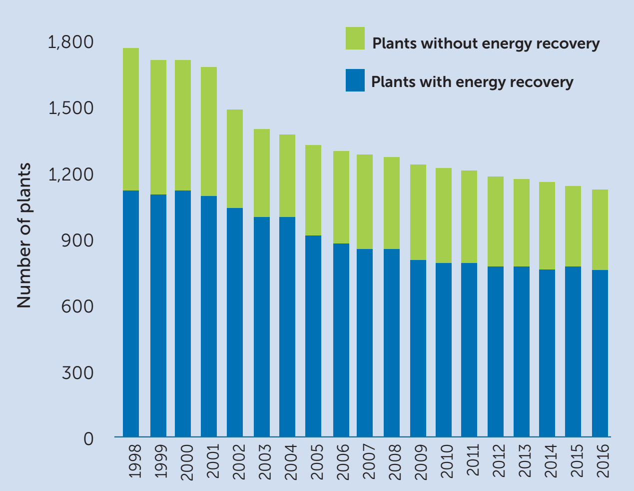
Current pollution control technology has greatly reduced the level of dioxins from incinerators compared to 1990s levels. If proper emission controls have been installed in thermal WtE plants, dioxin emissions from waste incineration are no longer a threat to public health. Since 1998, Japan has been slowly phasing out small capacity incinerators, as well as those without energy recovery (**Figure 1.7**), and increasing the energy efficiency of thermal WtE plants. MSW generation peaked in Japan in the year 2000 after the introduction of *The Basic Act for Establishing a Sound Material-Cycle Society as a Framework*, and the following specific recycling laws:

- Containers and Packing Recycling Act (1995)
- Home Appliance Recycling Act (1998)
- Food Recycling Act (2000)
- Green Purchasing Act (2000)
- Construction Recycling Act (2000)
- Automobile Recycling Act (2002)
- Small Appliance Recycling Act (2012)[4]



. Japan, however, has produced substantial plastic
ount of plastic packaging per capita (UNEP 2018).

Figure 1.7 Number of waste incinerators with and without energy recovery in Japan[4]



LESSONS LEARNED

Waste management progress in Japan provides a good example of energy recovery for less developed countries. Technological advancement allows developing countries to choose the less polluting thermal WtE technology, compared to what was available to them in the past. In concert with these new technologies, waste management strategies should be implemented based on local needs and subjected to periodic review and adjustment. It is important to note that the waste hierarchy is not a ladder for a waste management system. Developing countries should consider leapfrogging and adopting a top-down approach to introduce the 3Rs in their waste management systems before considering thermal WtE recovery options.

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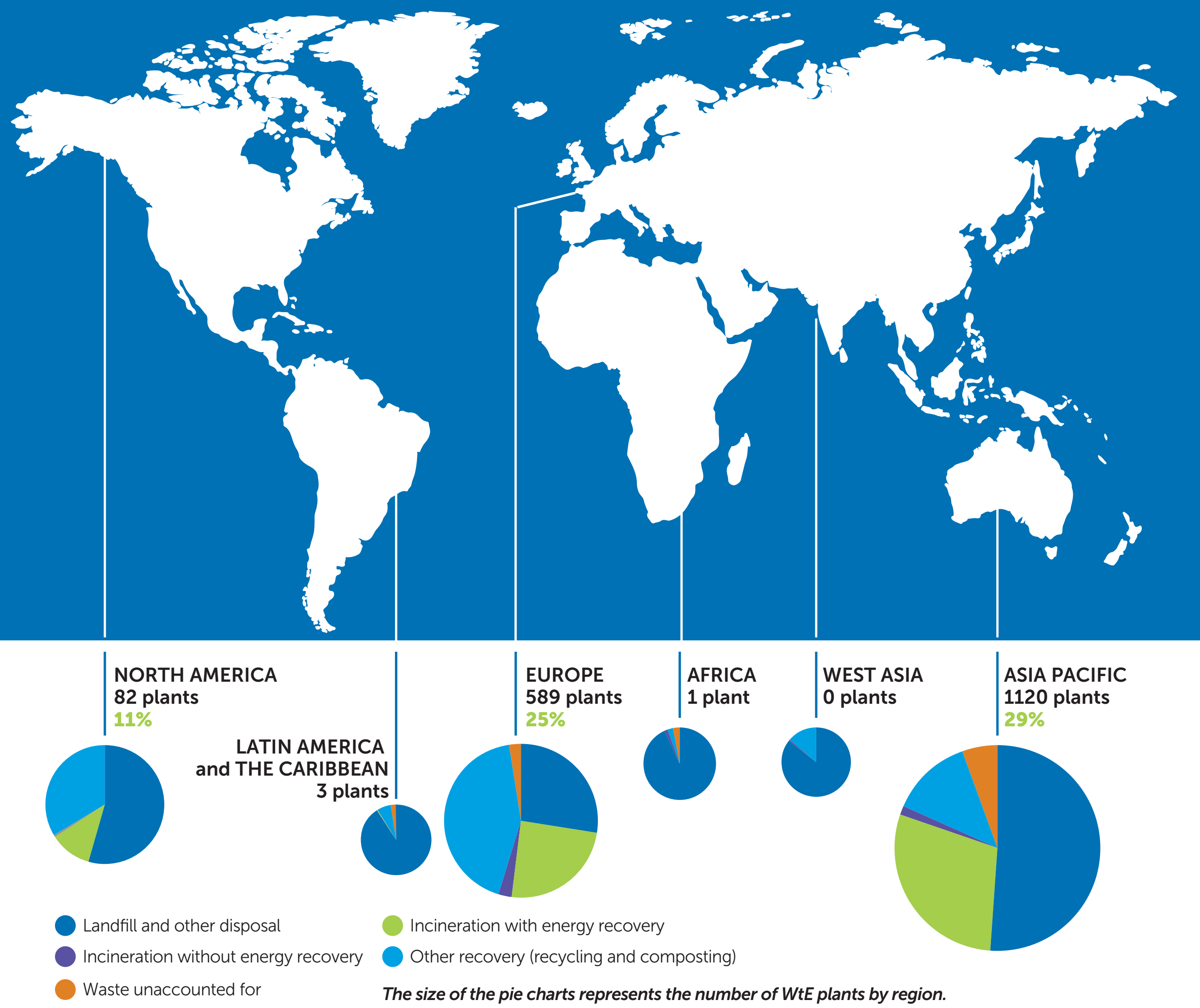
[4] Data retrieved in Oct 2018 from the waste database of the Ministry of the Environment, Government of Japan 2019

Figure 1.8 MSW incinerated with energy recovery and number of thermal WtE plants (by region)



The size of the pie charts represents the number of WtE plants by region.

Table 1.2 Waste treatment method in the six regions (by percentage)

	Landfill and other disposal	Incineration with energy recovery	Incineration without energy recovery	Other recovery (recycling and composting)	Waste unaccounted for
Asia Pacific	51.2	29.2	1.3	12.9	5.3
Europe	27.5	24.7	2.7	42.9	2.4
West Asia	89.5	0.0	0.7	15.5	0.02
Africa	93.1	0.0	1.6	2.3	3.0
North America	54.8	11.2	0.5	33.6	0.0
Latin American and the Caribbean	91.2	0.1	0.1	6.4	2.4
Global Average	59.8	15.2	1.2	22.2	2.4

Note: Estimation derived from latest available data from 122 countries, and extracted from the UNSD (2019), OECD (2019) and the World Bank (2018) "What a Waste 2.0" report. Years of data range from 2000 to 2016.
Incineration with energy recovery is often reported together with incineration without energy recovery as one combined category in waste databases, including at UNSD and the World Bank. Waste data reported by the OECD is the only data accounting for incineration with and without energy recovery. The percentage for incineration with energy recovery includes countries from the OECD with reported data, and assumes countries with reported data from the UNSD and the World Bank that own thermal WtE plants incinerate MSW with energy recovery.
"Waste unaccounted for" refers to the percentage of waste without a reported waste treatment method.

1.5 GLOBAL STATUS AND TRENDS

CURRENT STATUS

Globally, 216 million tonnes of collected MSW are incinerated each year, of which 15 per cent is incinerated with energy recovery (**Table 1.2**). Thermal WtE accounts for 29 per cent and 25 per cent of MSW incinerated in Asia Pacific and Europe respectively (**Figure 1.8**). At more than 50 per cent in all but one world region, landfill and open dumping remain major waste treatment methods. For example, over 90 per cent of collected waste in Africa and Latin America and the Caribbean is disposed of in landfills or open dumps (UNEP 2018).

There are over 1,700 thermal WtE plants worldwide (**Figure 1.9**). Over 80 per cent of thermal WtE plants are located in developed countries, led by Japan, France, Germany and the United States. Despite a great difference between the two countries in the number of thermal WtE plants, Japan and the United States both incinerate a similar amount of MSW with thermal WtE recovery. Many of the thermal WtE plants in Japan have only small incineration capacity. At present, the only thermal WtE plants in Latin America and the Caribbean are located in territories under European jurisdiction (Bermuda - Overseas British Territory, Martinique - French overseas region, and Saint Barthélemy - French overseas collectivity). The only thermal WtE plant in Africa is in Ethiopia (**Box 3**), and there are currently no operational plants in West Asia.

The global WtE market was valued at 9.1 billion USD in 2016, and is expected to increase to over 25 billion USD by 2025, maintaining a steady compound annual growth rate of over 5.5 per cent according to conservative estimates (**Figure 1.10**) (World Energy Council 2016b). Thermal WtE is the most widely established WtE technology and it leads the global market, accounting for 88.2 per cent of total market revenue in 2013 (World Energy Council 2016b).

Biogenic municipal waste is regarded as a renewable bioenergy source in some countries (IRENA 2018). Renewable energy generated 10 per cent of global electricity among all energy sources in 2015 (**Figure 1.11**) (World Energy Council 2016b). Biogenic municipal waste contributed to approximately 1 per cent of global renewable energy generation, amounting to a global total of 52 TWh of electricity in 2016 (IRENA 2018).

Globally, more than 200 thermal WtE plants are currently under construction and will be operational between 2020 and 2023. Thermal WtE plants are emerging in developing countries in Asia Pacific, including China, Thailand, the Philippines, Indonesia and Myanmar.

The major drivers of thermal WtE growth in developing countries include:

LAND CONSTRAINTS
Thermal WtE can reduce waste volume and mass by 75–90 per cent, thus reducing the demand for landfill space.

ENERGY GENERATION
The energy value in waste can be utilized to generate electricity and heat during the thermal WtE process. The biogenic fraction of waste in thermal WtE can contribute to a portion of a country's renewable energy.

