CCET guideline series on intermediate municipal solid waste treatment technologies

Composting

August 2020

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CCET guideline series on intermediate municipal solid waste treatment technologies:
Composting

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The International Environmental Technology Centre works with developing countries to implement sustainable solutions to environmental challenges, with focus on holistic waste management.

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Contents

List of Abbreviations

BOD	Biochemical Oxygen Demand
GHGs	Greenhouse Gases
JICA	Japan International Cooperation Agency
JOCVs	Japan Overseas Cooperation Volunteers
KITA	Kitakyushu International Techno-cooperative Association
KUC	Kuliyapitiya Urban Council
MSW	Municipal Solid Waste
NSWMSC	National Solid Waste Management Support Center
NVQ	National Vocational Training
PKK	Pemberdayaan Dan Kesejahteraan Keluarga (Family Welfare Movement)
RTs	Rukun Tetangga (Neighbourhood Units)
URENCO	Urban Environment Company
VOCs	Volatile Organic Compounds

About this Composting Guideline

Target audience & purpose of this guideline

This guideline focuses on the introduction of composting projects based on source separation of organic waste and aerobic fermentation at plants for Municipal Solid Waste (MSW) management in the cities of developing Asia.[1] The guideline aims to assist decision-makers and policy-makers at the local level, who have limited or no technical background on composting, to evaluate the feasibility of introducing composting projects as an appropriate strategic option for improving waste management. This guideline will:

(1) **provide a holistic understanding** about composting systems including both **advantages and disadvantages**, as well as requirements about the **technical and non-technical** aspects of planning sustainable composting projects, and

(2) propose **key evaluation criteria** and a **pre-check flow** to objectively determine and evaluate criteria when considering the potential of introducing composting projects.

Position of composting in the waste hierarchy

The introduction of composting should go along the **waste hierarchy** (Fig.1) for the management of waste with priority placed on prevention, followed by reuse, recycling, recovery, and disposal (Pires et al., 2019). The excess generation of edible food should be prevented and minimised at all points of the food supply chain, with inedible or expired food reused for animal feed (Teigiserova et al., 2020). Several options, including **composting, Anaerobic Digestion (AD), incineration, and landfilling**, are available to manage organic waste such as food waste, trimmed trees, swine faeces, and sewage sludge. **Composting**, generally categorised as recycling, **can be the most preferred technology option for organic waste** management to reduce environmental impacts and move forward toward the creation of a sustainable society.

Composting is just one potential element out of many in a functioning MSW system. Composting plants alone cannot solve existing waste problems, and **decisions on selecting composting as an appropriate technology should be made on the basis of an integrated MSW management plan in the respective city or country**.

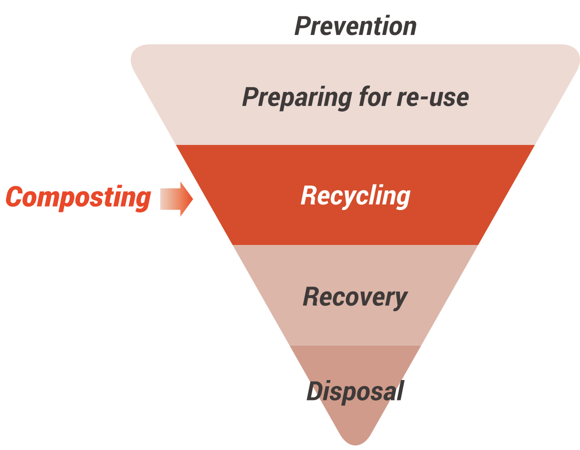


Fig. 1 Waste hierarchy for sustainable waste management (Source: EU Waste Framework Directive[2])

1 The terms "developed and developing countries" in the CCET Guidelines are used to define economies as classified by the World Bank in its World Development Indicators report published in 2016. The term "developed countries" refers to high-income countries and regions, while the term "developing countries" encompasses low-income, lower middle income, and upper middle income countries and regions.

2 EU Waste Framework Directive (Directive 2008/98/EC on waste): https://ec.europa.eu/environment/waste/framework/

Approach and structure of this guideline

This guideline was prepared primarily based on a review of the expertise and practical experiences of composting projects in Japan and other Asian countries, in addition to available literature. It emphasises the importance of source separation as well as compost demand to assess the feasibility of introducing successful sustainable composting projects, and consists of four main parts. The first part, "**Introduction**", includes basic information about the objectives and benefits of composting. The second section, "**Pre-conditions for Sustainable Composting**", describes the key evaluation criteria needed when planning a composting project and provides a pre-check framework for sustainable composting. The key evaluation criteria include technical, as well as non-technical aspects, i.e. social conditions, public awareness and cooperation of residents, institutional aspects, governance capability and financial aspects. The third part, "**Main Technology and Composting Processes**", briefly explains the types of waste suitable for composting, decentralised and centralised systems, and the main technical processes of composting. The fourth section, "**Case Studies**", highlights actual cases on composting projects from both developed and developing countries, and provides helpful lessons including a project that was unsuccessful. This guideline concludes with the authors' recommendations on composting projects.

In this guideline, the terms **composting**, **composting system**, and **composting project** are separately defined. **Composting** refers to a series of technical processes from acceptance of the raw materials to the production of compost. A **composting system** encompasses to a broader scope, including source separation, collection of organic waste and utilisation of compost, in addition to plant processes. A **composting project** refers to a series of tasks involved in planning composting systems, constructing and operating composting plants, securing demand for compost, and other related points.

In addition, this guideline does not address bio-drying technology, in which waste is simply dried biologically and eventually disposed of or used as cover soil on landfill sites.

Message for the busy reader

Busy readers can look over Chapter 1 to quickly gain a general overview of composting. For readers considering the potential of introducing composting projects, please use Fig. 3 on page 6 as a guide to check conditions that must be in place at the beginning of the planning stage. Details on the technology involved in composting projects can be found in Chapter 3.

1 Introduction

1.1 Objectives of composting

The role of compost, organic fertiliser derived from waste, has been overshadowed by the excessive use of pesticides and chemical fertilisers in agricultural practices. The lack of compost used in farm fields and the dependence on chemical fertilisers have had a number of negative impacts, such as deteriorating soil conditions, deficient or excess nutrients, insect outbreaks, and solidified soil, to name a few. **However, organic waste generated in daily life can help recover soil fertility if it is used to produce compost**.

The Food and Agriculture Organization of the United Nations (2011) has reported that roughly one-third of the food produced around the world is lost or wasted, a figure that is almost equivalent to a staggering 1.3 billion tonnes per year. Food waste makes up a significant part of MSW (Kawai et al., 2016) and contains a substantial amount of moisture. Untreated MSW in developing countries is mainly disposed in uncontrolled landfills or dumping sites and has been proven to be a source of methane (CH_4) gas due to the decomposition of food waste in an anaerobic state. Moreover, the direct disposal of organic waste in landfill sites results in the generation of putrid odours in surrounding areas and leachate rich in concentrations of Biochemical Oxygen Demand (BOD).

Organic waste, and food waste in particular, is a biogenic material and decomposes naturally. When organic waste is treated properly instead of dumped in landfill sites, fewer greenhouse gases are generated, and various environmental problems that result from improper disposal, such as odours, vermin, compromised water quality, fires and smoke, and pollution from vehicles transporting waste to landfill sites, can be alleviated. **Composting, a biodegradation process that transforms organic matter into water, carbon dioxide, energy, and composted matter** (Bagchi, 2004, Intergovernmental Panel on Climate Change, 2006), **has been adopted throughout the world over the years as a technology that can stabilise organic residues** (Diaz et al., 2007). Compost, the product of organic waste composting, can act as a partial substitute for chemical fertilisers (Nakakubo et al., 2012).

Compost is an effective soil conditioner. The longer farmers utilise chemical fertilisers, the worse the soil quality of farmland becomes. Compost can be used to recover soil conditions that are crucial to ensuring sustainable agricultural practices.

Composting aims to:

(1) **treat organic waste** such as food waste, garden waste, livestock excreta, and other types of waste in aerobic or anaerobic states and **deactivate causative bacteria, viruses, and weed seeds** through the heat of microbial fermentation, and

(2) **produce organic fertilisers** that physically improve soil conditions and act as a partial substitute for nutrients such as nitrogen, phosphorus, and potassium contained in chemical fertilisers, upon which modern agriculture fully depends.

1.2 Benefits of composting

Composting has two notable benefits: reducing negative environmental impacts from improper waste management and improving soil conditions. However, composting can also have several **disadvantages** if composting systems do not operate effectively. Similarly, some **requirements** must be met to introduce composting as a potential practice in terms of technology, the environment, Greenhouse Gas (GHG) emissions, resources and society as a whole (**Table 1**).

Table 1 Main advantages, disadvantages and requirements of composting

	Advantage	Disadvantage	Requirement
Technology	Composting can be practiced in almost any region, with the exception of extremely cold regions. Local aerobacter, actinomycetes and fungus play a primary role in the degradation of organic waste and the production of compost. Composting requires simpler equipment than other treatment technologies such as incineration. Composting also can apply at different scales, from household or decentralised efforts to large-scale centralised facilities.	Improper fermentation in an anaerobic state slow down the process, lower the quality of compost, and cause unpleasant odours. Poorly-performing equipment for removing contaminants such as plastics and glass leads to a serious downturn in demand for compost.	Adequate processes must be installed to remove as many contaminants as possible from the product mechanically and/or manually, such as plastic, paper, glass and metals. Source separation is necessary to avoid contamination. Moisture content, temperature, oxygen supply, pH, C/N ratio, particle size, and degree of compaction should be maintained within the appropriate range during the aerobic fermentation process.
Environment	The treatment of organic waste at composting plants helps mitigate or eliminate negative environmental impacts in and around landfill sites such as odours, vermin, fires and others.	Composting can also generate odours if the plant is not well designed and processes do not operate properly or efficiently. A mixture of ammonia, hydrogen sulphide, methyl mercaptan, and acetaldehyde causes odours. Flies and insects can breed in and around composting plants. The inappropriate disposal of contaminants and residues removed from the composting process may adversely impact the environment.	Operators should take measures to deodorise odours at composting plants. Temperatures during the fermentation process should be more than 50-55°C to destroy fly eggs and larvae. Double-entry doors can prevent adult flies from entering the plants.
GHG emissions	CH_4 gas emissions from landfill sites can be reduced. The fermentation process is conducted in an aerobic state and emits significantly less CH_4 gas than landfilling. Composting can reduce the need for chemical fertiliser, which is associated with large GHG emissions.	A certain amount of CH_4 and nitrous oxide (N_2O) gases are generated during the aerobic fermentation process. According to the 2006 IPCC Guidelines for National Greenhouse Gas Inventories, the emission factors of CH_4 and N_2O are 10 kg-CH_4/t-waste and 0.6 kg-N_2O/t-waste, respectively, by dry basis.	Composting requires regular turning and aeration to maintain aerobic conditions in the fermentation process and avoid GHG emissions.
Economic implications	Composting at decentralised levels can reduce transportation and operational costs. It is less expensive to construct and operate composting plants than incineration plants. Compost can enhance the local agriculture, food, and tourist industries.	Operators must secure land for composting plants as well as access roads. The more serious operators are about controlling odours, the more costly it will be to invest in and maintain deodorising processes.	The local government and stakeholders should recognise the additional benefits of producing soil conditioners other than waste management. A budget should be secured for maintenance, as well as to cover costs for construction and operation. Grants or loans may help local governments launch composting projects.
Resource perspective	Compost can improve soil conditions biologically, physically and chemically and contribute to the realisation of sustainable agriculture.	Compost derived from organic waste may not contain an adequate supply of nutrients or be fully substituted for chemical fertilisers. Some nutrients must be chemically added.	Local farmers must gain a better understanding of the effectiveness of compost for farmland and be motivated to use it. Local governments and residents should be aware of the various applications of compost for roadside trees, gardening, etc.
Social aspects, other	Source separation and decentralised composting projects at the community level can help develop and enhance social networks, community participation and awareness on local environmental issues.	Residents in urban areas are not likely to participate in the separation of food waste at source due to a lack of awareness and motivation. Finding suitable locations to construct composting plants is a challenge.	All stakeholders should be aware of the effectiveness of compost and be motivated to participate in composting projects. New legal systems may be required to strengthen and reinforce projects. Composting projects should be beneficial for all stakeholders including waste generators, municipalities and farmers.

