Guidelines for Technology Selection for Sustainable Solid Waste Management in Mongar, Bhutan

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Preface

Improper solid waste management causes environmental impacts and also affects human well-being. The amount of solid waste is growing rapidly in many of the developing countries with rapid urbanization. Bhutan is a small country located in Southeast Asia with an overall population of 0.7 million. The country has almost 70 percent of the land covered with forest and also has mountainous terrain. The topography makes it difficult for the transportation and disposal of solid waste and the current practices causes damage to pristine environment. Thus, it becomes very important to have appropriate waste management system suitable for local conditions. In addition, the lack of appropriate knowledge of the responsible stakeholders make the situation worst as they are not able to select the right technologies and management approach resulting in most of the waste being disposed to the landfill. If appropriate technology for integrated solid waste management are selected, this will reduce the amount of waste ending up into the landfill.

The objective of this guideline is to facilitate local government in selecting appropriate technology for sustainable solid waste management based on local context. In order to select the technology, a set of criteria is required. This report provides the major criteria and logical steps on which the decision can be made for selecting the technologies. Proper waste management will ensure the appropriate utilization of the resources and a drastic reduction in the waste going to the landfill. Examples of the criteria and selection of technologies based on the local conditions of Mongar, Bhutan are presented in this guideline. This can be adopted by other localities with similar situation in the country.

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CHAPTER 1: INTRODUCTION

1.1 Introduction

Problems related with inefficient management of solid waste have been considered as one of the most urgent socio-economic and environmental concerns for governments at all levels. With the rapid population growth, urbanization, as well as life style changes, anthropogenic impact is the main reason that degrades the ecosystem and affects the living organisms. Despite the fact that solid waste is the global major issue that needs to be tackled, developing countries have encountered many problems due to insufficient capacities and knowledge to prevent waste generation, manage waste, and handle the impacts of waste.

Accordingly, to have effective solid waste management (SWM) system, it is necessary to provide management and governance strategies to engage all stakeholders for collaborating and enhancing the overall sustainable development of societies. Regardless of the setting, any initiative cannot fit with the circumstances of all communities or cities; therefore, SWM processes will vary according to the context of waste and resources of each community.

Resource utilization is one of the most effective and ecological ways to manage the waste and extract the best use of it. Instead of discarding all the waste into landfills, a large amount of organic and recyclable waste is considered as a valuable source of alternative energy, raw materials, and byproducts. As such, it is essential to manage waste with appropriate technologies for greater management outcomes and more rigorous in monitoring and evaluating SWM system. Among SWM initiatives, an integrated solid waste management (ISWM) approach is important for sustainable development and appropriate resource utilization.

The main objective of these guidelines is to provide decision making tools for local authorities to adopt sustainable solid waste management practices in the local context. An example to follow the approach on selection of criteria and technology are provided for Mongar, Bhutan.

1.2 Approach for Criteria and Technology Selection

It is very important to have the knowledge of the current waste management situation of the location; therefore, baseline data collection is required. Baseline data may include, but not limited to, waste generation and composition, institutional framework, available technology and skills, financial resources, stakeholder involvement, and policy/regulations.

With the baseline data information, challenges and opportunities can be pinpointed and all possible solutions can be identified. These list of solution includes both technological and management options. The management options may include 3Rs strategies, public-private partnership, awareness raising campaign, education and training, and economic instruments.

With the changing consumption pattern of the resources and economic growth, it becomes very important to reduce and reuse the resources. Additionally, the waste can be changed to resources such as compost, biogas, and energy. This interception will minimize amount of waste to be disposed into the landfill, which should be the least preferred option in solid waste management.

Although there can be many possible solutions for managing the waste, however, not all solutions may be feasible for adoption. Thus, it is important to assess the appropriateness of each solution based on the set of criteria and local conditions as presented in Table 1. Criteria used for SWM are versatile and dynamic according to situations and circumstances of solid waste in each city. Therefore, this guideline includes 12 fundamental management criteria for eight operation and utilization techniques. The 12 criteria are technology development, types of solid waste, operating scale, success factors, final products, capital investment, operating cost, land requirement, needed operating skills, possible adverse impacts, and contribution to energy and food security. The eight SWM operation and utilization techniques include composting, anaerobic digestion, mechanical biological treatment, landfill, incineration; refuse derived fuel or solid recovered fuel, pyrolysis, and gasification. After making the assessment, the decision on the appropriate solution(s) can be made.