CLIMATE CHANGE IMPACT
Thermal WtE plants reduce greenhouse gas emissions by diverting waste from landfills and open burning and by replacing fossil fuels, leading to incentives for developing countries to achieve climate goals.

PUBLIC HEALTH AND ENVIRONMENTAL CONCERNS
In many developing countries, waste is often disposed of in open dumpsites. A shift to thermal WtE could improve hygienic and environmental conditions in these countries.

Thermal WtE is technologically mature and proven to greatly reduce waste volume. It is also energy-efficient and environmentally sound, if implemented with advanced technologies (**Table 1.1**). However, the lack of appropriate pollution control and monitoring standards, as well as lack of installed capacity, in most developing countries necessitates careful management of WtE plants and their by-products. This is often further compounded by a lack of strict emission standards and enforcing mechanisms, testing and analysis laboratories and controlled landfills for ash disposal, in addition to public health and environmental concerns over mismanaged plants. It is also debatable whether thermal WtE contributes significantly to climate change mitigation.

Figure 1.9 Top 11 countries with the most thermal WtE plants, including amount of waste incinerated with energy recovery

* Waste incineration data for China includes incineration with and without energy recovery.

Box 1 The world's largest thermal WtE plants

The world's largest thermal WtE plants are currently under construction in Shenzhen East, China and Dubai, United Arab Emirates. Both plants can process over 5,500 tonnes of waste per day, and will be operational by 2020. The plant in Dubai has a capacity of 185MW, which is roughly 2 per cent of Dubai's annual energy consumption. The plant in Shenzhen East has a capacity of 165MW and can handle one-third of the waste generated by the city of Shenzhen.

Dubai WtE plant.

Shenzhen East WtE plant with solar panel rooftop.

Source: Schmidt Hammer Lassen 2019; United Arab Emirates Government 2019

Figure 1.10 Conservative forecast of growth in global investment in all WtE technologies (Ouda and Raza 2014)

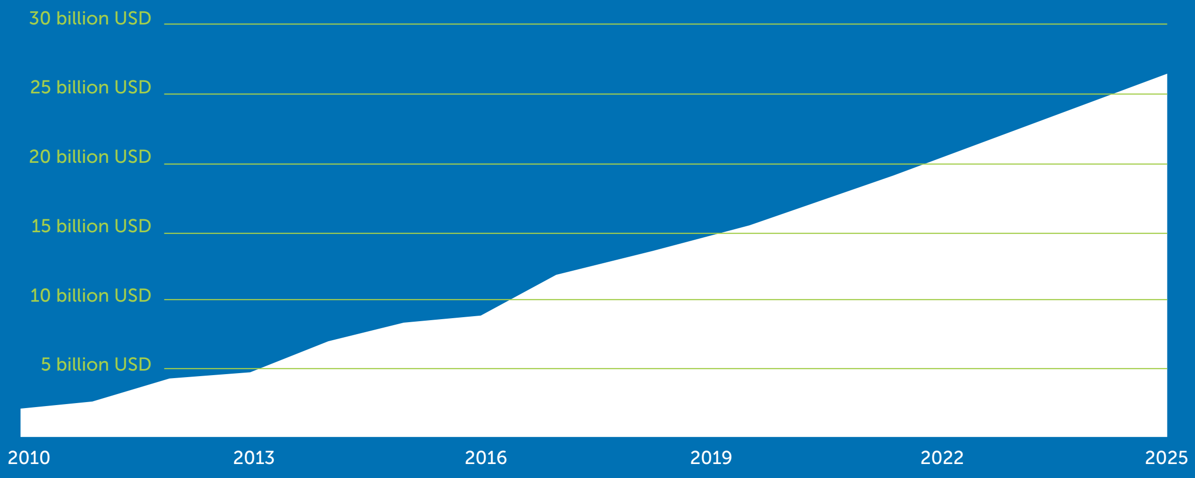
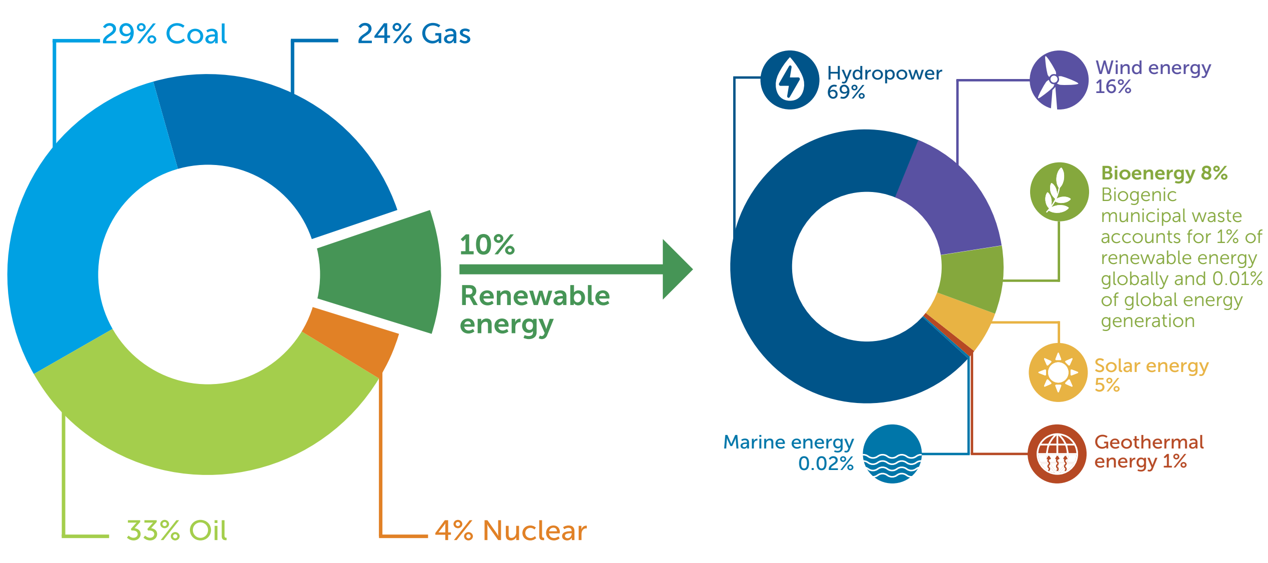


Figure 1.11 Percentage of global electricity generation by energy source, with percentage of renewable energies (IRENA 2018; World Energy Council 2016b).



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Challenges for developing countries

The implementation of thermal WtE in developing countries has technical challenges, such as waste characteristics, and governance challenges, which include social, financial and legislative aspects. These factors must be considered to ensure sustainable operation of thermal WtE plants. In this chapter, the challenges of implementing thermal WtE in developing countries will follow the primary framework of the Integrated Sustainable Waste Management concept.

2.1 WASTE CHARACTERISTICS

In developing countries, MSW is characterized by its high level of moisture and organic content, which yields a low calorific value. Though its calorific value is very low (**Figure 2.1**), organic waste averages from 53 to 56 per cent of MSW in low and lower-middle income countries (**Figure 2.2**). The energy efficiency of waste incineration is directly related to waste composition. According to ISWA Guidelines: Waste-to-Energy in Low and Middle Income Countries (2013), incineration requires a fuel with a minimal average calorific value of 7 MJ/kg, and should never fall below 6 MJ/kg for combustion without auxiliary fuel. The low calorific value of MSW collected in developing countries leads to its overall poor quality for thermal WtE. As an example, the calorific value of MSW in China typically ranges from 3.5–5 MJ/kg (World Energy Council 2016a).

Another incineration issue to consider is the high moisture content in organic waste and the presence of inert materials. In some developing countries, such as India, inert materials such as construction and demolition waste are present in mixed MSW. The presence of inert materials, in addition to other factors such as insufficient waste quantity and investor and public sector lack of due diligence, resulted in operational failure in several thermal WtE plants in India (**Table 2.1**).

Table 2.1 Reasons for closure of WtE plants in India (Planning Commission 2014)

Reason of closure	Timarpur	Vijaywada	Hyderabad
Investor and public sector lack of due diligence	✓	✓	✓
Poor quantity and quality of waste	✓	✓	✓
Presence of inert materials, such as construction and demolition waste, which makes the WtE process difficult and expensive	✓	✓	✓
Public outcry against plant location	✓	N/A	N/A
Plant's lack of financial viability	✓	N/A	N/A

Waste is theoretically suitable for incineration without auxiliary fuel when water content is below 50 per cent, ash content is below 60 per cent, and combustibility is over 25 per cent (The World Bank 2000). In developing countries, the high water content and low combustibility of waste makes it unsuitable for direct incineration. Waste streams in India and the Philippines are marginally suitable for incineration without additional fuel during summertime due to a lack of segregation (**Figure 2.3**). Seasonal variation of waste composition may move it further from combustibility. In addition, waste quantity may vary due to season and natural disasters. The risks associated with variation in waste value and quantity must be carefully assessed.

Figure 2.1 Net calorific value of different waste types found in MSW (World Energy Council 2016a)

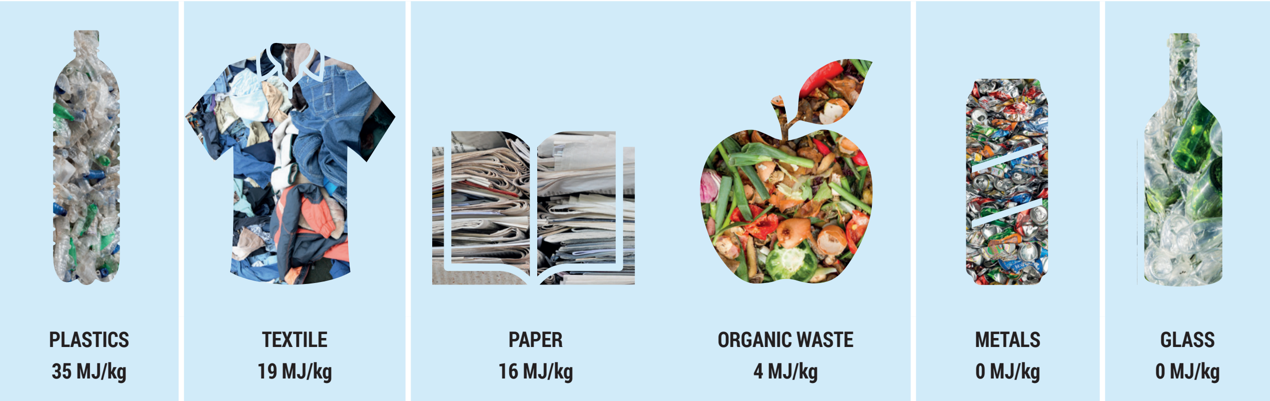


Figure 2.2 MSW composition in developing countries (World Bank 2018)