1.2.1 Reducing negative environmental impacts from improper waste management

Composting can reduce negative environmental impacts from inappropriate waste management at open dumping or landfill sites. Many developing countries rely fully on open dumping or uncontrolled landfilling in their MSW management practices because it is less expensive to construct and operate sites. However, the direct disposal of untreated organic waste in open dumping or landfill sites has indisputable environmental impacts at both the local and global levels. Improper disposal of organic waste in open dumping or landfilling results in the generation of GHG emissions and leachate high in BOD, which pollute ground water and rivers if not treated. Such improper landfilling of MSW also results in breakouts of fires, odours and vermin at disposal sites. MSW should be properly treated before it is landfilled to avoid serious environmental impacts. **Composting is one of the best options available to reduce the amount of organic waste being directly transported to dumping sites.**

1.2.2 Improving soil conditions

Years must pass for soil to form as it is affected by climate, geography, and biology. Soil is a mixture of organic and inorganic components composed of rocks, stones, clay, sand, volcanic ash, and animal and plant residues. Soil contains particles of various sizes, and has a cellular structure of moisture and air. Soil can be divided into three phases: solid, liquid and gas (Fig. 2). When in a solid phase, soil physically supports roots and adjusts the supply of nutrients. In a liquid phase, it supplies water and nutrients to roots. Soil in a gaseous phase supplies oxygen to roots. **The balance of the three phases greatly affects crop growth, and soil with a solid phase consistency of around 40% is considered suitable for cultivation.** Soil would have an extremely hard consistency if it were higher than 50% in a solid phase; at 30%, the consistency would be too soft (Japan Soil Association, 2014).

Soil with a higher proportion of clay has greater capacity to retain water but lower capacity to drain water. On the other hand, soil with a larger proportion of sand has greater capacity for drainage but lower capacity to retain water. Soil suitable for farming has the capacity to retain and drain water, retain nutrients and ventilate. To ensure that soil possesses this capacity, it should have an aggregated structure with a moderate mixture of clay and sand, and with "humus" as its key element.

Organic substances are continuously supplied and degraded in soil. Some organic substances do not completely degrade but remain in the soil in a complex composition and structure, known as humus. Humus enhances the soil's capacity to retain and drain water, preserve nutrients, ventilate, and act as a pH buffer. Humus also contains growth hormones such as auxin and cytokinin, which promote plant growth and result in an increased volume of roots. Compost can partly replace chemical fertilisers in terms of supplying nitrogen, phosphorus, and potassium. **More importantly, compost derived from food waste can be a source of humus, which cannot be produced artificially** (Hermann et al., 2011) **but demonstrates the various advantages mentioned above and contributes to the formation of a sustainable soil management and food recycling system.**

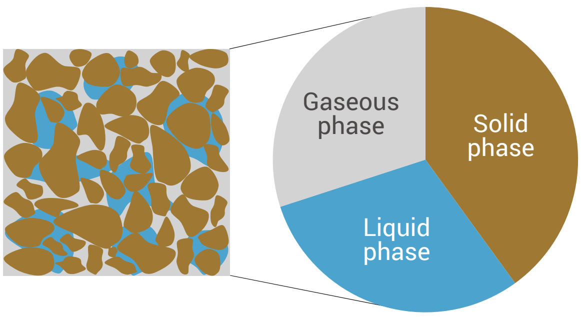


Fig. 2 Three phases of soil

Soil with a solid phase consistency of around 40% is suitable for cultivation. The proportion of soil in gaseous and liquid phases changes in line with dry conditions.

Box 1 Historical production and use of compost in Japan

Iwata et al. (2001) offers a historical perspective on agriculture and the use of organic fertilisers in Japan. In the Edo period (1603-1868), the main fertilisers used in agriculture were composed of young buds and leaves from broad-leaf trees, wild grass, barnyard manure, and human waste. Farmers at that time used these types of fertilisers because they did not have the means of purchasing expensive fertilisers such as dried sardines, oil cake, and soybean cake. Human urine and faeces were carefully collected to produce fertiliser, with farmers carting agricultural products to urban areas in the morning and returning to rural areas in the evening with human waste. This material cycle between urban and rural areas continued until the Meiji era (1868-1912). However, due to an increase in the population of urban areas during the Taisho era (1912-1926), there was an excess supply of human waste, which resulted in a breakdown of the material cycle between urban and rural areas. Although farmers mainly utilised the organic fertilisers they produced themselves with leaves, trees, and manure, some started to purchase oil cake, dried sardines and chemical fertilisers.

According to Fujita (1993), in the ten years following the end of World War II, the number of composting plants for MSW in Japan increased to 30 where European technologies such as the Dano system (Dziejowski et al., 2002) were applied. However, these European composting technologies were not suitable for MSW in Japan with its higher moisture content, since the technologies had been developed for waste in Europe that had a lower moisture content. At some plants in Japan, paper waste, such as newspapers, were mixed into food waste to reduce moisture content. Almost all composting plants had disappeared by the 1970s, and incineration became the predominant waste management technology used to manage MSW in Japan. Composting underwent a revival in the 1980s with an increase in the number of composting plants to treat sewage sludge, livestock manure, and agricultural waste. However, as of 2018, MSW delivered to composting plants accounted for only 0.5% of the total. Currently, there are about 100 centralised composting plants for MSW located throughout Japan.

Japan’s long history of using compost on farmland supplied nutrients to the soil, such as nitrogen, potassium, phosphorus and humus which encouraged microorganisms to flourish in the soil, created a sound balance between water drainage and retention, and acted as a chemical buffer. Japanese composting practices have been established on the principles of source separation of organic waste. Recently, a limited quantity of MSW is being managed at composting plants, but waste generators, who are required to be involved in composting projects, are actively separating organic waste at source and discharging it in order to supply high-quality raw material for composting.

1.3 Opportunities and challenges for cities in developing countries

In recent years, the amount of waste has increased dramatically, especially in urban areas, due to population growth, urbanisation and lifestyle changes in Southeast Asia and other developing countries. As a result, the importance of intermediate treatment facilities, such as composting plants, is on the rise to reduce the volume of waste as pressure increases on the existing capacity of final disposal sites. Centralised composting can be successfully applied to the cities or areas that meet all or most of the following:

(1) Cities or areas that seek alternative treatment systems to replace landfilling

(2) Cities or areas that can separately collect quality raw materials for composting

(3) Cities or areas that can secure enough demand for compost

(4) Cities or areas that can secure an adequate budget to operate composting plants for long periods of time

(5) Cities or areas that have adequate manpower and institutional arrangements to develop and implement sustainable composting projects

2 Pre-conditions for Sustainable Composting

Various conditions must be in place to ensure that a composting project is introduced successfully. Based on guides for decision-makers (Rand et al., 2000, Kamuk, 2013, Mutz et al., 2017), **key evaluation criteria can be verified from six perspectives: social conditions, public awareness and cooperation of residents, institutional aspects, governance capability, financial aspects and technological aspects.** Following the six perspectives together with relative key evaluation criteria for each, **a modified pre-check flow (Fig. 3) can be used as a guide at the beginning of the planning stage.** The key evaluation criteria and pre-check flow are presented to assist decision-makers and policy-makers in taking a closer look at whether local governments are able to prepare the conditions required for composting projects.

Key evaluation criteria are divided into three groups: **(1) mandatory key criteria (in pink), (2) strongly advisable key criteria (in yellow) and (3) advisable key criteria (in green).** Arrows should be followed to proceed to the next step in cases where evaluation criteria are met. If criteria have not been met, the following actions are recommended:

(1) in cases where mandatory key criteria are not met, **it is not yet suitable to introduce composting projects.** It is strongly recommended that the evaluation be suspended or that the situation be re-evaluated after improvements are made;

(2) in cases where strongly advisable key criteria are not met, **support measures should be introduced, or alternative proposals considered;**

(3) in cases where advisable key criteria are not met, **caution should be exercised as composting projects can be risky to implement.**

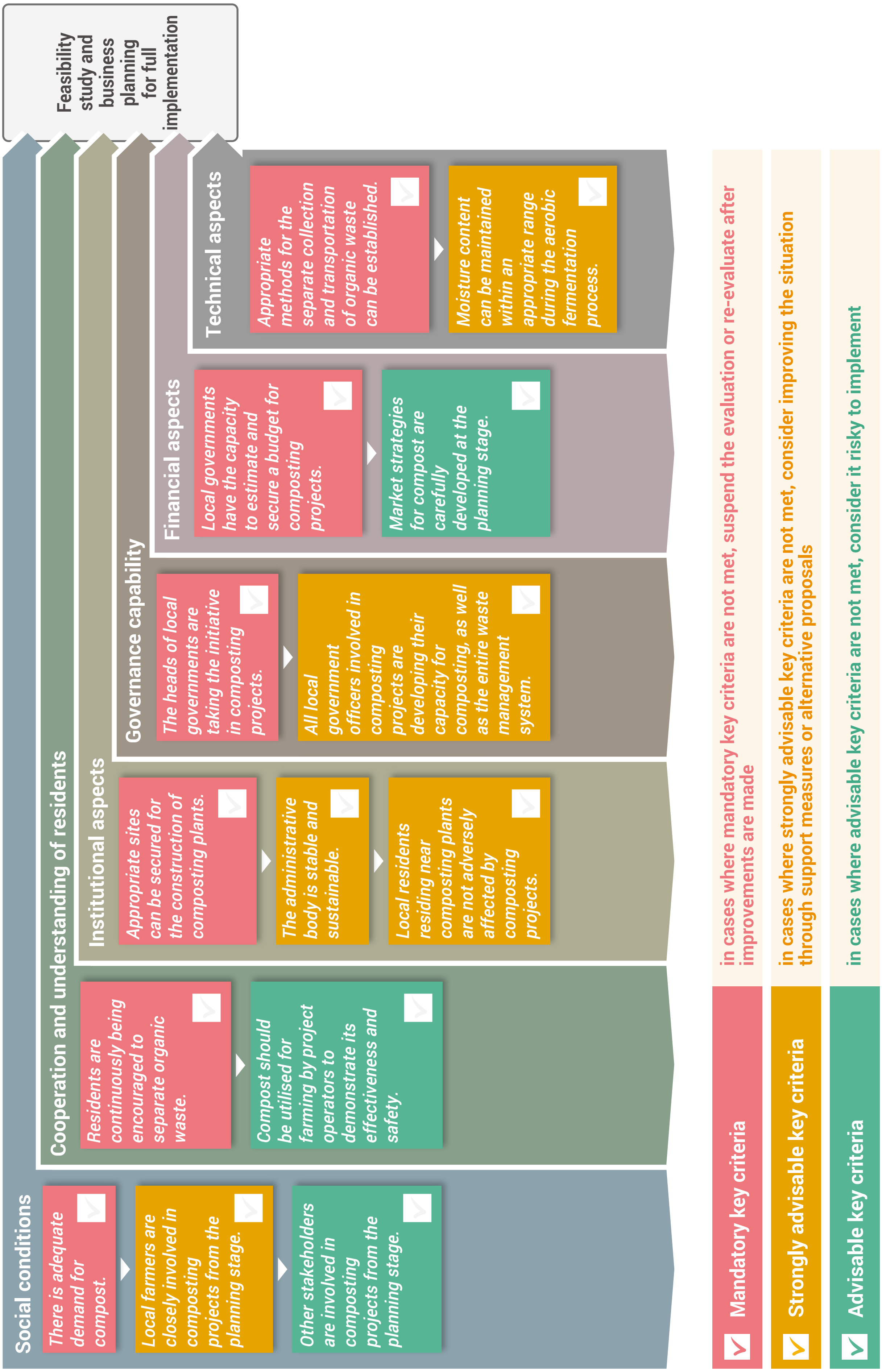


Fig. 3 Pre-check flow to be conducted at the beginning of the planning stage

Box 2 Stages of composting projects

As a composting project progresses, the types and numbers of stakeholders, geographical boundaries, and composting technologies may change. Progress can be divided into three stages: planning stage, setup and operating stage, and upgrading stage (Tasaki et al., 2016). Each stage may take months or years, depending on the local situation.