1.3 Waste Management Criteria

The 12 SWM criteria in terms of eight operation and utilization techniques to manage solid waste are presented in Table 1. The Table demonstrates an overview of waste utilization methods used in cities worldwide. However, to specifically selecting the criteria for particular location, scoring system may be applied. Table 2 demonstrates how the 12 criteria and 8 techniques can be selected as a waste utilization technique by applying scoring concept.

To identify potential waste operation or utilization techniques that are possible to be implemented for each city or community, Tables 1 and 2 can be used as a decision making tools that supports responsible authorities to decide which waste utilization techniques should be implemented.

Table1 Criteria on SWM operation and utilization techniques (Adapted from [1])

Criteria	Waste management operation/utilization methods							
	Composting (Aerobic)	**Anaerobic digestion (AD)**	**MBT**	**Landfill**	**Incineration**	**RDF or SRF**	**Pyrolysis**	**Gasification**
1. Technology status	Widely used	Widely used	Widely used in developed countries	Widely used; especially in developed countries (for gas recovery)	Widely used in developed countries	Widely used	Mostly applied in developed countries	Mostly applied in developed countries
2. Types of solid waste	Sorted organic waste; High lignin material (wood) is acceptable	Sorted organic waste; Animal or human excreta; Sludge; Less suitable for high lignin material	Unsorted waste without hazardous waste	Unsorted waste without hazardous and infectious waste	Unsorted waste	Unsorted waste without hazardous and infectious waste	Specific type of recyclable plastic waste	Waste; Pre-processed RDF or SRF from MBT
3. Appropriate scale	Small scale (Household: yard waste, vermicomposting); Large scale (Community: windrow, aerated, static pile, in-vessel)	Small scale (on-farm composting); Large scale (community organic waste)	Large scale (Community)	Large scale (Community, city)	Large scale (Community, city)	Large scale (Community, city)	Large scale (Community, city)	Large scale (Community, city)
4. Conditions for success	Temperature sensitive; Long residence time; Regular aeration required; Odor control; Clean input material; Contamination sensitive measure	Clean, homogeneous, and consistent input materials; Good process control (easily disruption of microbial)	Clean, homogeneous, and consistent input materials; Good process control	Clean, homogeneous, and consistent input materials; Good process control (leachate, methane, and contamination)	Homogeneous and consistent input materials; Good process control (syngas)	Clean, homogeneous consistent inputs; Good process control	Clean, homogeneous consistent inputs; Good process control	Homogeneous and consistent input materials; Good process control (syngas)

1 Sharp, A. and Sang-Arun, J., 2012. A Guide for Sustainable Urban Organic Waste Management in Thailand: Combining Food, Energy, and Climate Co-Benefits, IGES Policy Report 2012-02, ISBN: 978-4-88788-088-7.

5. Final products	Compost-like product	Compost-like product; Low calorific RDF; Heat	Compost-like product; RDF or SRF product; Heat	Biogas	Heat	RDF	Oil-like product	Heat
6. Capital investment	Low for windrow technique; Medium for in-vessel technique	High	Low	Medium	High	Medium	High	High
7. Operational cost	Medium for windrow technique; High for in-vessel technique	Medium for manual system; High for automated system	Medium	Medium	High	Medium	High	High
8. Land requirement	Medium for windrow technique; Low for in-vessel technique	Low	Medium	High	Low	Low	Low	Low
9. Needed skills	Technical skills required; Training required specially for in-vessel technique	Technical skills required; Training required	Technical skills required; Training required	Technical skills required; Training required	Technical skills required; Training required	Technical skills required; Training required	Technical skills required; Training required	Technical skills required; Training required
10. Potential adverse impacts	Odor and insect problem	Leakage of methane gas problem	Odor and insect problem	Problems form odor, insect, rodent, methane emission, leachate leakage, limited recovery efficiency of recyclable materials, fire	Pollution from syngas and toxic emission	Uncertain heating value	High energy consumption during operation; Noise and air-pollution	High energy consumption during operation; Noise and air-pollution
11. Contribution to energy security	None	Power generation from biogas	Energy from RDF; Power generation from combustion	Power generation from biogas	Power generation from heat	Energy from RDF	Power generation or use as raw materials of oil-like product	Power generation from heat
12. Contribution to food security	Use as compost for cultivation	Use as compost for cultivation	Use as compost for cultivation	None, high contamination	None	None, high contamination	None	None

The eight waste operational or utilization techniques are abbreviated as T1 to T8. These techniques are scored for different criteria that can be used as a guideline for a suitable adoption of SWM technique that will increase the effectiveness of SWM process and make it more sustainable.