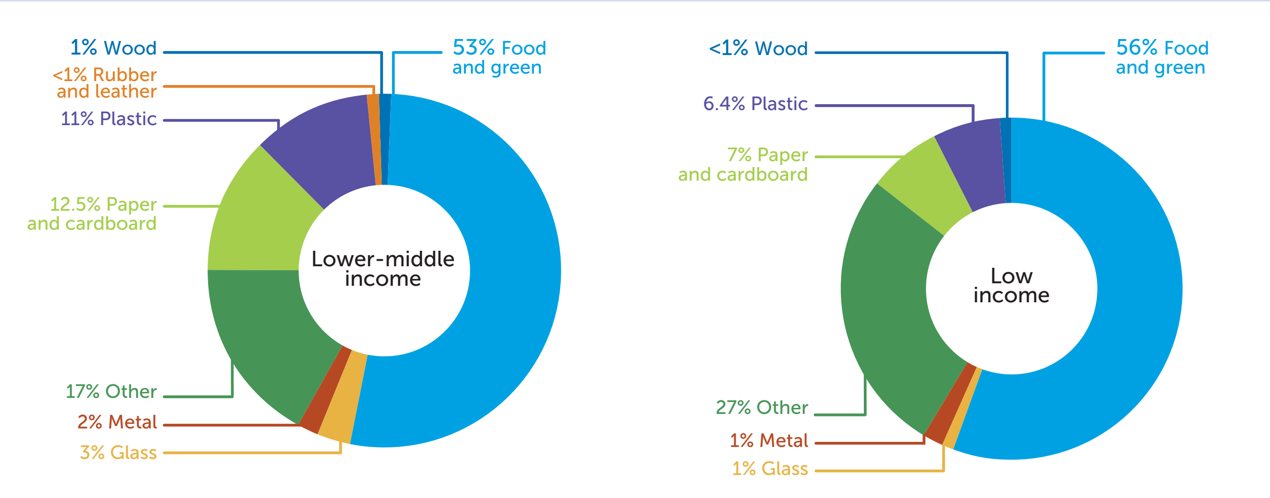
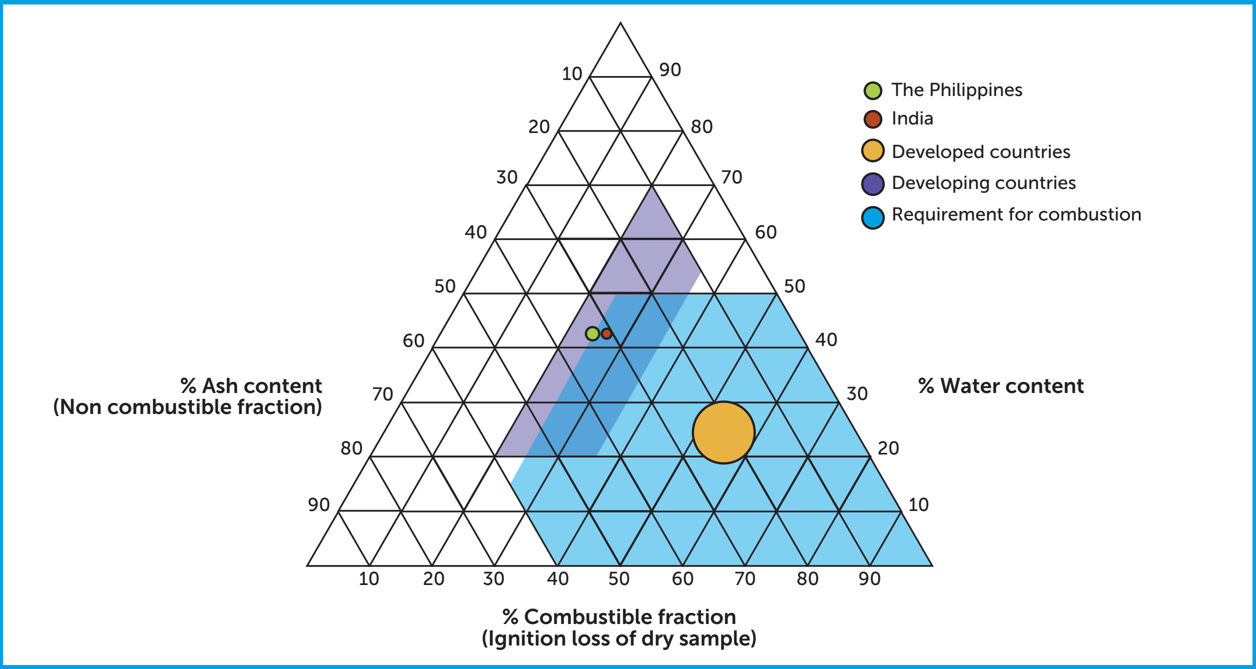


Figure 2.3 Tanner triangle for combustibility assessment of MSW (in percentage by weight)[1]



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[1] Data from developing and developed countries obtained from Public Interest Consultants (2007). Data from India and the Philippines shows summertime waste composition (UNEP 2005).

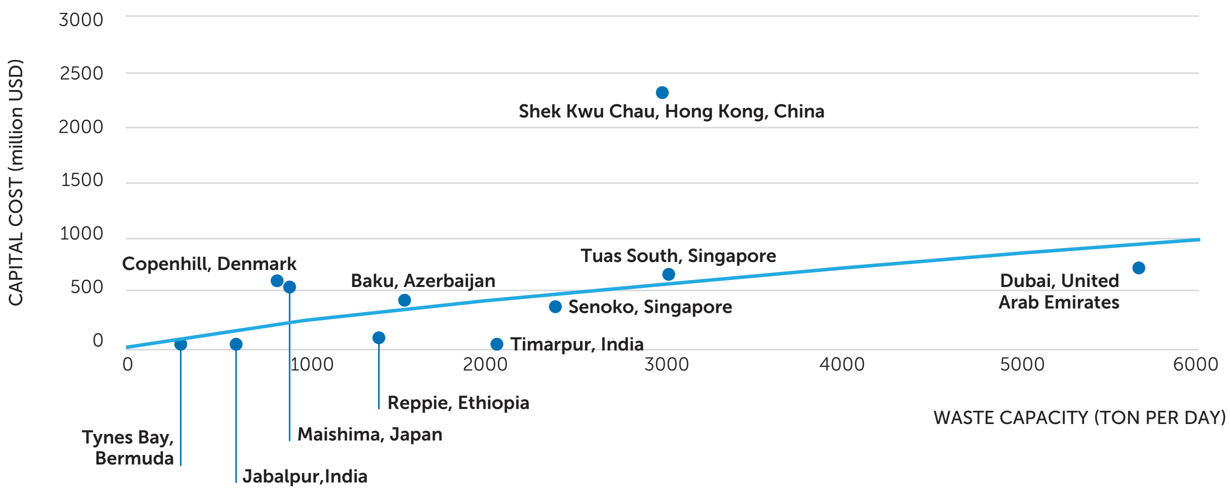
2.2 ECONOMIC ASPECTS

Investment and operation costs are the two major components that determine thermal WtE plant development. **Investment costs** refer to costs related to project planning and development, including siting, feasibility studies, permitting, consultation, design, land, equipment, and construction. **Operation costs** include the costs of labour, fuel, energy, maintenance and repair, emissions control and monitoring, revenue collection, public communication, management and administration, safe disposal of residues, accident response and decommissioning.

A thermal WtE plant requires large investment and operation costs that on average are much higher than other waste treatment methods. When assessing public financial support for thermal WtE, it is particularly important not to undermine the waste management hierarchy by discouraging waste management options with higher circular economy potential (European Commission 2017). **Table 2.2** shows the estimated total cost[2] of waste per tonne for different waste treatment methods. The total cost of a thermal WtE plant is generally higher in developed countries than in developing countries (**Table 2.3**). Although equipment costs for thermal WtE plants are roughly the same worldwide, engineering, construction and land and labour costs vary widely among countries with different income levels. It is therefore difficult to compare thermal WtE plant costs in different countries due to cost variations resulting from different local conditions. **Figure 2.4** shows the relationship between cost and incineration capacity of several thermal WtE plants in developed and developing countries. The capital cost of plants in developed countries is higher due to higher labour costs and more stringent architecture and emission standards. Given the bad reputation of incineration, requests are often made for thermal WtE plants to be iconic buildings. Though this often results in added cost, it can increase local acceptance, for example the Copenhill plant in Denmark and the Maishima plant in Osaka (**Figure 2.5**). Other major costs in developed countries that contribute to higher capital costs include land acquisition and construction (**Box 2**).

Figure 2.6 breaks down the estimated cost of a thermal WtE plant in Europe. Operational costs strongly depend on the lifespan of the plant. For a thermal WtE plant with an estimated lifespan of 40 years, **about 85 per cent of its total cost is attributed to the operational costs**, while in developing countries operational costs can account for at least 50 per cent of total plant cost (estimated in **Table 2.3**). Insecure long-term funding may lead to operational failure due to high operational costs, which may bring substantial financial risks to the municipality.

Figure 2.4 Comparison of investment cost and capacity of thermal WtE plants[3]



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[2] Estimated total cost refers to net operation and investment costs, minus revenues from resource recovery.

[3] The blue line shows the formula adopted from literature describing the cost-capacity relationship of thermal WtE plants (Haghi 2015). Shek Kwu Chau WtE plant in Hong Kong and Dubai WtE plant in United Arab Emirates are still under construction.

Table 2.2 Estimated cost for different waste treatment methods and technologies (UNEP 2015)

World Bank Project Data (Nominal Date 2006)	Low Income Countries	Lower Middle Income	Upper Middle Income	High Income Countries
"Income (GNI/capita/ 2006"	<876 USD	876-3465 USD	3466-10725 USD	>10725 USD
Waste generation (kg/cap/yr)	220	290	420	780
Collection coverage (percent of households served)	43%	68%	85%	98%
	Cost of collection and disposal (USD/tonne)			
Collection	20-50	30-75	40-90	85-250
Sanitary landfill	10-30	15-40	25-65	40-100
Open dumping	2-8	3-10	NA	NA
Composting	5-30	10-40	20-75	35-90
Waste-to-energy incineration	NA	40-100	60-150	70-200
Anaerobic digestion	NA	20-80	50-100	65-150

Disclaimer: All estimates are for comparative purposes only and are not indicative of actual costs at any particular local site. Costs for reduction, reuse and recycling are not captured in this table.