Planning stage
In the planning stage, the local government assesses the level of interest in local areas and starts to develop plans for the type of composting system and technology that will be used, amount of waste to be collected as a raw material, number and capacity of trucks to collect waste for composting, capacity of composting sites, initial and operational costs, quality and quantity of compost produced annually, and local demand for compost, and considers other relevant issues for inclusion in the plan. If a composting project is established based on source separation of organic waste, a feasibility study on source separation can be included in this stage. Feasibility studies on source separation should start on a small scale before expanding the target area of the composting project.

Setup and operating stage
In this stage, the local government has completed its assessment and developed plans for the feasibility of a composting project, and composting has been positioned as one solution for reducing environmental impacts. Next, the local government should secure a budget to design, construct and operate the composting facility. Generally, a local government enters into a contract with a private company to design and construct a composting facility. Some local governments operate the facility with their own staff, while others use private contractors.

Waste suitable for composting is collected and transported to a composting plant. The produced compost is distributed to users such as local farmers and residents.

Upgrading stage
Composting moves away from its singular focus on waste management, and shifts to an emphasis on enhancing local agricultural businesses. Local farmers find better ways of cultivating vegetables on farmlands using compost derived from organic waste to improve the quality of crops, which are then sold at local markets and used at local restaurants. As a result of this improved quality, markets and local restaurants can attract more customers, which leads to the establishment of a recycling loop for the food supply chain.

2.1 Social conditions

Mandatory key criteria

There is adequate demand for compost.

Securing adequate demand for compost products is a pre-requisite for the successful operation of composting plants. However, it is difficult to ensure an adequate level of demand for compost in high population density areas due to the lack of farmland. **Composting plants should be designed to be situated in places that are located near areas with substantial tracts of farmland.** If this is not possible, composting operators must secure demand for compost products connecting with existing fertiliser companies or creating new business networks. Then, a balance among the amount of waste to be treated, compost supplied, and compost delivered should be carefully estimated and verified at the planning stage.

Typically, one kilogram of compost per square meter is distributed annually to farmlands. In other words, if 10,000 tonnes of compost is produced annually, a minimum of 10,000,000 m^2 or 1,000 ha of farmland must be secured so that all produced compost will be used. Composting plants should be located near an area with considerable farmland to ensure the routine distribution of compost, while also taking into account the fact that a certain percentage of farmers are not willing to use compost. Plants should also be equipped with storage units for compost since demand varies seasonally and compost can be distributed to farmlands only two or three times a year. In addition to farmers, some residents may require compost for home gardening (Fig. 4) and cities can give preferential use of city waste-based compost in municipal gardens and parks and government premises.

Fig. 4 Compost packed in a 5-kg plastic bag for distribution to residents in Osaki Town, Japan

Strongly advisable key criteria

Local farmers are closely involved in composting projects from the planning stage.

Compost users are an absolutely essential part of composting projects. Without their understanding or support, local governments and other stakeholders will never be able to launch successful composting projects. **Local farmers, arguably the most vital users of compost, should be involved in the process from its inception.**

Compost can be used as a substitute for some nutrients that are present in chemical fertilisers, reducing their use and improving soil conditions. Farmers can use organic fertilisers such as compost derived from organic waste to maintain quality soil conditions. They should be engaged in composting projects from the planning stage to ensure that their opinions are reflected in plans as primary users of compost. Without the participation of local farmers who use compost regularly, producers will face challenges in selling compost in local areas or may need to find demand further afield.

Advisable key criteria

Other stakeholders are involved in composting projects from the planning stage.

In addition to local farmers, **local governments should encourage the involvement of key stakeholders from the planning stage, such as community group leaders, women's unions, agricultural cooperatives, commercial associations, restaurants, hotels, vegetable retailers, and households.** Community group leaders and women's unions can encourage residents to participate in separation at source and dispose of organic waste appropriately. In addition, households who have an interest, willingness and space for family farming or gardening can make household or backyard compost using their separated organic waste at source. Agricultural cooperatives can act as focal points for distributing compost to local farmers. Commercial associations can support the processing and distribution of agricultural products grown with compost. Restaurants, hotels and vegetable retailers as waste generators can provide information on the quantity and quality of organic waste generated regularly, which is helpful in making decisions on designing the capacity of composting plants. The approval and support of waste generators is essential in assuring that composting projects are sustainable.

2.2 Public awareness and cooperation of residents

Mandatory key criteria

Residents are continuously being encouraged to separate organic waste.

Residents are the primary generators of MSW. When local governments design a composting system combined with the separation of organic waste at source, residents play an important role in supplying this waste as raw materials for composting.

Good source separation determines whether a composting project succeeds or fails. **Three key parameters can be used as an indication of progress on source separation: participation rate, proper separation rate and proper discharge rate** as shown in Fig. 5 (Kawai et al., 2017). Participation rate, the most important parameter, refers to the proportion of waste generators who separate organic waste as a percentage of the total number of waste generators. Proper separation rate refers to a parameter that describes how accurately the organic waste is separated. Proper discharge rate is a parameter demonstrating that mixed waste is discharged appropriately by those who do not separate waste in order to avoid contaminating the waste that has been properly separated by residents as organic waste. **These three key parameters have an impact on the quantity and quality of the waste separately collected as organic waste, and should be a target for improving the quality and securing an adequate quantity of raw materials.**

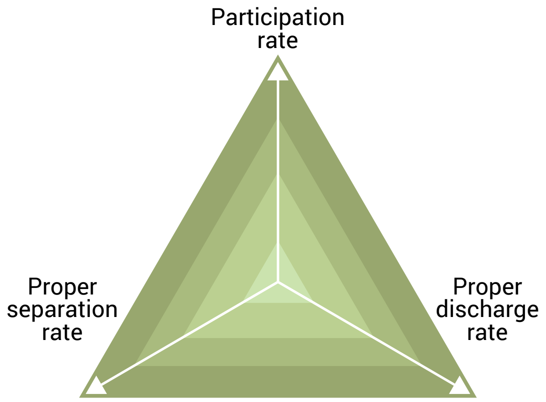


Fig. 5 Three key parameters for source separation of organic waste

There are several possible measures that can be put into place to increase the participation rate. Local governments need to create opportunities and conditions that minimise difficulties for residents when separating organic waste. To do so, the local government must frequently communicate with waste generators and identify existing problems with source separation and collection. The key point here is that residents should be continuously encouraged so they are motivated to separate waste for proper composting. Fig. 6 illustrates how behavioural psychology works

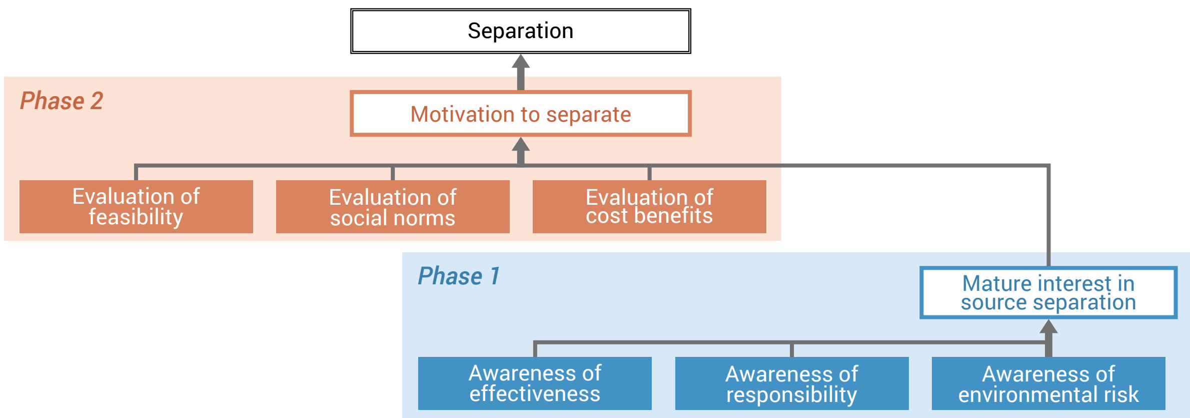


Fig. 6 Structure of behavioural psychology on source separation

when applied to source separation. In phase 1, residents develop a mature interest in source separation by becoming aware of risks to the environment caused by human activities, their responsibility in reducing environmental impacts, and the effectiveness of source separation (e.g. establishing recycling loops or food supply chains, Fig. 7). In addition, residents can be motivated to separate food waste by evaluating whether source separation is appropriate as it may require additional work, time and costs, the need to involve family or neighbours in source separation, and whether instructions and equipment for source separation have been sufficiently prepared by local governments. Purchasing vegetables grown with compost at local markets (Fig. 8, 9) may help waste generators, that is, vegetable consumers, recognise how their involvement in separating organic waste at source contributes to agricultural practices and keep them motivated to continue collaborating with composting projects.

National and local governments have an option to set up new legal systems to promote source separation; for example, waste will not be collected if it is not separated properly, or waste generators will be fined if they do not separate waste appropriately. Legal systems can help promote and improve source separation, but the groundwork should be carefully laid. Strict systems may inconvenience waste generators in their daily lives, while permissive systems may result in a loss of effectiveness for proper source separation.

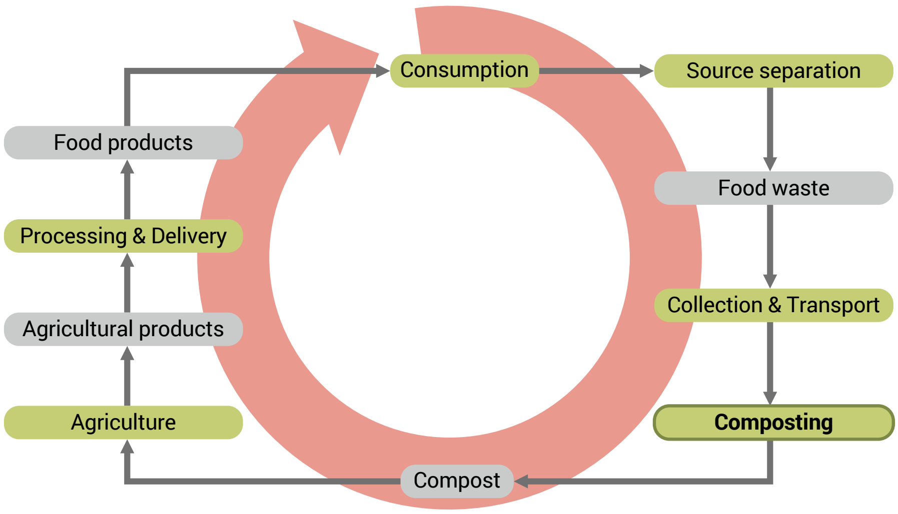


Fig. 7 Recycling loop of food supply chain based on source separation

Fig. 8 Vegetables grown with compost in Motegi Town, Japan

Fig. 9 Vegetables grown with compost in Ikeda Town, Japan

Advisable key criteria

Compost should be utilised for farming by project operators to demonstrate its effectiveness and safety.

The effectiveness and safety of compost for farming may be unknown when a project is launched. Target users may have a negative impression of compost derived from waste, such as that it causes odours or contains unsuitable waste like plastic, glass, or metals. Because of this, residents and other waste generators may lose sight of the objective of separating organic waste at source, and farmers may be hesitant to use compost. **To enhance the cooperation and understanding of both waste generators and compost users, it is advisable for project operators to prepare test farmland plots where compost can be utilised for farming to demonstrate its effectiveness and safety (Fig. 10).** This demonstration should be positioned so that it promotes public awareness on composting.

Fig. 10 Test farmland in Osaki Town, Japan

2.3 Institutional aspects

Mandatory key criteria

Appropriate sites can be secured for the construction of composting plants.