Level of impact and influence of each criterion is determined specifically on how each operation or utilization technique affects the specified criteria. The impacts are transcribed into numbers, which the weight of each criterion ranges from '3' (positive influence), '2' (neutral or indifferent influence), and '1' (negative influence). However, this scoring number can be adjusted by the assessor as used in the case study for Mongar, Bhutan (score 1 to 5).

As presented in Table 2, each criterion is assigned a value according to its score. This can help local authorities or waste management practitioners to easily identify the appropriate waste utilization methods that suit the local situation.

Therefore, to ensure the effectiveness and efficiency of SWM system, it is substantially imperative for responsible authorities and related stakeholders to collaborate and take all important factors into consideration before deciding which waste management criteria, operations/utilization techniques, and scoring should be used. The above provides basic guideline of selecting appropriate SWM operation and utilization techniques.

In addition to appropriate technology selection, there are some other factors that may also influence the success of solid waste management. For community based waste management, leadership and transparent management, clear role and responsibility of stakeholders, good attitude of residents, and localization technique are important.

Table 2 Simplified table of impact and influence of criteria on SWM operation and utilization methods

Criteria	T1	T2	T3	T4	T5	T6	T7	T8
(1) Solid waste characteristics								
- Organic or biodegradable	3	3	3	2	1	2	1	1
- Recyclable	1	1	2	1	2	2	3	3
- Commingled waste	1	1	1	2	2	1	1	1
(2) Waste quantity								
- Small amount (household or small community levels)	3	2	2	3	1	1	1	1
- Medium amount (medium to large community levels)	3	3	3	3	3	3	3	3
- Large amount (large community to city levels)	3	3	3	3	3	3	3	3
(3) Compliance with laws								
- Local	3	3	3	3	3	3	3	3
- National	3	3	3	3	3	3	3	3
(4) Land requirement								
- Small area	3	2	2	1	3	2	2	2
- Large area	3	3	3	3	3	3	3	3
(5) Multisector involvement								
- Community	3	3	2	2	1	2	1	1
- Private company	3	3	3	3	3	3	3	3
(6) Public acceptability	2	2	2	1	1	2	2	2
(7) Possible adverse impacts								
- Environment	2	2	2	1	2	2	2	2
- Society	2	2	2	1	2	2	2	2
- Economy	3	2	2	1	1	1	1	1
(8) Demand for final products	3	3	2	1	3	2	3	3
(9) Initial investment	3	3	2	2	1	2	1	1
(10) Operating cost	3	3	2	2	1	2	1	1
(11) Time consuming for entire process	2	2	2	1	3	3	3	3
(12) Complexity and required skills	3	2	2	3	1	2	1	1
Total score for each waste utilization technique	**55**	**51**	**48**	**42**	**43**	**46**	**43**	**43**

Waste utilization techniques: T1 = composting, T2 = AD, T3 = MBT, T4 = sanitary landfill, T5 = Incineration, T6 = RDF, T7 = Pyrolysis, T8 = Gasification

Influence of impact of each criterion: 3 = Positive, 2 = Neutral, 1 = Negative

CHAPTER 2: CASE STUDY OF MONGAR, BHUTAN

2.1 General Information of the Country

Bhutan is a small landlocked nation located in eastern Himalayas, bordered by India in the east, south and west and by China in the north with total areas of land 38,394 km^2. The country is entirely mountainous rising from southern foothills of 160 m above sea level to over 7,500 m high peaks in the north [1].

The GDP of Bhutan is mostly contributed through hydropower and agriculture activities. In 2013, Bhutan's gross domestic product per capita was US$ 2,440 [2]. Unfortunately, this unprecedented socio-economic achievement is accompanied by adverse impacts on natural resources and the environment.