Table 2.3 Estimated costs of thermal WtE plants in developed and developing countries (GIZ 2017)

	Initial investment	Capital costs	Operation and management costs	Total cost	Revenues from energy sales	Costs to be covered
	In million Euros	Euros per tonne				
Developed country	135–185	80–115	180	260–295	60 (heat and electricity) 27 (electricity)	200–235
Developing country	30–75	22–55	20–35	42–90	2–10 (electricity)	40–80

Note: Figures shown are rough estimates and do not include land costs. The estimation assumes an incineration capacity of 150,000 tonnes per year. Thermal WtE plants in developed countries are assumed to have advanced technologies and two furnace lines. Plants in developing countries are assumed to have a basic technologies with one furnace line.

Figure 2.5 (Top) Copenhill plant, Copenhagen, Denmark; (Bottom) Maishima plant, Osaka, Japan

Copenhill was comissioned in 2018, and includes an artificial ski slope on the plant's rooftop. The building exterior of the Maishima plant in Osaka was designed by Austrian artist Friedensreich Hundertwasser.

Box 2 Hong Kong - The shift from landfills to thermal WtE

The Shek Kwu Chau WtE plant in Hong Kong, which will be commissioned in 2024 with a waste capacity of 3,000 tonnes per day, has an estimated capital cost of over 2 billion USD. The high capital cost is due to plant siting and high labour and construction costs in Hong Kong. The plant will be situated next to a remote island called Shek Kwu Chau, which involves reclamation of 16 hectares of land. Operational costs of the 15-year contract are estimated to be over 1.7 billion USD.

At present, Hong Kong relies on sanitary landfills for waste treatment. Due to land constraints and increasing waste generation, the WtE plant and composting facilities are planned as the waste treatment alternatives for reducing reliance on landfills. This decision has raised environmental concern in regard to the loss of 31 hectares of habitat of the endangered Chinese White Dolphin and the Finless Porpoise. A marine conservation park has been proposed to mitigate this loss and conserve both species.

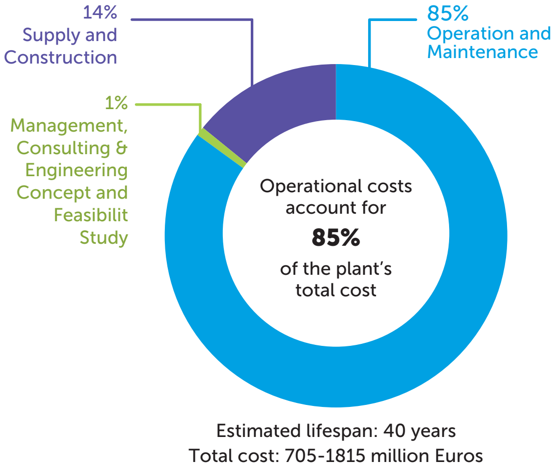
Source: Environmental Protection Department, Government of Hong Kong Special Administrative Region (2019)

Due to high investment costs, thermal WtE plants with only basic technical standards are emerging in low-income countries (GIZ 2017). These low-cost plants may omit technical backup systems such as pumps, piping, electronic control systems, a second furnace and appropriate flue gas filter systems, or use lower steel quality for highly stressed furnace components. Whether these low-cost plants can meet appropriate technical and emission standards in the long term remains unknown. Breakdown risks associated with these low-cost plants are higher due to the lack of backup systems. Consequently, operational costs may increase and the operable lifetime of the plant may be shortened. This could lead to higher negative human health impacts and irreversible environmental damage.

Long-term funding sources must be secured for sustainable operation and maintenance of a WtE plant. Sources can include **direct revenues**, including plant gate fees, direct waste fees on citizens and revenues from the sale of energy products. In addition, **indirect revenues** from regularizing open waste dumping and increasing tipping fees at landfills are also possible financial sources.

Other external funding opportunities include **government subsidies (Box 3), international funds, and private sector investments** (**Box 4**). Municipalities may consider regional-based WtE projects rather than city-level projects to obtain regional or national level government funding. **Public-private partnerships** can help municipalities raise private capital from investors. Public-private partnerships have different frameworks, and the private sector is often involved in building, designing and operating the WtE facility during the contractual period.

Figure 2.6 Estimated total cost of a thermal WtE plant in Europe (Neubacher 2010)



Decommissioning cost is not included in the operational costs in this figure as data is not available.

Box 3 Reppie, the first thermal WtE plant in Africa

Thermal WtE projects often support a country's waste management and climate policy, and rely on government subsidies as a major source of revenue. The Reppie WtE plant, completed in 2017, was fully funded by the Ethiopian government as part of the country's Climate Resilient Green Economy project. Ethiopia aims to become a middle-income economy by 2025, and has set as one of its major goals cutting its greenhouse gas emissions. The Reppie plant was built at the Koshe dumpsite, where approximately 80 per cent of Addis Ababa's waste is incinerated. The plant could potentially improve environmental and health conditions near the dumpsite, prevent accidents like the Koshe landslide, and abate future methane emissions (UNEP 2017). Yet, the plant had to cease operations just weeks after its inauguration, and is currently in the process of reopening (Addisfortune News 2019). The plant also raises concerns about the livelihoods and relocation of waste pickers living at the Koshe dumpsite.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On 11 March 2017, a landslide at the Koshe dumpsite killed more than 110 people.

Box 4 Jabalpur WtE plant – a public-private partnership

Jabalpur WtE plant in India is a long-term public-private partnership. The plant was commissioned in 2016 with a waste capacity of 600 tonnes per day. The project is supported by grants from the Government of India (under the "Clean India Mission" programme) and Government of Madhya Pradesh, which covers about 60 per cent of project cost. Remaining costs are covered by capital from the private operator. The project is positioned on design, build, finance, operate, and transfer, with a performance-based concession period of 21 years (inclusive of the 2 year construction period). Public grants will only be reimbursed after the private operator has satisfactory output and performance. One advantage of a public-private partnership is that it makes projects financially viable, and project completion and output risks are shared with the private operator. Private operator efficiency also allows for effective project management.

Source: Regional Directorate (Central) Central Pollution Control Board Bhopal (2016)

2.3 LEGAL ASPECTS

Thermal WtE legal challenges vary in developing countries, depending on the specific country and local conditions. Legal aspects are closely tied to social, economic and environmental aspects. In the Philippines, the challenge arises from the seeming policy contradiction of both an incineration ban and existence of thermal WtE guidelines (**Box 5**). In China, even though government policies provide economic incentives for thermal WtE development (**Box 6**), regular noncompliance in regard to environmental emission standards provides another set of legal and environmental challenges.

While developing countries are opening up to thermal WtE, the European Union is moving away from it and other forms of incineration, and is gradually phasing out public financing and support for energy from mixed waste recovery (European Commission 2017). In this context, the European Commission suggests redefining the role of thermal WtE to ensure that increases in reuse and recycling are not hampered and that overcapacities for residual waste treatment are averted (European Commission 2017).

Thermal WtE legislation should comply with internationally recognized emission limits to avoid irreversible damage to environmental and public health (GIZ 2017). As these limits are often not recognized in developing countries, they should first be developed in line with internationally recognized standards, such as the European Union's Industrial Emissions Directive (**Table 2.4**), and allow ample capacity for adequate monitoring and enforcement.

2.4 ENVIRONMENTAL ASPECTS

The health and environmental impacts of thermal WtE are continuing public concerns. Thermal WtE plants built from the 1970s to the 1990s in countries such as Japan and United States caused a large amount of air pollution due to dioxin and furan emissions.

What are dioxins and furans?

Dioxins (polychlorinated dibenzo-p-dioxins) and furans (polychlorinated dibenzofurans) are groups of toxic persistent organic pollutants and known human carcinogens. They are formed as by-products of high temperature thermal processes due to **incomplete burning and the presence of precursors** (IPEN 2005). Human short-term exposure to high dioxin levels may result in skin lesions such as chloracne, patchy darkening of the skin, and altered liver functions (World Health Organization, 2016). Long-term exposure is linked to impairment of the immune system, the developing nervous system, the endocrine system and reproductive functions.

(World Health Organization 2016)

Globally, waste incinerators are one of the leading sources of dioxins and furans (Stockholm Convention 2017). Appropriate combustion conditions are necessary to reduce dioxin emissions in thermal WtE plants. The combustion temperature should be at least 850ºC with a minimum retention time of 2 seconds (European Commission 2018). Dioxin decomposition reaction is faster than generation at higher temperatures. Flue gas oxygen concentration should be at least 6 per cent in volume (European Commission, 2018). To avoid dioxin and furan formation, exhaust gas must be cooled quickly.

With the current technology, dioxin and furan emissions can be reduced through the above measures, coupled with a gas filtering system using a scrubber and bag filters (Mukherjee et al. 2016). Improvements in the design and operation of combustion and flue gas cleaning systems have resulted in plants that can reliably achieve lower emission limit values than the European Union's Industrial Emissions Directive (2010/75/EU) (**Table 2.4**).

To ensure minimum environmental and health impact, thermal WtE plants should ideally meet the stringent European Union emission standards. Yet in developing countries, there are often no, or less strict, incineration emission standards and/or related law enforcement for thermal WtE. For example, in China and India, although national emission standards for waste incineration are available, requirements are less strict than European Union standards (**Table 2.4**). Excessive dioxin emissions from thermal WtE plants have been recorded in both countries (**Box 7**). Poor operation and maintenance has resulted in higher dioxin emissions in plants in developed countries as well (**Box 7**).

Box 5 Incineration ban in the Philippines

The Philippines is the only Asia Pacific country with an incineration ban enforced by law. According to the Philippines Clean Air Act of 1999, incineration, which is defined as "*the burning of municipal, biomedical and hazardous waste, which process emits poisonous and toxic fumes*", is prohibited in the country. This incineration ban was lifted, however, for thermal WtE through approval of *Guidelines Governing the Establishment and Operation of Waste to Energy Technologies for Municipal Solid Wastes* in 2016. The thermal WtE debate continues in the country as the Guidelines are contradictory to the Clean Air Act. Nevertheless, two thermal WtE projects in Quezon City and Puerto Princesa City are currently in the planning stages.


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Box 6 China's WtE revolution

China has the fastest WtE market growth among developing countries. In 2017, there were 286 thermal WtE plants in the country. China's 13th Five Year Plan encourages separate treatment and non-incineration of organic waste, as well as the safe management of MSW. It recognizes the current waste incineration trend and concerns with operating incinerators around the country while stressing the need for stronger monitoring of incineration pollution, including air emissions, waste water discharge, and fly ash disposal. It is estimated that by 2020 more than 50 per cent of MSW will be treated with thermal WtE, and the country will have more than 400 operating thermal WtE plants (Chi 2017). Government economic incentives are the major driver for thermal WtE growth in China. The state funding policy requires investors to contribute 30 per cent of the capital investment for the project, with remaining costs raised by national subsidies or commercial bank loans (Zhang et al. 2015). Thermal WtE plants have a 5 per cent income tax exemption, and are required to pay a feed-in tariff of 0.04 USD/kWh. They additionally can receive waste disposal fee subsidies from the local government (Zhang et al. 2015). Despite these numerous economic incentives in China, incinerators still cannot cover their full costs, particularly social and health costs, which are externalized through public healthcare and to individual citizens (Zhao 2017).