Securing a construction site is a fundamental element of satisfying requirements and achieving the goals of composting plans. Sites are subject to various laws and regulations, such as urban planning and building standard laws, and thus, it is important to design plans from a comprehensive perspective. The stability and reliability of the local government are also an important part of this criterion. **The most important point in constructing composting plants is the ability to secure a site where consent from local residents in surrounding areas can be obtained.**

Strongly advisable key criteria

The administrative body is stable and sustainable.

Since MSW is managed as a public service and composting plants should be in operation for decades, **the stability of the administrative body is a key point for the sustainability of a composting project from an institutional perspective.** Whether composting plants are operated by local governments or private companies, local governments must take the initiative on composting projects. If a private company that has managed and operated a composting plant withdraws, local governments must immediately find an alternative contractor to operate the plant and secure destinations for waste that cannot be composted until operations can be restarted at the plant.

Strongly advisable key criteria

Local residents residing near composting plants are not adversely affected by composting projects.

The operation of composting plants may pose issues for nearby residents due to the high volume of traffic for transporting waste, odours, and vermin or insects from composting plants. In line with regulations during construction and operation phases, **the operators of composting plants should pay special attention to residents in surrounding areas to ensure that these plants do not have an adverse effect on their daily lives and environment.**

Composting plants can play a positive role in developing neighbourhoods, for example, by allocating sections for residents who do not have space to grow their own crops by using the compost produced at the plant.

2.4 Governance capacity

Mandatory key criteria

The heads of local governments are taking the initiative in composting projects.

The introduction of composting projects is influenced by political trends and strongly impacted by the will of those in power in local governments. **The head of the local government, such as the city mayor, must have a positive attitude towards the construction and operation of composting plants.** The roles of related departments of the local governments must be clarified initially, with officers in charge appointed by the head of the local government.

After the election of the head of a local government, the new leader often pivots on policies that have been implemented under the former head. However, the new leader should not interrupt ongoing waste management plans, for example, by changing personnel, if that was not part of promises made during the election. Waste management systems are developed based on careful communication between various stakeholders including residents and farmers as well as local governments.

Strongly advisable key criteria

All local government officers involved in composting projects are developing their capacity for composting, as well as the entire waste management system.

Local governments should formulate specific plans to establish composting projects that take into account a variety of considerations, including future owners or operators of composting plants, amount of waste collected as raw materials from sources, number and capacity of trucks to collect waste for composting, capacity of composting plants, type of composting technology, life cycle costs including initial and operational costs for composting, quality and quantity of compost produced annually, and local demand for compost. Feasibility studies on source separation can be included at the planning stage if composting projects will be established based on source separation by waste generators. A feasibility study on source separation should be initiated on a small scale before the project area is expanded. To proceed with these steps, **all local government officers in charge should develop their capacity on composting as well as waste management systems prior to the start of a project.** External support can be sourced through the involvement of outside experts and consultants, as needed. The department of the local government in charge of composting should maintain its level of capacity even if personnel are reshuffled.

2.5 Financial aspects

Mandatory key criteria

Local governments have the capacity to estimate and secure a budget for composting projects.

Local governments should estimate budgets to construct, operate, and maintain composting plants while they are in service once a decision has been made to move forward with a composting project. To estimate the budget that will be needed for a composting project, local governments can request external experts and consultants to provide technical support, if necessary. If contractors own and operate plants, the local government should estimate the tipping fee per tonne of waste to be paid to the contractors. It is preferred for the government to allocate land to private operators for constructing composting plants since searching for land can prove to be a highly challenging task for private operators. Where applicable, local governments should also consult with national governments or international donor agencies to negotiate terms for grants or loans to construct the plants. Local governments also need to secure a budget for the collection and transport of waste. Items needed to collect separated waste, such as collection containers, should be adequately prepared by local governments to help residents easily dispose of waste. A budget for disseminating information and public awareness should also be available at all times to encourage residents, especially people moving from other areas, to take part in source separation for composting.

Advisable key criteria

Market strategies for compost are carefully developed at the planning stage.

An adequate demand for compost is important for composting projects in terms of the balance between raw materials and compost. In addition to the quality of compost, demand is also dictated by the selling price of compost and transportation fees. Appropriate prices for compost should be analysed taking the price of chemical fertilisers and different types of compost into account. The project operators should discuss the price of compost with local farmers in advance and develop marketing strategies in the initial stage of planning. An alternative use of compost is in parks and to improve streetscapes. In the event that demand for compost falls, it is advisable to assess and estimate latent demand for compost in sectors other than agriculture.

2.6 Technological aspects

Mandatory key criteria

Appropriate methods for the separate collection and transportation of organic waste can be established.

The raw materials for composting should not contain contaminants such as non-biodegradable and hazardous waste, as they have a negative effect on the final quality of compost. The initial inclusion of non-organic components such as plastic and glass in waste collected as organic waste determine the impurity content at the end of the composting process (Cerda et al., 2018). Plastic waste contained in compost is not biodegradable but eventually decomposes into smaller pieces under the influence of sunlight, although it remains in the soil as microplastics for millennia. **If organic waste is separated well at source and municipalities successfully collect only waste that is suitable for composting, it will not be necessary to utilise a series of well-equipped mechanical processes to separate and remove contaminants.** The separation of the organic components of MSW at source is an important process because it reduces non-organic content in the waste collected as organic waste (Cerda et al., 2018, Hargreaves et al., 2008). The separate collection of organic waste is an essential element in supplying better raw materials to produce high-quality compost.

There are several options for the separate collection and transport of organic waste (Table 2, Fig. 11), and the most suitable option should be adopted based on the local situation and detailed feasibility studies on the collection of organic waste for composting. Plastic waste is one of the greatest challenges facing the world. Bio-plastic bags may have two types; the petroleum-

Table 2 Options for the separate collection and transportation of organic waste based on the experiences in Japan

Packaging for collection and transportation	Location	Type of truck	Frequency	Time
Plastic bag Paper bag Plastic container	Curbside Collection point	Flatbed Compactor	Designated day Every day	Morning Afternoon Evening

based plastic which can be biodegraded, and the plastic bag which is (partly) composed of biogenic materials. As of now, there are various types of bio-plastic bags and it is still doubtful whether any bio-plastic bags can be fully degraded in the soil. Plastic bags can be used as packaging for organic waste if the plastic bags are surely removed at composting plants by mechanically or manually.

Plastic containers are placed in each community to collect organic waste from households in the community (Fig. 12, 13). All households participating in the separate collection of organic waste discharge organic waste in the shared containers. Any contamination in the containers can be recognised at first sight. Plastic containers are reused after cleaning inside.

Fig. 11 Paper bags for collecting organic waste in Ikeda Town, Japan

Fig. 12 Placing organic waste into containers at a collection point in Nagai City, Japan

Fig. 13 Flatbed truck for transportation of food waste in Nagai City, Japan

Strongly advisable key criteria

Moisture content can be maintained within an appropriate range during the aerobic fermentation process.

The moisture content of the compost mixture is an important factor as it provides a medium for transporting dissolved nutrients required for the metabolic and physiological activities of microorganisms (Kumar et al., 2010). To activate aerobic bacteria, the moisture content of the feedstock should be kept above 40%, while a higher moisture content prevents air from blowing into the feedstock. Food waste has a high moisture content of around 70% to 80%. To maintain aerobic conditions, it is necessary to reduce the moisture content by adding organic additives such as sawdust (Fig. 14) or rice husk (Fig. 15) at the initial stage of the aerobic fermentation process. Dry leaves (Fig. 16), grass (Fig. 17) and tree trimmings can also be used to adjust moisture content. Kaneko et al. (1986) reported that a moisture content of 50% to 60% at a constant temperature with adequate aeration maximises respiratory activity.

Fig. 14 Sawdust stored at a composting plant in Motegi Town, Japan

Fig. 15 Rice husk used to adjust moisture content at a composting plant in Nagai City, Japan

Fig. 16 Dry leaves stored at a composting plant in Motegi Town, Japan

Fig. 17 Grass stored at a composting plant in Osaki Town, Japan

Box 3 Key actions needed for successful composting projects

A review of existing composting projects helps in identifying key actions that can lead to the development and implementation of successful composting projects (Table 3). Some key actions may have a significant impact on further development, while others may not be effective at all, depending on the local situation. Actions do not need to be followed in the order presented in the table, but can be reviewed and implemented as the situation demands.

Table 3 Types and characteristics of composting projects

Types of actions	Examples
Planning	Clarification of objectives, preparation of action plans
Involvement of key persons	Involvement of local chief executive, community leaders and farmers
Cooperation with stakeholders	Cooperation with business associations, agricultural associations, women's associations
Allocation of personnel	Designation of departments and officers in charge
Collection of information	Interviews with experts on composting technology and agriculture
Study of select cases	Visits to sites and interviews with key persons
Review of case studies	Study on the feasibility of separating organic waste at source in the model area, verification of the effectiveness of compost on agriculture
Organisation of explanatory meetings	Arrangement of periodic briefings for residents and other stakeholders
Implementation of public relations campaigns	Distribution of information on composting projects in local magazines, websites, SNS, and personal communications
Organisation of lectures by experts	Arrangement of scientific lectures by professionals to residents
Confirmation of local positions	Submission of questionnaires to residents involved in source separation
Branding	Requests for copy, logo and mascots for composting projects
Authentication	Certification of the quality of compost and agricultural products based on standards
Evaluation	Presentation of awards to residents and communities who have collaborated in the composting project, evaluation of improvements in recycling rates and value for money

3 Main Technology and Composting Processes

3.1 Waste suitable for composting

Organic waste that can decompose biologically is suitable for composting. Below are examples of organic waste that can be used as raw materials for composting:

a) Food waste such as residue from cooking preparation and leftovers after meals (Fig. 18)

b) Leaves and trimmed trees

c) Rice and wheat straw

d) Cattle and swine faeces

e) Night soil and sewage sludge

f) Vegetable and fruit wastes coming from fresh or public markets

Note that c), d) and e) may not be categorised as MSW but may be managed independently in some countries.

Fig. 18 Food waste suitable for composting collected from households in Hanoi City, Vietnam

Seashells, eggshells, shrimp shells, chicken bones, pork bones, beef bones, coconut shells and fruit seeds are not suitable for composting due to the difficulty in degradation (Fig. 19), although these wastes are often categorised as food waste. These wastes should preferably be removed from the raw materials for composting if facilities do not have the proper processes to remove them. Also, waste with high salt and pungent components should be minimised because this renders bacteria inactive during the composting fermentation process.

Fig. 19 Food waste unsuitable for composting collected from households in Hanoi City, Vietnam

Waste that does not biologically decompose, such as plastics, metals, glass, oil, cigarette butts, gum, diapers, and other such items, is not suitable for composting since it may interfere with the composting process. Paper waste is often categorised as unsuitable for composting even though paper is biodegradable. The aerobic fermentation process for composting generally takes from ten days to three months (Elango et al., 2009), but a much longer period is required for paper to decompose. Farmers tend to avoid using low-quality compost containing pieces of non-biodegradable waste, such as plastics and glass.

Hazardous and harmful waste, such as medicines, dry batteries, spray cans, pesticides, mercury thermometers, and other items, should not be mixed in raw materials for composting since mixing hazardous waste has an adverse effect on the quality of compost (McDougall et al., 2001), and eventually threatens the health of people who ingest the crops harvested on farmland where compost was used.

The use of cattle and swine faeces and sewage sludge requires careful attention to be paid to the proximate and chemical composition. Milk cows ingest copious amounts of water and faeces contain higher moisture content. On the other hand, the faeces of cows used for meat have a much lower moisture content, while pig faeces generally contain a significant amount of moisture. Bedding for cows and pigs such as rice straw, rice husk and sawdust is an excellent mixture used for reducing the moisture content of faeces. Residual components of herbicides in feed crops may remain in faeces and cause growth problems for crops when compost derived from cattle and swine faeces is used on farmlands.

Sewage sludge is the organic and inorganic residue produced during wastewater treatment, and contains substantial quantities of nitrogen and phosphorus in combination with high levels of organic constituents (Arthurson, 2008). However, the heavy metal content in sewage sludge has been a major limitation for compost derived from sewage sludge (Amir et al., 2005). Appropriate guidelines and standards to handle faeces and sewage sludge should be prepared to assure compost quality.