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Box 7 Reported cases of dioxin emissions from thermal WtE plants

CHINA

According to China's National Implementation Plan for the Stockholm Convention on Persistent Organic Pollutants (2007), waste incineration is the third largest source of dioxins in the nation. *Ni et al.* (2009) reported dioxin emissions from 19 thermal WtE plants in China and discovered that 78 per cent do not meet the European Union standard of 0.1 ng TEQ/Nm^3. In 2014, chicken egg samples taken near an MSW plant in Hangyang, Wuhan were found to have high dioxin and furan content (Petrlik 2015). Due to the dioxins problem from thermal WtE plants, China tightened national dioxin emissions standards in 2014 from 1.0 to 0.1 ng TEQ/Nm^3 (Zhang et al. 2015), which is the same as the current European Union standard. Many large-scale thermal WtE plants with proven technologies and high emission controls have recently been constructed in China. The city of Ningbo has set emission targets that are stricter than the European Union's Industrial Emissions Directive (2010/75/EU) (Zhan 2018). As the thermal WtE industry has matured in China, technology is no longer a barrier to keeping dioxin emissions at a safe level. Continuous monitoring is still necessary, however, especially for small-scale thermal WtE plants, to ensure emissions limit compliance.

INDIA

The Okhla WtE plant is controversial in India and has caused a public outcry due to dioxin and furan problems. The plant was commissioned in 2012 to replace the previous failed plant (**Table 2.1**). In 1987, the old Timarpur plant faced the problem of low calorific value of waste (2.5–2.9 MJ/kg), which led to operational failure and its closure just 21 days after opening (Shah 2011). The new plant, known as the Okhla plant, was accused of emitting a large amount of dioxins and furans in the neighbourhood, which posed serious citizen health risks (Planning Commission 2014). In 2013, residents filed a public interest litigation in the Delhi High Court, which was later transferred to the National Green Tribunal (Luthra 2017). After inspection and monitoring from the Delhi Pollution Control Committee and the Central Pollution Control Board, the plant was verified as non-polluting and complying with India's emission standards. The plant is thus allowed to continue its operations. The company was liable to pay 25 lakhs (equivalent to 30,000 Euros) as environmental compensation for noncompliance of stack emissions up to the year 2014.

NETHERLANDS

In 2013, high concentrations of dioxins and furans were found in the eggs of chickens that lived near the Reststoffen Energie Centrale incinerator, despite the plant being equipped with advanced emissions control technologies and stringent emissions limits of 0.01 ng TEQ/Nm^3 (Zero Waste Europe 2018b). Dioxin emissions exceeding the Industrial Emissions Directive limit were later discovered during the transient stages of plant operations, such as during start-up and cleaning (Zero Waste Europe 2018b). During cold start-up operations (i.e. slowly raising the temperature in the furnace from room temperature to combustion temperature), dioxins can be formed through de novo synthesis in the temperature window from 250°C to 450°C when sufficient inorganic chloride is present. Studies have concluded that dioxin and furan emissions are substantially higher in transient stages after a cold start-up than in stable combustion conditions (Gass et al. 2002; Wilken et al. 2003). The Reststoffen Energie Centrale case raises the importance of independent long-term monitoring for plant emissions, in addition to inclusion of dioxin monitoring during transient operating stages.

Table 2.4 Emission standards for thermal WtE plants (Ji et al. 2016; ISWA 2013; Central Pollution Control Board, Government of India 2016)

Pollutants	Unit	Best Available Techniques Associated Emission Levels	Industrial Emissions Directive 2010/75/EU	China National Standard GB18485-2014	India National Standard
Particulate matter	mg/m^3	1-5	10	30	50
Hydrogen Chloride	mg/m^3	1-8	10	60	50
Hydrogen Fluoride	mg/m^3	<1	1	-	4
Sulphur dioxide	mg/m^3	1-40	50	100	200
Nitrogen oxides	mg/m^3	120-180	200	300	400
Carbon monoxide	mg/m^3	1-10	50	100	100
Total organic carbon	mg/m^3	5-30	10	-	20
Mercury	mg/m^3	0.001-0.02	0.05	0.05	0.05
Cadmium	mg/m^3	0.005-0.05	0.05	0.1	0.05
Lead	mg/m^3	0.005-0.5	≤0.5	1	0.5
Other heavy metals	mg/m^3	0.005-0.5	≤0.5	-	
Dioxins and Furans	ng TEQ/Nm^3	0.01-0.1	0.1	0.1	0.1
Ammonia	mg/m^3	<10	N/A	N/A	N/A
Opacity	Ringelmann	n/a	N/A	10%	N/A

Note: "-"refers to no emission limit. TEQ = Toxic Equivalent

2.5 SOCIAL ASPECTS

Public opposition is often a major obstacle for thermal WtE projects in both developed and developing countries. Public approval, or "social license", must be obtained in order to build a thermal WtE plant. This section discusses the main causes of public opposition, including plant **site allocation**, the **lock-in effect**, and potential **trade-offs of the 3Rs** for thermal WtE.

1. SITE ALLOCATION

Thermal WtE has had negative publicity due to its adverse environmental and health impacts. Even though some current thermal WtE plants meet European Union standards, plant siting often triggers public backlash due to concerns over irreversible environmental and health impacts, and the Not In My Back Yard (NIMBY) phenomenon. A set of key criteria should be followed when choosing sites for thermal WtE plants that follow European Union standards (The World Bank 2000).

Thermal WtE plants should be located

- Relatively close to a controlled and well-operated landfill for residue disposal
- In medium or heavy industry land-use zones
- In industrial areas close to power plants
- In proximity to energy distribution networks
- In a region where transportation time from the waste generation area to the plant is minimized

2. LOCK-IN EFFECT

The lock-in effect generally refers to a dedicated investment in a thermal WtE project, and the requirement of a fixed amount of waste for incineration over the plant's life. The lock-in effect could lead to undermining waste prevention, reuse and recycling policies and programmes due to lack of funds to develop those systems, or "put or pay" contracts that mandate municipalities provide a fixed amount of waste to the incinerator or pay a fine. These conditions pose a risk to the waste management hierarchy, and can hamper waste reduction, and in turn dampen the potential boost that local economies often get through reduction, reuse, recycling and composting. In developed countries with effective prevention and recycling systems, reduced amounts of MSW for incineration can lead to thermal WtE plant overcapacity (**Box 8**).

Unlocking incineration from waste management

In the future, increases in recycling and waste minimization may lead to decreases in available waste for thermal WtE. This is likely to be the case in regions such as Europe where waste prevention, reuse and recycling policies are strong and well enforced. Unlocking incineration from waste management systems will be a critical challenge in both developing and developed countries. The risk in developing countries, however, is that thermal WtE plants will undermine attempts to establish or consolidate waste prevention, reuse, source separation, recycling, composting and anaerobic digestion systems. Thermal WtE plants are not flexible and cannot process a decreasing amount of waste. Companies that manage them often attempt to force governments into producing a high volume of waste, or pay heavy fines through put or pay contracts. These fines, in addition to the high cost of thermal WtE, make it difficult for governments to implement alternative and more sustainable waste management systems based on the higher levels of the waste hierarchy.

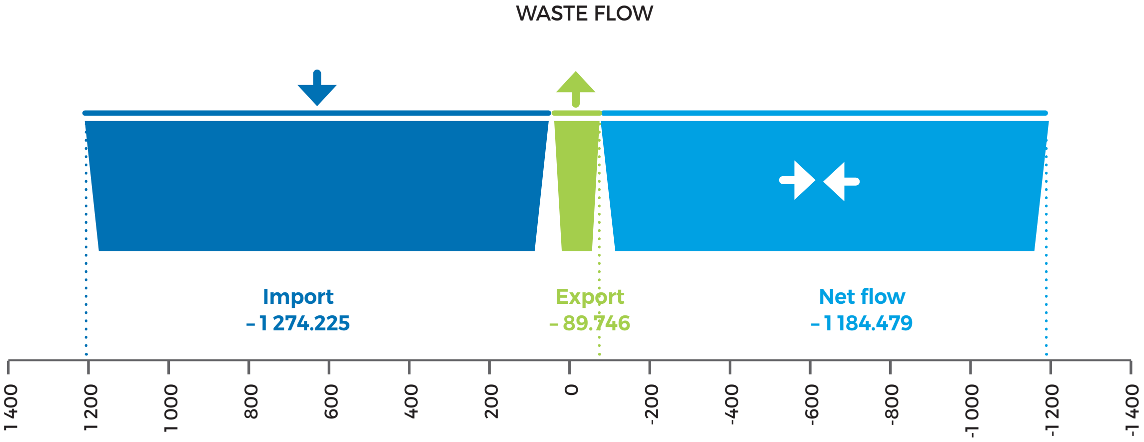
To avoid the lock-in effect, countries should carefully project future waste amounts and enact a long-term plan for sustainable waste management that focuses on waste prevention, reuse, recycling, composting and anaerobic digestion systems. Countries should avoid put or pay contracts, as well as long-term contracts that lock them into decades of burning waste that could have been prevented, reused or recycled.

Box 8 Running out of rubbish in Sweden?

Sweden imported net waste of over 1.1 million tonnes for R1 energy recovery* in 2014 (**Figure 2.7**). It had a shortage of MSW for incineration at the time due to successful waste reduction efforts and overcapacity of the WtE plant. At the Sävenäs WtE plant in Gothenburg, the decision to build a new boiler line in 2009 resulted in the lock-in of waste for incineration (Corvellec et al 2013). The current reduction in waste generation in the county has resulted in the Sävenäs plant not being able to obtain enough waste to reach its designated capacity. This overcapacity problem was solved by importing waste from neighbouring countries, such as Norway, for incineration. Due to the lower gate fee in Sweden, Norway has an incentive to export waste rather than burn it in its local plants (Corvellec et al 2013).

*R1 energy recovery refers to thermal WtE plants that comply with the R1 formula of the European Union Waste Framework Directive 2008/98/EC.

Figure 2.7 Sweden's waste imports and exports for R1 energy recovery in 2014. Data obtained from Eurostat (in thousand tonnes)



3. THE 3RS TRADE-OFF

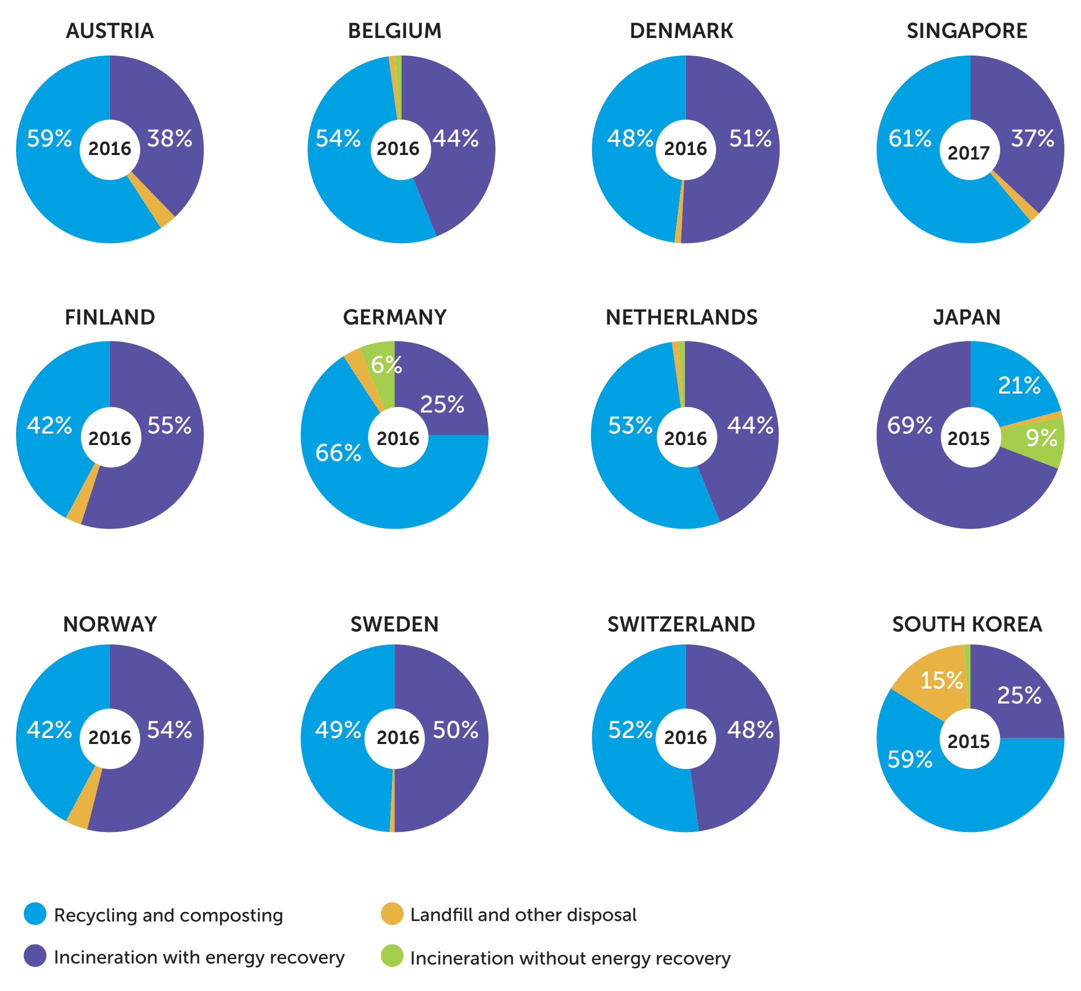
Thermal WtE plants require a minimum amount of feedstock for operations. This could potentially divert waste away from the 3Rs as the feedstock, such as plastics, paper, cardboard and wood, is often recyclable. Thermal WtE plants also lack the ability to process a flexible, decreasing amount of waste.

In many European countries, high recycling rates give the impression that thermal WtE can complement recycling (**Figure 2.8**). These figures appear to show that with a well-developed waste sorting system, recyclable wastes can be separated from the waste stream, leaving only non-recyclable waste for thermal WtE. However, several studies have shown that thermal WtE plants burn mostly recyclable or compostable waste (Zero Waste Europe 2017; GAIA 2013). Figures for current recycling rates also do not show a heavy reliance on waste exports for recycling abroad, with no accountability regarding the final destination of these materials. As a result, domestic recycling investments remain insufficient, and the job creation potential of recycling remains largely untapped. The unsustainability of the export model for plastic recycling in particular was exposed when China and other countries banned or severely restricted plastic waste imports. The European Commission has recently emphasized the need for countries to reduce thermal WtE due to its risk as an "infrastructural barrier" to achieving higher recycling rates (European Commission 2017).

In addition, municipalities are often required to provide a consistent volume of waste for incineration, which could impact the livelihoods of informal recyclers. In developing countries, recycling is mostly done by informal recyclers, often at no cost to local municipalities (World Bank 2018). Informal recyclers are a vulnerable demographic that includes women, minorities, migrants, children and the elderly. Despite this, they are not always considered stakeholders in thermal WtE projects (WIEGO 2018). Informal recyclers should be engaged in recycling dialogues and their concerns should be addressed during thermal WtE planning.

To avoid the potential trade-off of using recyclable waste for incineration, developing countries should prioritize the 3Rs when introducing thermal WtE. Legislation to ban the incineration of recyclable and compostable waste, or introduction of a fee on the waste that is incinerated and landfilled, are two possible measures to prevent waste trade-offs. However, an incineration tax can be counterproductive in countries with a high reliance on landfills – landfill taxes must be higher than incineration taxes to conform to the waste management hierarchy. Providing incentives, such as a container deposit scheme, is another possible strategy to encourage waste recycling.

Figure 2.8 MSW treatment methods in selected countries[4]



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[4] Data from OECD and the World Bank from year 2015 to 2017.

* Singapore figures include industrial waste such as construction and demolition waste, ash and sludge, and scrap tires in the recycling rate calculation. The domestic waste recycling rate in Singapore is 21 per cent.

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Opportunities

3.1 CLIMATE RATIONALE

DOES THERMAL WTE CONTRIBUTE TO GLOBAL WARMING, OR CLIMATE MITIGATION?

Carbon neutrality, in a global sense, means net zero emissions of anthropogenic CO_2 (UNEP 2014). In the context of thermal WtE, CO_2 released from biomass combustion is assumed to be offset by the CO_2 initially absorbed through photosynthesis. Emission credits for the use of non-fossil waste as a substitute for fossil fuel are also calculated as part of carbon neutrality.

> In the 2006 IPCC guidelines, carbon emissions from biogenic waste are excluded from waste inventories and are instead under the Agriculture, Forestry and Other Land Use section in order to avoid double-counting. This does not necessarily mean biogenic waste is climate irrelevant, despite frequently being misinterpreted in this way. Agencies such as the Environmental Protection Agency in the United States have recommended that biogenic carbon emissions be counted when assessing emissions from individual waste or energy facilities (Environmental Protection Agency 2010).

The carbon neutrality assumption is being challenged by a growing number of experts (Liu et al. 2017; Cherubini et al. 2011) that have assessed the global warming potential of biomass-associated combustion. Researchers have also highlighted that human activity has profoundly altered the natural carbon cycle in a way that exacerbates climate change, in particular due to impacts from the timing of anthropogenic biogenic carbon emissions (Searchinger et al. 2009; Cherubini et al. 2012; Levasseur et al. 2013; Bellinger and Hogg 2015).

Biomass may take many years to regrow to the point where it absorbs the biogenic CO_2 emitted from thermal WtE. The global warming impact of biogenic CO_2 during the regrowth period has been shown to correlate with the crop rotation cycle (**Table 3.1**). Biomass with a short rotation length of one to two years, such as corn, soybean, agricultural residue, and grasses, has a negligible impact on global warming. However, if produced from forests with long rotation lengths, wood and paper waste could significantly impact global warming. Researchers estimated that biomass with a rotational length of 100 years (i.e. boreal forest) has a comparable global warming potential of direct CO_2 emissions over a 20-year period. The climate impact of CO_2 emissions from biomass combustion, in addition to emissions throughout the biomass life cycle, must be considered in order to avoid overestimation of the climate benefits of thermal WtE.

Depending on the waste composition, direct fossil-origin CO_2 emissions from stacks can range from 250–600 kg per tonne of incinerated waste (Johnke et al. 2001; Fellner et al. 2007; Larsen et al. 2013; Fuglsang et al. 2014), which is comparable to CO_2 emissions from coal combustion (International Energy agency bioenergy 2013). When biogenic emissions are included, direct CO_2 emissions from the stack are approximately 1,000–1,100 kg per tonne of waste (UKWIN 2018; Bellinger and Hogg 2015; International Energy Agency Bioenergy 2013). Life cycle assessments that include biogenic CO_2 emissions show that burning MSW results in much higher CO_2 emissions than burning fossil fuel (Bellinger and Hogg 2015; UKWIN 2018).

Table 3.1 Global warming potential of greenhouse gases emitted from incineration (IPCC AR5 2014; Cherubini et al. 2011)

GHGs	Global warming potential for a given time-horizon			
	IPCC AR5 (2014)		Cherubini et al. (2011) FIRF*	
	20 years	100 years	20 years	100 years
Carbon dioxide, CO_2	1	1	/	/
Methane[#], CH_4	84	28	/	/
Nitrous oxide, N_2O	264	265	/	/
Biogenic CO_2 (r = 2) e.g. fast growing crops (such as corns, soybeans, grasses)	/	/	0.04	0.01
Biogenic CO_2 (r = 50) e.g. tropical forest	/	/	0.87	0.21
Biogenic CO_2 (r = 100) e.g. boreal forest	/	/	0.96	0.43

Note: The thermal WtE process does not emit methane as a waste gas, but small amounts of methane may be emitted from waste secured in a waste bunker.