Box 4 Recycling rates in the food supply chain

According to FAO (2019), approximately 30% of the food produced globally is either lost or wasted annually. This is happened at different stages of the food supply chain, including food manufactures, wholesalers, retailers, service industries and households. Considering its negative impacts towards food-security, economic lost and environmental pollution, reduction of food loss and waste has identified as a first priority according to the waste hierarchy and 3Rs. Redirecting of edible food to be reused, such as animal feed and recycling food waste are also important before dispose them in the landfills. A larger amount of less-contaminated food waste can be collected from food manufacturers than from actors further down the food chain (Fig. 20). Recycling rates for food waste generated by food wholesalers, retailers, and food-service industries as well as households tend to be lower because of less efficient collection practices and higher contamination rates. Note that contamination here does not refer to hazardous materials, but to waste unsuitable for composting such as paper, plastic, glass, metals, and other items. Households are a primary focus for tackling MSW issues as they are the main sources of food waste for composting.

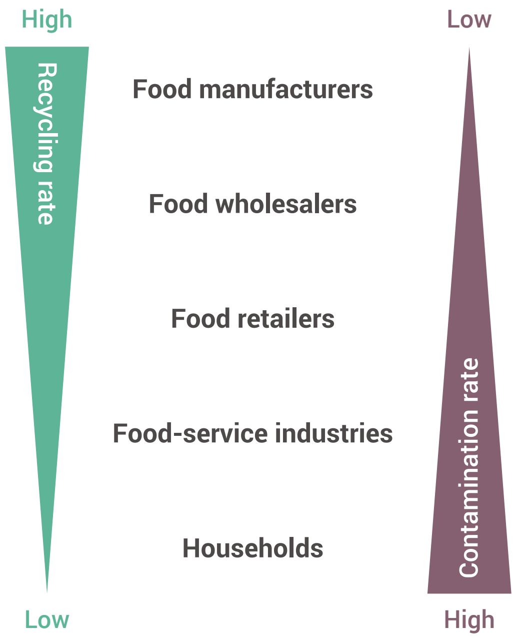


Fig. 20 Recycling and contamination rate of food waste generated by actors along the food supply chain

3.2 Types of composting systems

In developing countries and in major cities in particular, MSW generation is on the rise as populations grow, and local governments are being confronted with the challenge of how to manage this increased waste. As waste generators are responsible for reducing waste as much as they can, one solution for reducing MSW generation is **household-based and community-based composting**. The more households actively separate organic waste from other waste and compost organic waste themselves, the less MSW municipalities need to collect and manage. If households cannot secure adequate space for composting at home or in communities, local governments may choose to concentrate and manage MSW at composting plants rather than transport organic waste to landfill sites. Since it is difficult to completely remove contaminants such as pieces of plastic and glass from compost, this guideline strongly recommends that organic waste be separated at source as much as possible before collection and transportation.

3.2.1 Household- and community-based composting (decentralised composting)

Households and communities can produce compost on their own from organic waste, if adequate space is available in their houses and communities to set up containers, and if organic waste is separated well at source. **Household and community-based composting, also known as a decentralised composting system, is technically easier to manage.** Various types of containers are used for composting at the household and community level, such as plastic baskets (Fig. 21), clay pots, cardboard, and iron or plastic barrels (Fig. 22), and well-ventilated containers are recommended. Lining the inside of the baskets with cardboard can help keep moisture content stable (Fig. 23). The waste in baskets and containers should be mixed regularly to maintain aerobic conditions.

Odour is the most critical environmental issue for household- and community-based composting. Odour occurs in anaerobic conditions caused by excessive moisture during the fermentation process. Moisture content, one of the most important parameters, should be monitored and maintained at around 60% for aerobic fermentation to be successful. The moisture content of food waste is generally around 80%, but food waste with higher moisture content, such as leftover watermelon, should not be included as a raw material. Squeezing or straining out moisture from food waste before disposing of it in baskets and containers can prevent excessive moisture, stop anaerobic decay, discourage odour and

Fig. 21 Baskets for household composting in Surabaya City, Indonesia

Fig. 22 Plastic barrel for community-based composting in Surabaya City, Indonesia

Fig. 23 Cardboard-lined basket in Surabaya City, Indonesia

deter insects. Sandwiching dry soil between layers of food waste has a positive effect in absorbing odours and repelling insects, as well as removing moisture.

When community-based composting is introduced, the local government should carefully select and secure spaces where containers can be set up for fermentation based on consensual agreement with the community. An appropriate number of containers should be set up based on the number of households supplying organic waste. Compared with household-based composting, containers used for community-based composting should be equipped with ventilation and drainage functions since a larger amount of organic waste will be placed in these containers which may become anaerobic due to the higher moisture content.

A case study on household- and community-based composting in Surabaya, Indonesia is described in 4.1.

3.2.2 Centralised composting

If local governments have confirmed that they can sufficiently gain the cooperation of local waste generators in separating organic waste, they may opt for centralised composting. Although the type and number of processes at composting plants depend on the quality of raw materials, composting usually includes the following processes: **adjusting moisture content, fermentation, and mechanical separation, in addition to the separate collection of raw materials at source.** Fig. 24 illustrates the typical flow of the composting process. Plastic bags are removed in the initial process if they are used to collect and transport raw materials. Since raw materials for composting generally have a high moisture content, sawdust and rice husk are often added to absorb and adjust the moisture content. Next, raw materials are biologically decomposed in the fermentation process through aerobic fermentation, the more common type of fermentation. In addition to vapour, CO_2, CH_4, and N_2O gases are generated as a result of the decomposition of organic waste. After the fermentation process, contaminants such as metals, glass and plastic are removed, and finally compost is produced. Composting plants must also be equipped with a deodorising process if residents are in the vicinity. The main processes of centralised composting (fermentation, mechanical separation and deodorising) follow below.

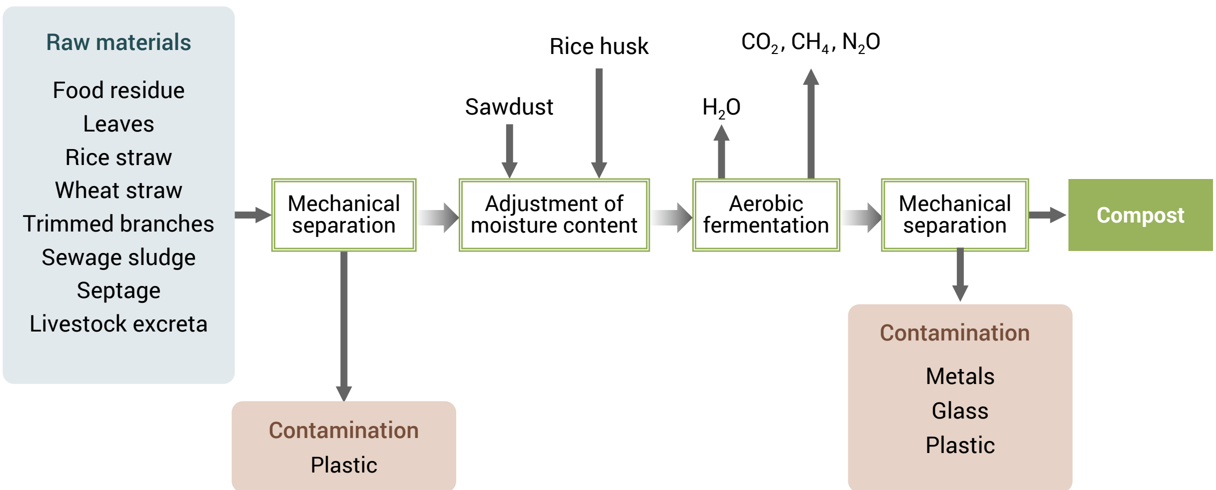


Fig. 24 Typical flow of the composting processes

3.3 Fermentation

Fermentation is divided into two types: **aerobic treatment and anaerobic treatment.** Anaerobic treatment refers to the process in which anaerobic bacteria decompose and stabilise organic components in the absence of air. Anaerobic treatment requires a longer period of time that can last up to ten months to complete the fermentation process due to the slow anaerobic reaction. Aerobic treatment refers to the process in which aerobic bacteria decompose and stabilise organic components in an air-rich environment (Fig. 25, 26). This treatment requires that a certain concentration of oxygen be maintained by feeding air into the mixture through stirring and mechanical ventilation. Aerobic treatment produces compost in a shorter period of time. This guideline focuses on aerobic fermentation because of the simpler technology involved and the higher potential for installing and operating composting plants in developing countries.

Fig. 25 Primary aerobic fermentation process in Osaki Town, Japan

Fig. 26 Secondary aerobic fermentation process in Osaki Town, Japan

The effectiveness of the fermentation process is influenced by factors such as temperature, oxygen supply, moisture content, pH, C/N ratio, particle size, and degree of compaction (Onwosi et al., 2017). These factors can be maintained and improved by mixing organic waste (Getahun et al., 2012) and supplying moisture when necessary. Blowing or drawing air into the bottom of the mixture is also an effective way to supply oxygen and enhance aerobic fermentation. If the moisture content is too high, it is impossible to feed air into the waste, which results in an anaerobic state. During the fermentation process, organic components are reduced to about 50% due to biological decomposition, and the moisture content in the raw materials also decreases due to the evaporation of moisture caused by fermentation heat.

3.4 Mechanical separation

In addition to fermentation, centralised composting facilities require another important process called mechanical separation. **Mechanical separation is used to remove contaminants from the mixture both before and after the fermentation process (Fig. 27).** The level of mechanical separation influences the quality of compost. Several methods of mechanical separation are necessary to completely remove contaminants, even if organic waste is collected separately from other waste.

Fig. 27 Mechanical separation after the fermentation process in Nagai City, Japan

3.4.1 Sieving

Sieving is the process of physically removing larger particles using screens before or after fermentation. Biodegradable components become smaller during the fermentation process. After the fermentation process, the sieving process can physically separate non-biodegradable components from compost. Due to the high moisture content of compost just after primary fermentation, and the various types of non-biodegradable waste such as plastic films and textiles contained in the mixture, screens may become blocked. Screens can be put through a series of movements to avoid blockages: up-and-down, back-and-forth, circular, and trommel (Fig. 28).

Fig. 28 Trommel to remove contaminants after the fermentation process in Ikeda Town, Japan

3.4.2 Ferrous metal separation

Ferrous metals (Fe) can be sorted with magnets that attract Fe from composting streams. This can be carried out, for example, with an **overband magnetic separator or a magnetic drum (Fig. 29).**

Fig. 29 Magnetically separated metals in Hanoi City, Vietnam

3.4.3 Electromagnetic separation

Non-ferrous metals can be sorted by using the eddy current separators. An eddy current is induced by a series of rare earth magnetic or ceramic rotors at the head of a conveyor that spins at high speed independently of the conveyor. This process induces temporary magnetic forces in non-magnetic metals of the same polarity as the rotor, repelling the metals and then separating them from feedstock.

3.5 Deodorising

Odours must be deodorised in composting plants if they are located around residential areas. However, it is difficult to eliminate odours completely, which are much stronger when compost is acidic, in comparison to when it is in a neutral or alkaline state (Sundberg et al., 2013). Ammonia, Amines, dimethyl sulfide, acetic acid and Volatile Organic Compounds (VOCs) are key causes of odours (Mao et al., 2006; Maulini-Duran et al., 2014; Scaglia et al., 2011). **Biofilters such as soil (Fig. 30) and compost itself are methods generally employed in composting facilities to treat and reduce odours.** An important strategy for reducing odours from compost is to rapidly pass through the initial low-pH phase. This can be accomplished through a combination of high aeration rates that provide oxygen, and additives such as recycled compost (Sundberg et al., 2013).