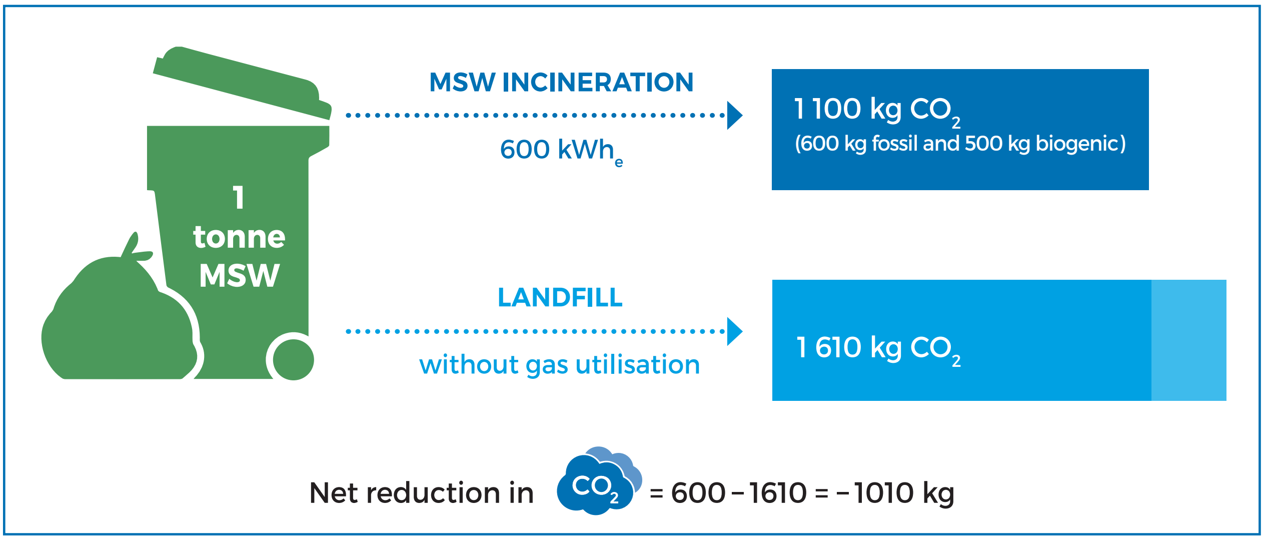
*FIRF = Full impulse response function. This function considers all possible sinks for the removal of CO_2 from biomass combustion, including the terrestrial biosphere, oceans and on-site biomass regrowth.

r = rotation length (in years)

Thermal WtE can reduce greenhouse gas emissions if it is used as an alternative to open burning, uncontrolled dumping and sanitary landfills. Thermal WtE can avoid methane gas emissions from decomposing organic waste in landfills and prevent environmental pollution associated with leaching. For each tonne of MSW incinerated in a thermal WtE plant, the equivalent of 1,010 kg of CO_2 can be avoided by diverting waste from landfills without methane gas utilization when excluding biogenic carbon emissions (**Figure 3.1**). The energy generated in thermal WtE plants can power households in a region, which reduces reliance on fossil fuel power generation and the associated emissions.

Thermal WtE is sometimes considered a climate mitigation measure because the biogenic waste in MSW is treated as carbon-neutral, and emission credits can be earned through fossil fuel substitution. However, the neutrality of biogenic carbon is questionable, as illustrated above, while the fossil fuel substitution decreases as energy policies worldwide move towards renewable energy options.

Figure 3.1 **CO_2 savings from thermal WtE**



3.2 WTE IN SMALL ISLAND DEVELOPING STATES

Waste management is a big challenge for small island developing States due to the limited availability of land for landfills. Thermal WtE may appear to be a good opportunity for small island developing States to build a self-sustainable waste management system with energy recovery. However, in addition to the common challenges faced by developing countries, these countries face other unique challenges due to island characteristics and environment (UNEP 2019).

Many small island developing States are vulnerable to extreme weather events or natural disasters. As most islands are low-lying and located along the track of tropical storms, the operational risks of thermal WtE plants, including the safe disposal of incineration residues, are high. The direct disposal of incineration residues inland may **contaminate freshwater sources**. In Bermuda, bottom ashes from thermal WtE are disposed offshore and utilized as artificial reef and reclamation materials. This practice, however, has caused a halo of **contamination around nearby sediment and coral reefs** with the release of dioxins, furans, mercury and other hazardous chemicals (Jones 2010) (**Box 9**). Bottom ash could alternatively be utilized as a material for road construction, which has been widely applied in European countries, including Denmark, France, Germany and the Netherlands (ISWA 2015). In addition, **tourism and natural disasters** may lead to a sudden surge in waste quantity, and therefore an appropriate storage system might be required.

At present, there are three small island countries with thermal WtE plants: Bermuda, Martinique, and Saint Barthélemy. These islands are all French and British overseas territories and benefit from financial, political and institutional ties with the United Kingdom and France (Arden and Allan 1995; Fielding 2014). A growing number of small island developing States, such as Jamaica, Mauritius and the Maldives, are now considering thermal WtE as part of their waste management systems, although not without resistance from local communities, particularly in Mauritius (Rootes et al. 2009; Mediaterre 2009; Rodriguez 2011;

Lorson and Karsdarli 2015). The regionalized waste management approach in the Maldives is a good reference for other small island developing states when considering the incorporation of thermal WtE (**Box 11**).

Box 9 Bottom ash recycling in Bermuda

Bottom ash is made up of 80–85 per cent minerals, with the remaining 15–20 per cent ferrous and non-ferrous metals (CEWEP 2019). After the ferrous and non-ferrous metals are extracted, the residual ashes are often disposed of in landfills. To minimize final disposal of waste in Bermuda, residual ashes are further utilized for land reclamation and constructing artificial reefs. Bottom ash is used as a substitute raw material for clay to produce ash concrete blocks. As part of the Bermuda's artificial reef programme in 1991, ash concrete blocks are disposed offshore to form an artificial reef (Arden and Allan 1995). The artificial reefs were colonized by a diversity of animals including sponges, tunicate and corals. At present, the bottom ashes from the thermal WtE plant are disposed in an offshore reclamation site (Jones 2010). Yet, research has shown that the ash has created a halo of contamination around nearby sediment and coral reefs with the release of dioxins, furans, mercury and other hazardous chemicals (Jones 2010).

Box 10 Waste management in Sardinia

The story of waste reduction on the Italian Island of Sardinia is a prescriptive case study for small island States. In 2003, only 3.8 per cent of the waste generated in Sardinia was collected separately, with the majority of the remaining waste sent to landfills or incinerated. Since 2003, however, the island has been implementing measures to reduce waste, including compulsory separate waste collection standards, increased landfill taxes, promotion of door-to-door collection schemes and the introduction of a bonus/malus system for municipalities to incentivise progress in waste management. As a result, separate collection rates increased to 56 per cent by 2016 and waste generation per capita decreased from 520 kg per inhabitant in 2013 to 443 kg per inhabitant in 2016. This progress has reduced demand for disposal and incineration facilities (Zero Waste Europe 2018c).

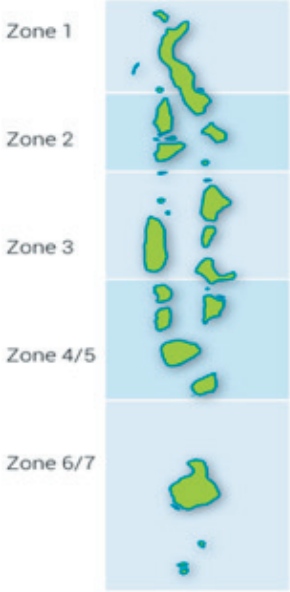
Box 11 A waste solution in the Maldives

The Maldives is one of several small island developing States incorporating thermal WtE into its waste management system. As the predominant waste treatment method in the Maldives, open burning has caused pollution and health issues. Uncontrolled disposal of solid waste, including foreshore dumping and open burning, is estimated to account for 15 per cent of the country's greenhouse gas emissions (Ministry of Environment, Republic of Maldives 2019). To manage this waste problem, a regionalized waste management system was introduced by dividing the country into seven regional zones, with each containing one regional facility for material and energy recovery (**Figure 3.2**) (Amir 2018). This waste management project is partly funded by The World Bank, Asian Development Bank and the Maldives Government.

An island waste management centre with composting facilities and a waste storage area was planned for construction on each inhabited island. The waste collected at the island centres will be transported to the regional centre in each zone for recycling and incineration. At present, one incinerator has been constructed on Vandhoo (Zone 2), an uninhabited island. The heat energy from incineration on Vandhoo is currently not utilized, but future plans call for industrial use (Lorson and Karsdarli 2015). The other zones are under ongoing development, with three more WtE plants planned at Kulhudhuffushi, Thilafushi and Addu city (Amir 2018; Lorson and Karsdarli 2015). This regionalized waste management system is a good reference for other small island developing States.

Open burning of waste in the Maldives.
Credit: Premakumara, IGES-CCET.

Figure 3.2 Regional waste management system in the Maldives



Credit: Christiane Marwecki

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Key considerations

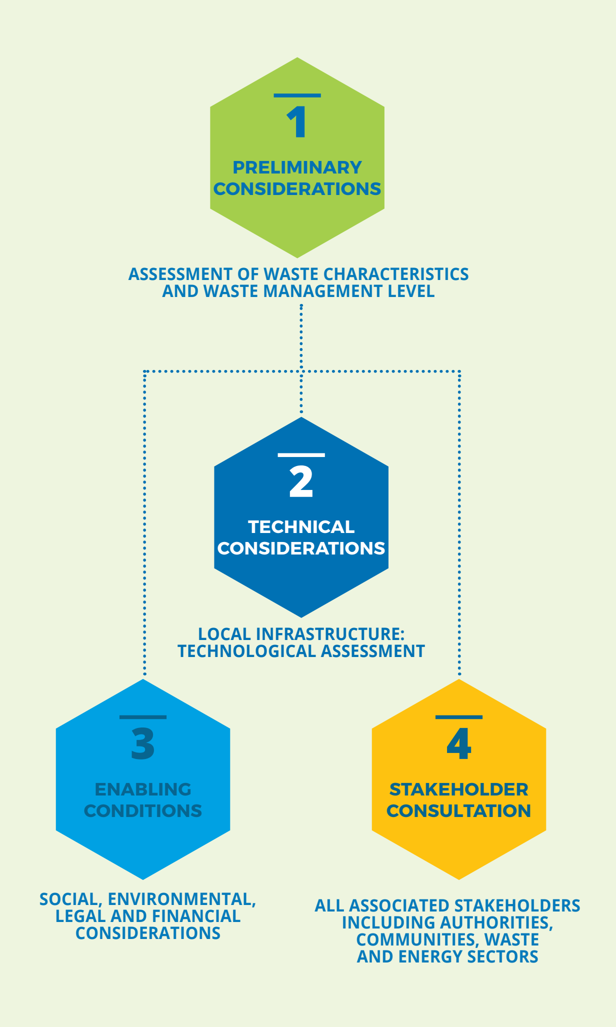
To establish an integrated waste management framework in developing countries, **waste prevention and the 3Rs should always be the top priorities**, unless life cycle thinking justifies diversion from this hierarchy. The 3Rs have the potential to reduce waste disposal while building local economies through providing green jobs and formalizing the work of informal recyclers. A thermal WtE plant has less climate impact than landfills and opening burning, but the fraction of biogenic carbon emissions has to be considered when evaluating the plant's overall climate change impact. Many of the technical, economic, social, environmental and legal challenges in relation to thermal WtE have yet to be overcome.

Before making a political decision to implement thermal WtE, it is necessary to first evaluate all the physical and strategic aspects and challenges in a life cycle thinking approach. The major considerations detailed in this chapter should be carefully assessed during the project planning phase to determine if thermal WtE is an appropriate waste management option for municipalities.

4.1 CONSIDERATIONS FOR DEVELOPING COUNTRIES

The implementation of a thermal WtE project involves various stages, from planning, preparation and construction to operation and decommission. This section draws on the experiences of thermal WtE projects in both developed and developing countries, as discussed in previous chapters, to present major considerations for the thermal WtE planning stage. **Figure 4.1** incorporates both the physical components and governance aspects of the Integrated Sustainable Waste Management framework into four major considerations. For the project planning phase, the timeline follows **Figure 4.1**, starting with (1) preliminary considerations, followed by (2) technical considerations, and lastly the parallel examination of (3) enabling conditions and (4) stakeholder consultation.

Figure 4.1 Implementation timeline of the four major considerations for the Integrated Sustainable Waste Management framework



1. PRELIMINARY CONSIDERATIONS

Waste characterization is the first important step in preliminary considerations of thermal WtE. A **waste assessment survey** of the region should be carried out to evaluate waste characteristics and trends and make future projections. Necessary waste data to collect includes waste composition, calorific value, quantity, collection coverage, recycling rate, recovery rate and landfill disposal rate. In addition, factors that may affect **future waste quantity** should also be assessed. These include population, intercity and transboundary waste flow, waste from the tourism industry, and waste from natural disasters. If waste will be imported from other cities or municipalities, a waste assessment survey of these cities or municipalities should also be carried out in order to better evaluate potential impacts on waste composition and calorific value.

The next step is an **assessment of the overall waste management performance** of the city or municipality using the data obtained from the waste survey as benchmark indicators. A waste management assessment tool, such as the "Wasteaware" Integrated Sustainable Waste Management benchmark indicators, can be used as a diagnostic for the city or municipality to determine the performance of its MSW management system. Wasteaware is applicable to cities in high, middle and low-income countries, and has been applied to more than 50 cities on six continents. The Wasteaware indicator set follows the Integrated Sustainable Waste Management framework (**Figure 1.4**). It combines well-established quantitative indicators for waste generation and composition as well as qualitative composite indicators for three main physical components: waste collection, waste treatment and disposal, and the 3Rs, and three governance aspects: stakeholder inclusivity, financial sustainability and legislative framework.

To implement thermal WtE, a city or municipality's waste characteristics and management level should meet the following preliminary requirements (GIZ 2017; ISWA 2013):

- Waste characteristics
  - MSW should be sorted, with no or only small fractions of minerals and hazardous wastes
  - The average lower calorific value of waste should be at least 7 MJ/kg, and never below 6 MJ/kg
  - MSW quantity should be over 100,000 tonnes per year
- Waste management level
  - Systematic waste collection and transportation exist
  - MSW is disposed in well-controlled landfills
  - A collection fee system exists and citizens pay for it
  - A comprehensive legal framework addressing WtE is available
  - Waste prevention measures are being implemented, MSW dry recyclables and organic waste (both yard and food waste) are separated at the source and are separately collected, and there are robust recycling and composting (or anaerobic digestion) systems in place
  - High recycling and composting (or anaerobic digestion) rates

2. TECHNICAL CONSIDERATIONS

If the above preliminary requirements are fulfilled, the city or municipality can move on to the technical or infrastructure considerations of thermal WtE. **City or municipality infrastructure and conditions** must be carefully considered, including:

- Availability of a controlled landfill close to the thermal WtE plant for flue gas cleaning residue disposal
- Market availability and disposal options for thermal WtE residue
- A mature and efficient waste collection and transportation system to transport waste to the thermal WtE plant
- The type(s) of energy (i.e. electricity, heat, fuel) to be generated, and the demand of, and access to, energy products produced for local end users
- Local capacity to monitor emissions and conduct and analyse emission tests for POPs and other pollutants

Cities or municipalities should consult experts or the private sector to carry out an **assessment of all potential WtE technologies** based on the overall waste management performance and local conditions. Consultants or private companies with previous WtE project experience in developing countries are highly preferred. In developing countries, where the organic waste fraction is large, alternative WtE technologies such as anaerobic digestion could be more effective than thermal WtE for treating waste. Other WtE options should always be assessed.

To minimize incineration and the final disposal of waste at landfills, strategies that maximize the reuse, recycling and composting of materials intended for thermal WtE should be proposed. Examples of these strategies include development of waste sorting facilities to extract material for recycling before it is sent for waste incineration, and utilizing incineration residues for road construction or reclamation materials. Otherwise, thermal WtE introduction could derail the waste management hierarchy, due to the lock-in effect that may divert waste from the 3Rs.

3. ENABLING CONDITIONS

A **life cycle assessment** that includes a cost benefit analysis of thermal WtE and other potential WtE technologies should be carried out to compare these technologies' costs. The social, economic, and environmental impacts and co-benefits of a WtE plant throughout its life cycle should be considered. Site location should also be carefully assessed. In addition, GHG emissions should be comprehensively assessed. The assessment should include all direct emissions at the stack level, including biogenic carbon emissions, as well as indirect emissions from burned materials that could have been reused or recycled. The amount and toxicity of flue gas and waste residues should also be carefully examined. WtE technologies generate waste gases and residues that can potentially cause air, water and soil pollution. The Sustainable Assessment of Technologies (SAT) Methodology developed by UNEP-IETC (UNEP 2012) is a technical assessment that can be used to analyze such social, economic and environmental impacts of thermal WtE. This methodology can help to identify the best possible technology option, as well as the potential impact of the proposed technology intervention on the environment, the implications for sustainable development, and the cultural and socio-economic consequences.

A comprehensive **legal framework** that is in place before the implementation of WtE technologies is also necessary. The decision to build a thermal WtE plant that has a minimum lifespan of 20 years would affect the city or municipality's long-term waste management planning. The city or municipality should review and address the presiding legal framework before introducing thermal WtE. The following are some important legal considerations that should be addressed:

- Emissions standards laws relating to thermal WtE plant flue gas and residue waste disposal should be enforced and meet strict international standards
- Thermal WtE monitoring and regulatory compliance laws should be enforced
- A plant decommissioning law should be enforced
- To prevent plant overcapacity, thermal WtE should be integrated into the national waste management strategy

A financial model for the life cycle of the thermal WtE plant that includes the planning, commission, operations and decommission stages is needed for making relevant financial decisions related to raising capital, budgeting, and forecasting. The model should analyse all possible costs and revenues, in addition to waste pretreatment and transportation costs. Cities or municipalities should be careful not to lower technical and emission standards in order to lower costs**.**

A thermal WtE plant is a large investment for developing countries. As discussed in chapter 2, **long-term financial resources** are necessary for sustainable plant operation. Initial investment costs can be covered by public or private funding bodies. These investments can include:

- Government subsidies
- International funds
- Investments from the private sector through private-public partnerships
- Tax/fiscal incentives

Thermal WtE plant long-term operations costs can be partly covered by direct or indirect revenues, including:

- Direct waste fees imposed on citizens
- A plant gate fee
- Higher landfill tipping fees
- The sale of electricity, heat or residues produced by the plant

Apart from financial resources, **access to foreign currency** is another necessary requirement. Access will allow plants to acquire spare parts and skilled maintenance workers for operations. A thermal WtE project should not be initiated in a country if its key technology must be imported and there is no access, or a delay in access, to purchases in foreign currency (GIZ 2017).

4. STAKEHOLDER CONSULTATION

Stakeholder acceptance is crucial to implementation of a thermal WtE project. A stakeholder mapping and analysis of the potentially affected groups and communities must be carried out so that specific initiatives or compensatory strategies can be launched. The stakeholders may include (ISWA 2013):

- **Authorities:** Local governments, planning authorities, environmental authorities, health authorities and traffic authorities
- **Community:** Local citizens, non-governmental environmental organizations, community groups and local scavengers
- **The waste sector:** Waste generators, the waste recycling industry, the waste collecting industry and landfill operators
- **Energy sector:** Power producers, power distribution companies, district heating companies and power/energy users

Depending on local conditions, additional stakeholders may be identified.

Opposition from local citizens and non-governmental environmental organizations should be expected due to the potential health and environmental impacts. Cities or municipalities should complete an evidence-based feasibility study on thermal WtE that includes a life cycle assessment, cost benefit analysis and environmental impact assessment in order to keep the public informed of planning progress and encourage it to support policy decisions. Municipalities can foster communication with stakeholders and the public through open consultations and dialogues.

4.2 CHECKLIST FOR DECISION MAKERS

Waste data and characteristics

☐ *Does the waste quality and quantity meet thermal WtE requirements?*

☐ *Do seasonal waste variations and transboundary waste flow affect future waste projections?*

☐ *Is the MSW sorted at the source in the environs of the city or municipality, for both households and commerce?*

☐ *What percentage of the waste sent for disposal is recyclable or compostable?*

☐ *Are source recyclables and organics collected separately and sent to recycling and composting facilities?*

Infrastructure

☐ *Does systematic waste collection and transportation exist?*

☐ *Is a controlled landfill available for safe disposal of thermal WtE residues?*

Environmental aspects

☐ *Do emission standards for thermal WtE follow international standards?*

☐ *Are compensatory strategies available to mitigate environmental impacts?*

☐ *Is there installed capacity to regularly monitor emissions, including for persistent organic pollutants?*

☐ *What are the occupational health risks for workers and how can they be mitigated in everyday operations and in case of serious accidents?*

Economic aspects

☐ *Is the energy produced accessible to local users and/or available for sale in the market?*

☐ *Is there an available market for thermal WtE residues?*

☐ *Have long-term financial sources been secured?*

☐ *Is there access to foreign currency?*

Legal aspects

☐ *Does a comprehensive legal framework exist for all planned WtE technologies?*

☐ *Is there a decommission plan or decommission regulations in place for the thermal WtE plant?*

Social aspects

☐ *Can the working conditions of informal recyclers be improved?*

☐ *Are compensatory strategies available to mitigate social impacts?*

☐ *Are all relevant stakeholders being considered and consulted?*

Risk assessment

☐ *What are the flooding and tsunami risks, and what would the environmental and health impacts be if the plant was flooded?*

☐ *What is the hurricane or cyclone risk, and what environmental and health impacts would result if the plant was damaged by a hurricane or cyclone?*

☐ *What is the seismic risk, and what environmental and health impacts would result if the plant was damaged by an earthquake?*

☐ *What is the elevation of the site, and what environmental and health impacts would result if the site was affected by rising sea levels?*

Alternatives

☐ *Are there alternative WtE technologies that better suit the local conditions?*

☐ *Is thermal WtE, including biogenic CO_2 emissions, a good option in the local context according to the life cycle assessment?*

☐ *Is there a way to improve rates of recycling and composting?*

☐ *Are there waste prevention policies in place?*

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