Fig. 30 Soil for deodorising in Nagai City, Japan

4 Case Studies

4.1 Surabaya City, Indonesia

Surabaya, the second largest city in eastern Java with a population of three million people, serves as an important commercial and industrial capital of the province. This city of three million people generates over 1,500 metric tonnes of MSW a day in the following sectors: residential (68%), markets (16%), commercial/industrial (11%), streets and open spaces (5%), with organic waste comprising more than 50% of the composition of MSW (Gilby et al., 2017). The city has succeeded in reducing the amount of MSW generated by more than 20% over a three-year period (2005-2007) by promoting composting practices with the establishment of composting centres and the distribution of thousands of composting baskets to residents, introduction of waste separation and reduction activities at households, community-managed waste collection, and the organisation of community clean-up campaigns and waste recycling activities with local NGOs, the private sector (formal and informal) and media (Maeda, 2009). **Surabaya's achievement exemplifies how a city can reduce a large amount of waste in a short period of time with a limited budget by first targeting organic waste and establishing a composting-based integrated sustainable waste management system** (Maeda, 2009: Premakumara et al., 2011).

Before the establishment of Surabaya's solid waste management model of composting, MSW was mainly landfilled. The waste issue in Surabaya peaked in October 2001 with the closure of the only final disposal site belonging to Surabaya City at Keputih, creating havoc as waste destined for this site lined the streets around the city.

In 2004, the Kitakyushu International Techno-cooperative Association (KITA) in Kitakyushu City and Pusdakota, a local NGO in Surabaya, worked together to design a pilot project in Kampong Rungkut Lor, a low-income neighbourhood located adjacent to the largest industrial area in the city. After six months of trial and error, an efficient composting method known as the Takakura Method (named after a composting expert from Kitakyushu) was developed based on a traditional windrow composting method and adopted at Pusdakota's composting centre. The Takakura Method uses fermentation microorganisms as seed compost, which were originally cultured from local fermented foods, such as soy sauce, yoghurt, and fermented beans (*tempe* and *tape* in Indonesian), fruits and vegetable peels, rice bran and rice husks. The most remarkable feature of the Takakura Method is its speed; it takes only one to two weeks to decompose a large portion of the organic compounds, in contrast to the windrow or other methods that usually take more than three months. Therefore, the Pusdakota composting centre started producing quality compost in large quantities (1.4 metric tonnes/day) from organic waste separated at source collected from the community.

Surabaya City scaled up the project by adopting the same composting method at existing composting centres, establishing new centres, and distributing thousands of composting baskets to residents. As a result, the city operated 13 composting centres (Fig. 31) with a capacity of about 40 tonnes a day in total, to process a large amount of organic waste collected from vegetable markets and street/park maintenance activities and has distributed 19,000 baskets (Fig. 32) to households for free.

The city purchased the baskets from Pusdakota and outsourced the distribution of baskets to PKK (Pemberdayaan Dan Kesejahteraan Keluarga, a women's group) and other NGOs, taking advantage of their grassroots access to communities. These NGOs have set up a network of community environmental leaders called environmental cadres, who teach residents how to produce compost from kitchen waste using the baskets, as well as what environmental and health impacts can be expected by keeping the kitchen environment garbage-free. Environmental cadres then follow-up by monitoring the usage of the baskets to troubleshoot common problems. Many households followed suit, which changed the mindset of residents and discouraged people from dumping waste on streets and in streams, and as a result, created greener and cleaner communities. Pusdakota also started functioning as a community waste station with the separate collection of organic and inorganic waste, including recyclables, thus encouraging waste segregation at source.

Fig. 31 Composting centre

Fig. 32 Takakura composting basket

As reported by Maeda (2009), the promotion of composting has a multiplying effect of more than double in terms of waste reduction—40 tonnes a day by 13 composting centres, 40 tonnes a day by 40,000 households, and 120 tonnes a day by using and recycling other dry waste (waste banks and manufacturing handicrafts from plastic waste). Moreover, **Surabaya spends just one to two percent of its total solid waste management expenditure to achieve these results, including the operation and maintenance of 13 composting centres, distribution of composting baskets, supporting the activities of PKK, NGOs and environmental cadres, and organising the Green and Clean Campaign.** All of these activities amounted to only IDR 1.5-2 billion (USD 150,000-200,000) annually from 2006 to 2008. Other cities are encouraged to adopt a similar strategy based on the following five steps (Maeda, 2009).

Step 1 Waste reduction target setting and institutional setup

First, local governments should set waste reduction targets with the mayor's support. A lead department should be designated, which is often the solid waste management department, and co-ordination should be developed with other related departments, including park management, environmental management and city planning departments.

Step 2 Set up market-waste composting centres

A local government can immediately start a composting project by setting up a composting centre and processing the organic waste from vegetable markets that would otherwise be transported to and disposed of at final disposal sites. A composting project requires space and a building for the composting centre, a shredder for cutting the waste into pieces and technical training for staff. The project can be launched on a small scale, such as by processing one tonne of compost a day on a trial run and using the produced compost at city parks, and then gradually scaling up the project after confirming effects.

Step 3 Identify community partners and distribute compost baskets

It is advisable to identify partner communities or schools where strong leadership or community bonds already exist rather than targeting the entire city from the very outset of the project. Developing a network of community environmental leaders who teach residents how to use composting baskets and monitor progress is also an effective approach, as exemplified in Surabaya's case. The active involvement of PKK, which works closely with the city government and co-ordinates with other NGOs and environmental cadres, is another advantage that other Indonesian cities can emulate as PKK is present in every city. Composting baskets can be distributed for free as waste reduction impacts will be larger than actual distribution costs in a few years.

Step 4 Set up community-based composting centres

Supporting local partners in establishing community composting centres through the provision of capital, buildings and equipment is an effective approach to encourage community participation in solid waste management. Another option is to provide shredders and technical training for existing community material recovery facilities. The city government may need to act as the buyer of the produced compost or assist in marketing the compost to farmers to support operations, especially at the beginning stage. City governments can also encourage community participation by first setting up composting centres for market waste, gradually accepting household waste and then handing over operations to the community.

Step 5 Organise community clean-up campaigns

Organising a community clean-up campaign and allowing communities to compete with one other is an effective approach to encourage community participation. Co-organising the campaign with private companies and media groups is an excellent strategy to mobilise resources, widely publicise the campaign and encourage further participation by communities.

There are several critical elements that can be found in Surabaya's success.

1. Social conditions: There were no new sites available to be used as a landfill in Surabaya due to a scarcity of public land. People noticed the hygienic effects of keeping the kitchen environment garbage-free, which would otherwise rot and attract flies and cockroaches, and consequently may have an undesirable impact on the health of family members. Residents understood that the practice of composting was one way to solve this problem.

2. Technological aspects: An efficient household composting method, known as the Takakura Method, was developed to produce quality compost. Composting centres provided follow-up support.

3. Institutional aspects: Surabaya City has been developing various activities to carry out waste management as an administrative measure. Step-by-step development was added in proportion to the progress of improving waste management such as the introduction of composting, updating the compost centre, upgrading the resource separation and

recycling centre, allocating and maintaining a budget for waste management improvement, publicising the city planning master plan, setting up waste reduction targets, and developing an award system, among others.

4. **Governance capability:** The city has a positive attitude towards composting and demonstrates leadership in all activities as explained above. Meanwhile, in collaboration with NGOs, private companies, and the media, Surabaya organised a community clean-up campaign called the Green and Clean Campaign. The number of participating communities (Rukun Tetangga, RTs) involved in the campaign increased from 325 in 2005, the first year of the programme, to 1,797 by 2008, which is about 20% of all RTs in the city.

5. **Financial aspects:** Surabaya has distributed 19,000 compost baskets for free over the past five years and procured baskets from Pusdakota for approximately IDR 100,000 (USD 10) per unit. Assuming the distribution cost, including the promotional and educational activities carried out by NGOs and environmental cadres, was also IDR 100,000 (USD 10) per basket, then the total expenditure by the city for the five-year period was IDR 3.8 billion (USD 380,000). On the other hand, assuming each basket helps reduce one kilogram of organic waste a day, then 19,000 baskets can reduce 19 tonnes a day, which is roughly 6,900 tonnes a year. As the cost for solid waste management in Surabaya is about IDR 230,000 (USD 23) per tonne of waste, the cost saved from waste reduction can be approximated at IDR 1.6 billion (USD 160,000 = 6,900t x USD 23/t) a year. Based on this assumption, the city can recoup its initial investment in 2.5 years and maintain waste reduction effects.

   In addition, as the actual total amount of reduced waste is much larger than the combined compost production capacity at composting centres and households, it is inferred that both the promotion of household-based composting and the separate collection of organic waste function as ways to encourage residents to further reduce other types of dry waste. Therefore, the free distribution of thousands of composting baskets helps to offset any associated costs in a few years and is an activity that can be recommended for other cities to follow suit.

6. **Public awareness and cooperation of residents:** Generally, residents had three incentives to practice household composting. First, most people enjoy using the self-produced compost for plants and gardens. Second, they noticed that rotting waste in kitchens could have an undesirable effect on the health of family members. And third, residents can generate extra income for their households by selling compost and plants or vegetables grown using it. For example, Pusdakota purchases the compost produced by basket users at IDR 700 (USD 0.07) per kilogram, which enables a household to receive an income of IDR 4,200 (USD 0.42) a month by producing one kilogram of organic waste a day as about 20 percent of the input ends up in the final product .

However, waste-to-energy incineration has recently become a focus in Indonesia's national waste management strategy. Under Presidential Decree No.18 of 2016, seven Indonesian cities (Jakarta, Tangerang, Bandung, Semarang, Surakarta, Surabaya, Makassar) have been nominated as eligible for support in developing WtE incineration projects. However, since WtE plants require a minimum of 1,000 tonnes of MSW a day to operate at peak efficiency, Surabaya is facing new challenges in sustaining its composting system as waste is diverted elsewhere.

4.2 Kuliyapitiya Urban Council, Sri Lanka

With the establishment of the National Solid Waste Management Support Center (NSWMSC) and the inception of the PILISARU Programme (a national program launched by the Ministry of Environmental and Natural Resources), Kuliyapitiya Urban Council (KUC) put forward a proposal to establish an integrated solid waste management system in the city. **This integrated approach solved many issues in managing waste, including the construction of a composting facility to manage biodegradable waste, recycling centre for resource recovery, semi-engineered landfill for the disposal of residual waste and a low-cost wastewater treatment system for sewage as well as leachate management.** Today, the Kuliyapitiya integrated waste management facility has enabled Kuliyapitiya to thrive as it recovers resources from MSW (Karunarathna, 2020).

Change from collection and disposal practices to an integrated MSW management approach

With a population of 6,554, KUC is the second largest township in Kurunegala District, North Western Province of Sri Lanka. Until the right leadership appeared in 2009, and in the absence of basic infrastructure for MSW treatment or disposal, Kuliyapitiya Urban Council was no different from any other small local authority in that it delivered substandard MSW services to the public while placing the ultimate burden on environment. The Kuliyapitiya Urban Council struggled to manage the city's large quantities of waste generated from households, commercial enterprises and public places.

Until 2008, all waste was openly disposed on barren land at one corner of the city (Fig. 33). As the mountains of disposed waste grew higher, workers burned it to secure enough space for the next day. The smoke from burning waste created an unpleasant environment and posed significant health risks for residents. KUC faced enormous pressure to close the dumping site and shift operations to a remote location. However, finding a place to dump the waste was almost an impossible task as land resources within the city limits were scarce.

Environmental Preservation Centre of KUC

The establishment of NSWMSC in 2007 and the inception of the PILISARU Programme in 2008 created opportunities for local authorities, including the Kuliyapitiya Urban Council, to look for much needed technical and financial assistance. The KUC put forward a proposal to establish

Fig. 33 Kuliyapitiya waste disposal facility before improvement in 2008 and after setting up the Environmental Preservation Centre in 2009 (Karunarathna, 2020)

an "Environment Preservation Centre" (Fig. 33), an integrated waste treatment and disposal facility, on the same land that had been used as a dumpsite for many years to help reduce the amount of waste sent for final disposal. Planners proposed an integrated waste treatment and disposal facility that would include a small biogas unit for highly problematic and spoiled waste, a composting facility for biodegradable waste, a facility to sort and recover recyclable waste from non-biodegradable waste and a small semi-engineered landfill facility for the disposal of residual waste.

The composting facility was one of the first full scale windrow composting systems capable of handling up to 10 metric tonnes of biodegradable waste. Once the composting facility commenced operation in 2009, the biggest challenge was to sort mixed MSW received through the conventional collection system. Five to six workers were employed full-time to sort incoming waste. Due to the high cost of this extra labour, issues with worker's hygiene and the inefficiency of the entire system, KUC spent more than expected at the beginning of the project, requiring them to develop short- and long-term measures to implement a source-segregated waste collection system for the entire city.

Implementation of source-segregated waste collection

From the start, the most challenging task facing the urban council was to encourage the public to become involved in segregating waste. In 2009, the Bell collection system was introduced in one ward as a pilot project. Bell collection is a system where a collection vehicle for biodegradable waste plays a unique tune to announce its approach to households so residents can directly unload household garbage bins into the collection vehicle (Fig. 34). A collection worker on the vehicle inspects the waste to make sure it is completely segregated. In cases where waste had not been separated properly, residents received a warning and the waste was not accepted. In general, the residents in the city cooperated with this source-segregation collection system since collection was conducted on a regular basis. The support and encouragement from higher authorities helped workers effectively implement the collection of waste separated at source. With this system to separate waste at source, the composting facility did not require as many workers on a full-time basis. The positive steps taken by KUC were recognised, and the PILISARU project donated a skid steer loader to aid composting operations.

Fig. 34 Source-segregated collection by the Bell collection system (Karunarathna, 2020)

With the success of this pilot project, KUC expanded the scheme to two other wards in 2010. Residents were informed of the new collection scheme through community meetings, posters, and notices in residential areas, and formal awareness campaigns were organised in schools and public/private sector institutions. In 2014, reusable bags were distributed to households to aid in the separation of biodegradable and non-biodegradable waste. By 2016, KUC started to implement source-segregated waste disposal and collection in the entire city. Once the entire KUC residential community had adjusted to this disposal and collection scheme, KUC developed strategies targeting populations migrating to the city for work, trade, shopping and other purposes.

The KUC's decision to obtain help from experts such as NSWMSC and Japan Overseas Cooperation Volunteers (JOCVs) significantly helped in the implementation of this scheme. Since 2009, KUC has been a destination for JOCVs to work with communities in introducing sound waste management practices, source-segregated waste disposal, and recycling.

Windrow composting of biodegradable waste

Workers for the Environmental Preservation Centre were hired from nearby communities and placed in permanent cadre. There are nine workers engaged in daily operations, with one worker placed at the compost sales outlet and another worker trained to operate the skid steer loader. The overall management of the site is handled by a trained supervisor who is also responsible for record keeping.

First, waste is bought to the facility by six waste collection tractors and unloaded on a concrete floor. Waste is thoroughly inspected, and any remaining non-biodegradable waste is removed manually. The biodegradable waste feedstock is loaded into a wooden frame using the loader and gradually piled up to a maximum height of 2m. The initial pile height is about 2m; however, the pile decreases in height to 1.5m or less within few days (one week maximum) due to rapid degradation and compaction (Fig. 35).

The first windrowing of the new pile is carried out after two weeks, with piles windrowed weekly after that period. Although heavy waste during the windrowing process is handled entirely by the loader, a worker spreads and uniformly compacts the waste in piles. Water is added to the mixture during the windrowing process, especially while the composting pile is undergoing maturation after 10 weeks of initial decomposition.

Leachate from the waste piles is diverted to a treatment plant through a concrete drain system. Leachate is minimal during dry spells, which allows even outdoor concrete floors to be used to pile fresh waste. However, operations are restricted to indoor spaces during the rainy season, when an excessive amount of leachate is generated. The leachate treatment facility is a locally designed coconut coir brush-based system that mimics attached growth biological treatment. The leachate treatment system also receives partially digested sewage collected from households and institutions. The wastewater treatment system has been designed for optimal operation when both types of wastewater are treated together. Treated wastewater is reused at the composting plant whenever watering is required during the windrowing process.

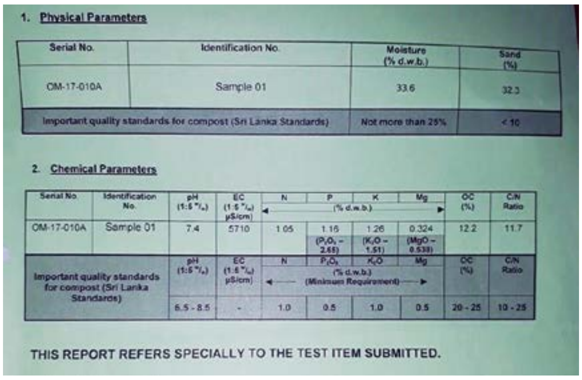
Fig. 35 Piling up composting feedstock using wooden frame and skid steer loader (Karunarathna, 2020)

Matured compost is sieved using a trommel screen with a standard size specified by the Sri Lankan government. Residue collected after backend sieving and a portion of the matured compost are mixed with incoming fresh waste to control moisture and increase bulkiness. However, a small portion of residue, plastic particles and inert waste is disposed at the semi-engineered landfill site.

Compost products and quality assurance

The most challenging task in the compost production process is to maintain the steady and appropriate quality of the final product. The incoming waste includes a substantial amount of fine inert contaminants at source as well as during handling at the composting facility. Waste from both public spaces and private institutions contain a significant amount of soil and sand which eventually end up in the produced compost.

With the exception of a higher amount of sand, the produced compost satisfies all quality standards for use as agricultural compost. Compost quality testing (moisture, sand ratio, pH, EC, N, P, K, Mg, OC, C/N ratio) is regularly carried out at least once every six months by sending compost samples to government approved laboratories. The results of this independent quality testing (Fig. 36) are made available to buyers, which guarantees product quality. This practice has built confidence in buyers and helped to maintain a steady demand for compost.



1. Physical Parameters

Serial No.	Identification No.	Moisture (% d.w.b.)	Sand (%)
OM-17-010A	Sample 01	33.6	32.3
Important quality standards for compost (Sri Lanka Standards)		Not more than 25%	< 10

2. Chemical Parameters

Serial No.	Identification No.	pH (1:5 w/v)	EC (1:5 w/v) µS/cm)	N	P	K	Mg	OC (%)	C/N Ratio
				(% d.w.b.)					
OM-17-010A	Sample 01	7.4	5710	1.05	1.16 (P_2O_5 – 2.65)	1.26 (K_2O – 1.51)	0.324 (MgO – 0.538)	12.2	11.7
Important quality standards for compost (Sri Lanka Standards)		pH (1:5 w/v)	EC (1:5 w/v) µS/cm)	N	P_2O_5	K_2O	Mg	OC (%)	C/N Ratio
				(% d.w.b.) (Minimum Requirement)					
		6.5 - 8.5	-	1.0	0.5	1.0	0.5	20 - 25	10 - 25

THIS REPORT REFERS SPECIALLY TO THE TEST ITEM SUBMITTED.

Fig. 36 A sample compost quality test report (Karunarathna, 2020)

Environmental, economic and social benefits

The KUC maintains all financial records from the Environmental Preservation Centre to ensure that a full financial audit can be conducted at the end of each year and to demonstrate the financial sustainability of the centre. About 100 metric tonnes of compost is produced annually. The total operational cost of processing biodegradable waste at the composting facility is LKR 2,289 (USD 13.5) per metric tonne; however, a greater portion of this cost is recovered through the sale of compost, and the absolute operational expenditure is only LKR 289 (USD 1.7) per metric tonne.

A financial analysis shows that a good composting system can recover much of its expenditure on waste disposal through compost sales. **Accounting for the social and environmental benefits of composting, it is imperative that the overall benefits of the composting scheme are far and above those of conventional open dumping.** The composting facility has achieved KUC's main target of reducing the volume of waste in the landfill. Capitalising on the success of the Environment Preservation Centre, KUC's long-term vision is to make Kuliyapitiya a zero-waste city. The strategy to achieve this vision is by promoting recycling and encouraging household-based composting to reduce the burden on the centralised composting facility.

At present, KUC has been able to considerably reduce the amount of waste disposed at the semi-engineered landfill site. Estimates show that the composting facility receives 4.9 tonnes/day of biodegradable waste. Out of a total 2.1 tonnes/day of non-biodegradable waste, about 1.79 tonnes/day is recovered at the material recovery facility as recyclables and only 0.32 tonnes/day is disposed at the semi-engineered landfill site. The remaining waste is either disposed onsite as compost produced from households or recycled through informal recyclers.

The composting facility has created job opportunities in nine neighbouring villages. The unique human resource management system at the centre with flexible work hours and overtime enables the KUC to attract young and educated workers from neighbouring villages and allows the facility to operate continuously even on weekends and public holidays. All workers are supplied with personal protection gear to protect them from contaminants. Moreover, all staff must undergo professional training to receive their National Vocational Qualification (NVQ level 2). At least once a year, KUC conducts health check-ups for all workers.

The composting facility is well managed, keeping fly and odour issues to a minimum, which benefits communities located nearby. At present, KUC has completely banned the burning of waste at the disposal site as well as in the city.

Key outcomes and lessons learnt

The KUC case demonstrates the results that can be gained from the successful implementation of a composting system and associated facilities to find a solution to waste management issues in a small city. **The key achievement in this case is the shift from a "collect and dump" scenario to one in which resources are recovered through the establishment of an integrated waste treatment and disposal facility where resources in urban waste can be recovered and recycled.**

First and foremost, the key to success was the commitment of KUC's leadership in finding a long-lasting solution to its waste issue. Leadership made crucial decisions at the right time to change from conventional waste management practices to an integrated waste management approach. As a small local authority with limited financial resources and technical expertise to move forward, KUC opted to look for outside opportunities and resources.

The collaborative financial and technical support from the national government through NSWMSC and the PILISARU Programme assured the steady progress and full implementation of KUC's waste management action plan. Once financial and technical support were guaranteed, KUC implemented source-segregated waste collection that could be achieved within three years. Steady collaboration with NSWMSC and the PILISARU project helped the council to secure continuous support for expansion and to launch supportive awareness activities.

Benefits are shared among all stakeholders and the workforce, in particular. Workers are encouraged and rewarded with a sense of ownership of the centre and are motivated to contribute more.

Residents perceive the positive changes in the system and support KUC in its mission to maintain the sanitary conditions of the city and final disposal site. In return, residents are provided with a well-organised and regular waste collection system.

4.3 Hanoi City, Vietnam

With financial support from the Spanish government, the Hanoi Urban Environment Company (Hanoi URENCO) constructed a composting plant in Cau Dien that started operation in 2002 to produce compost from MSW (Fig. 37). To enhance composting activities, a source separation and collection project was established with technical support from the Japan International Cooperation Agency (JICA) through its "Implementation support for the 3R initiative of Hanoi city for cyclical society" programme over three years from 2006 (Japan International Cooperation Agency et al., 2009; Taniguchi et al., 2011). In this project, **organic (biodegradable) and inorganic (non-biodegradable) waste was separated by residents in four model areas, and the organic waste was collected and transported separately to the composting plant.** According to guidelines designed by the Hanoi city government, biodegradable food and garden waste were categorised as organic waste, with other waste (including non-biodegradable food waste such as seashells, chicken bones, and coconut shells) categorised as inorganic waste. Items such as paper, textiles, and wood are generally categorised

Fig. 37 Aerobic fermentation at a composting plant in Hanoi City, Vietnam

as organic, but they are regarded as inorganic in Hanoi because of the lengthy time required for biodegradation.

The source separation and collection project was implemented in Phan Chu Trinh in the Hoan Kiem District and Nguyen Du in the Hai Ba Trung District. This area represented about 0.2% of the more than seven million residents of Hanoi (General Statistics Office of Vietnam, 2015). All households, as well as business entities such as offices, shops, restaurants, and hotels, are obligated to separate organic and inorganic waste and discharge each type of waste into designated containers.

Various methods were adopted to publicly disseminate information on the source separation and collection project and how to appropriately separate organic and inorganic waste during the JICA project in order to encourage households to become involved in the process. Guidebooks on source separation were distributed to all households and waste collectors for Hanoi URENCO in the model area. Waste collectors were trained as instructors on source separation to provide guidance to residents. A number of informational meetings were held for residential group leaders and household members. Information on source separation was disseminated through local radio stations and community message boards. Local TV programmes collaborated to popularise the practice of separating waste at source in Hanoi.

In the model areas in Hanoi, organic and inorganic waste could be discharged into designated waste collection containers from 18:00 to 20:30 every day. Some waste generators used dust bins, and others used plastic bags to dispose of waste. In either case, organic waste was disposed into green containers and inorganic waste into orange ones (Fig. 38). Both types of containers were set up side-by-side every day on the main streets by Hanoi URENCO workers before the beginning of the drop-off period.

The project continued in two of the model areas

Fig. 38 Containers for organic waste (green) and inorganic waste (orange) in Hanoi City, Vietnam

after the project finished in 2009. However, progress has not been monitored by any of the participating agencies since the completion of the JICA project.

Kawai et. al. (2017) proposed three key parameters (participation rate, proper separation rate and proper discharge rate) for behaviour related to source separation of household organic waste, and monitored the progress of the programme based on the physical composition of household waste sampled from 558 households in the model programme areas of Hanoi in August 2014. The results showed that 13.8% of 558 households separated organic waste, and 33.0% of households improperly discharged mixed (unseparated) waste. About 41.5% of the waste (by weight) collected as organic waste was contaminated by inorganic waste, and one-third of the waste disposed of as organic waste by waste generators was inorganic waste.

Currently, although Hanoi URENCO does not separately collect organic waste, it collects mixed waste, all of which is transported to the landfill site. No containers for the separate collection of organic and inorganic waste are placed on the streets in Hanoi. It seems that Hanoi URENCO experienced a continuous downturn in demand for compost and, as a result, reduced the amount of compost produced. In the end, they ceased transporting waste collected as organic waste to the composting plant. It is crucial that continuous demand be secured for compost to ensure sustainability. The low quality of the raw materials for composting negatively affected the quality of compost because pieces of plastic and glass could not be removed. Most farmers are reluctant to use poor-quality compost even if it costs less than chemical fertilisers.

4.4 Nagai City, Japan

Nagai City is located in Yamagata Prefecture, with a population of 27,000. Local farmers in Nagai City recognised that the condition of soil on their farmlands was deteriorating due to the long-term use of chemical fertilisers. They determined that **organic fertilisers needed to be used on farmland to improve soil conditions, and that food waste generated in the kitchens in their own homes could be used as the raw material for organic fertilisers**. The city government of Nagai supported the establishment of environmentally-friendly agriculture based on proposals by its residents. Food waste mixed with other combustible waste, which had been disposed of at the local incineration plant, is now collected from approximately 5,000 households in Nagai to produce organic fertiliser at the composting plant (capacity of nine tonnes per day of food waste) using rice husk and cattle faeces. The composting system reduces combustible waste by 30% and annually produces 400 tonnes of organic fertiliser. All the compost produced is distributed to local farms to grow crops, which are sold and consumed locally. This guideline shows the steps of how this composting system was established in Nagai (Tasaki et al., 2016), which may be helpful for other local governments that are considering the development of composting systems.

Following a suggestion from the mayor of Nagai City, who encouraged the public participation of local communities, a committee composed of residents was established to discuss the next master plan of the city. A working group on agriculture was launched under the committee to promote the local farming industry. By investigating examples in other areas, the committee found ways to produce compost derived from food waste for use as organic fertiliser. The working group on agriculture compiled its recommendations on promoting the development of a composting system through the collection of food waste from households and the use of the compost produced on farms. The mayor adopted these recommendations as part of a new master plan on the future of agriculture.

The residents who were involved as members of the working group on agriculture established a study team on organic agriculture and invited farmers, members of the chamber of commerce, and members of the women's union to take part. The study team negotiated with the mayor and successfully received financial support for their study to achieve the recommendations made for the new master plan. The members of the study team on organic agriculture started to investigate how to collect food waste from households, different types of composting, ways of utilising compost and other activities related to sustainable waste management. They compiled and submitted a final report on food waste composting to the mayor.

Based on the results of the investigation, the study team independently analysed the feasibility of food waste composting. A member of the study team asked the women's union to collaborate with the feasibility study, and 30 households started to separate food waste at their homes. Another member of the study team who owned a restaurant separated food waste for composting on a trial basis. Collection bins for food waste were set up in two areas, and food waste was disposed of in the bins twice a week. The separated food waste was collected by the study team and transported to a composting depot at a local cattle farm, where food waste was mixed with cattle faeces and fermented aerobically. The farmers who were members of the study team utilised the compost for agriculture and grow vegetables, which were distributed to the households who had cooperated in separating food waste. The feasibility study lasted for two years with municipal subsidies offered to purchase necessities and rent a truck to collect food waste.

The study team introduced their activities online, and people interested in this initiative visited the food waste composting site in Nagai. The mayor ordered the farm policy planning division of Nagai City to expand activities on food waste composting in the city. Other related divisions provided and shared necessary data and implemented public awareness activities to introduce these activities. A promotion team was established in collaboration with related divisions of the Nagai city government.

Nagai City officially initiated a feasibility study on the separation and collection of food waste in model areas in partnership with the study team on organic agriculture. The farm policy planning division acquired a budget, and the study team carried out the feasibility study. Since the feasibility study required an increase in the number of cooperating households, the network of the women's union collaborated with the study team to increase cooperation with 100 households in the residential area. Through a process of trial and error, they concluded that buckets (Fig. 39, 40) were the best option for keeping food waste at home and bringing it to collection bins based feedback from users. The farm policy planning division of Nagai City recognised the residents' high level of interest on food waste composting and finally decided to implement composting on a full scale following a feasibility study in the model area.

Together with the study team on organic agriculture, Nagai City embarked on an initiative to formulate a project plan to construct and operate the composting plant and encourage organic farming using compost. Good practices on food waste composting in other areas of Japan were investigated, in which the importance of demand for compost was emphasised. These good practices also suggested that it was important to demonstrate to users the advantages of using compost. Based on this investigation, the city decided to collect food waste from central residential areas only. This is because households in rural areas in Nagai City managed food waste on their own and because transporting food waste from rural areas was inefficient.

Based on the composting plan, Nagai City constructed a composting plant with a subsidy from the Ministry of Agriculture, Forestry and Fisheries (Fig. 41). The composting plant used cattle faeces from livestock farmers and rice

Fig. 39 Discharging food waste using a bucket at a collection point

Fig. 40 Food waste discharged into a collection container

Fig. 41 Composting plant in Nagai City, Japan

husk from rice farmers to mix with food waste. The proportion of food waste, cattle faeces, and rice husk changed and improved through trial and error. Officers from the environmental division of the city government visited areas where food waste was constantly being separated and collected together with members of the study team on organic agriculture to promote and monitor the activity in the early days. The study team members carefully explained that source separation of food waste was necessary to create a sound environment for the future and asked local people for their cooperation in separating food waste at home. The members of the study team on organic agriculture were committed to utilising the compost produced at the composting plant.

The study team on organic agriculture faced a challenge in determining how to increase the number of farmers utilising compost. As a solution, a guideline on cultivation methods using the compost was developed, and a system to certify crops produced according to the guideline was established, with a certification office set up in the farm policy planning division of the city government. In this system, special labels are attached to farm products to indicate their status as certified products (Fig. 42). The members of the study team on organic agriculture held meetings for farmers and residents to explain about the food waste composting and certification system. The study team also endeavoured to increase the number of shops and restaurants using certified farm products in cooperation with the network of the local chamber of commerce (Fig. 43).

Nagai City had instituted a policy to consume local farm crops by promoting its use in school lunches. The farm policy planning division of the city government negotiated with the board of education on the use of certified rice and vegetables for school lunches in the city. Farmers who supplied certified farm crops for school lunches increased their use of the produced compost, which resulted in increased demand for the compost. The city government launched a public awareness campaign informing residents about the effects of food waste composting on school lunches and called for residents to take further steps to separate food waste at home. Nagai City and the study team on organic agriculture were commended by the prefectural government for expanding the local production of farm products for local consumption.

Fig. 42 Label for certified products

Fig. 43 Sales of vegetables grown with compost at a local market

5 Conclusion and Recommendations

Composting aims to treat organic waste biologically and to produce compost, an organic fertiliser, that improves soil conditions chemically, biologically and physically. **Composting helps reduce the volume of MSW disposed in landfill sites in developing countries and dramatically reduces environmental impacts by producing the compost that users need. Composting also reduces methane emissions from landfills and lowers carbon footprint. In addition, household and community-based composting can specifically bring social and economic benefits to the users.**

Composting projects are strongly recommended for cities or areas that seek alternative treatment systems to replace landfilling. The city or area should be able to separately collect quality raw materials for composting, secure enough demand for compost, and safeguard an adequate budget to operate composting plants for decades. The city or area should also have a sufficient level of manpower and institutional capacity to ensure that composting projects are sustainable.

Compost should not contain contaminants, such as non-biodegradable or hazardous waste, as they can negatively impact quality. This guideline asserts that the separate collection of organic waste is an essential element in supplying quality raw materials for composting to produce high-quality compost. There are several options available to residents for the separate collection and transport of organic waste. **The most suitable option should be adopted based on local situations and detailed feasibility studies to ensure that only high-quality waste is collected.**

A composting system needs users, such as local farmers, who should be included from the very start of the planning stage to ensure that their opinions are reflected in the system. Without the involvement of local farmers who use compost regularly, composting systems will not be successful in accomplishing the goals of the local government to reduce the amount of waste disposed of in landfills and streamline waste management.

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About the CCET Guideline series

CCET in partnership with the United Nations Environment Programme (UNEP) - International Environmental Technology Centre (IETC) and the Ministry of Environment, Japan (MOEJ) provides technical assistance to national, sub-national and local governments in developing countries on the development and implementation of waste management strategies. During the implementation of CCET activities, it was found that the issue of waste management is more complex in developing countries, characterised by dramatic urbanisation that has led to an increase in volume and types of waste (including dangerous chemicals and metals, such as mercury, lead, etc.), but with a lack of capacity to sustainably perform proper waste management, including legislation and policies for realistic long-term planning, limited collection and a lack of proper disposal, scavenging issues, poor funding, low public awareness, and other issues. Furthermore, a significant number of inappropriate technologies and equipment has been introduced due to insufficient knowledge on sustainable waste management practices. There is an urgent need to provide accurate information to assist policy-makers and practitioners so that they have a clear and holistic view of all waste management technologies.

The CCET guideline is a series consisting of key technology options that act as pieces of a puzzle to identify an optimal technology mix for addressing the unique challenges faced by governments. It is commonly accepted that there are no universally right or wrong answers to what technology is appropriate for any one region. Rather, solutions need to be developed locally and tailored specifically to local needs and conditions. Citizens and stakeholders need to be involved in designing a diverse set of services which, in turn, needs to be delivered at affordable costs. As with the pieces of a puzzle that form a clear picture when connected, the CCET guideline series offers knowledge-based support for the development of strategies and action plans.

The main purpose of this guideline series is to assist policy-makers and practitioners at the national and municipal levels in selecting appropriate waste management technologies and executing related policies to improve waste management. CCET is focusing on fundamental intermediate treatment technologies, including composting, Mechanical-Biological Treatment (MBT), Anaerobic Digestion (AD), and Waste-to-Energy (Incineration).

This guideline series:

(1) is a user-friendly, knowledge-oriented product that provides clear, concise and comprehensive points, which makes it easy to identify optimal options at a glance;

(2) has been developed from a “resource perspective” rather than a “waste treatment perspective” based on the concepts of the 3Rs, waste hierarchy and circular economy;

(3) addresses both the physical (technical) elements of collection, disposal and recycling as well as the “soft” aspects of governance, public awareness and participation, and institutional and financial aspects to encourage social engagement; and

(4) is supported by good practices.

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