The country's population in 2014 was 745,153 [3]. With population concentration in the urban areas and changes in consumption pattern driven by economic gains, various social challenges have surfaced lately. Escalation of solid waste generation especially in urban areas has emerged as one of the serious challenges to the Royal Government of Bhutan (RGoB).

The RGoB, over the past years has been searching for options and opportunities to tackle thess challenges. However, high demand of resources coupled with mere technological capacity limits, the chances to improve the deteriorating situation is minimal. The fragile mountain ecosystem adds to the limitation of finding and developing landfill sites. To date, public participation in the waste management system has not been strong. The waste quantity generated may not be alarming compared to the waste quantities in other countries, but for the population size and urbanization system in a steep mountain terrain, it has become a serious concern.

2.2 General Information of the Selected City, Mongar

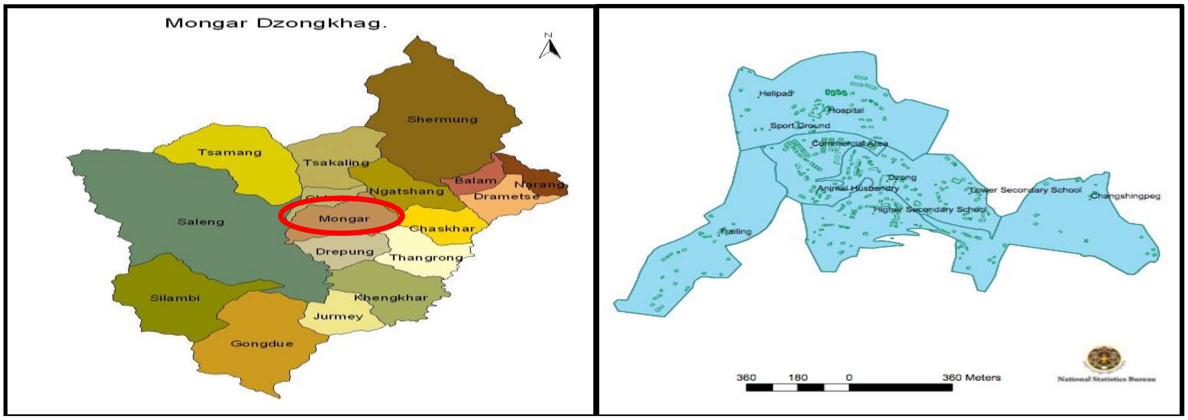
Mongar District as shown in Figure 1(a), is located in the eastern Bhutan at 27°25' N latitude and 91° 2'E longitude [4]. Mongar district's population is 35,534 calculated in year 2016 [5]. The total area covered by this district is 1,940.26 sq.km, with altitudes ranging from 400m to 4000m above mean sea level [4]. Therefore, the lower and southern parts are sub-tropical while northern and higher regions have temperate climatic conditions. Summer can be hot and humid and winter cold. Mongar town is located in Mongar District with the sub-tropical and temperate climatic zones.

The average temperature in 2017 ranged from 15°C to 30°C with a maximum of 26°C and a minimum of 8.2°C recorded for Mongar district [6]. A total of 1000 mm of rainfall is common with most of the rain falling from June to September. At some locations in humid, subtropical south, a rainfall of 7,800 mm per year has been registered, ensuring the thick tropical forest.

Mongar town is divided into six zones for the purpose of administration and management of the municipal area as shown in Figure 1(b). These six zones are:

1. Town area (commercial)

2. Trailing area
3. Hospital area
4. Naling area
5. Kadam area
6. Changshingpeg area



(a) (b)

Figure 1 (a) Map of Mongar District showing Mongar Town and (b) Map of Mongar town showing six different administrative zones

2.3 Solid Waste Management

A. Waste collection and transportation

The waste collection system in Mongar town consists of 2 refuse collector trucks, which moves around the municipality area collecting waste from different areas. The efficiency and effectiveness of the collection of waste is therefore, to a large extent dependent on the reliability of these two waste collector trucks.

At present, the municipality employs two types of waste collection methods:

I. **Door to door collection**: Households dump their waste in the municipal truck, which moves from door to door of the residents.

II. **Community waste collection**: Community waste bins are located in certain parts of the town, where local residents can dispose their waste. The municipality later empties these community bins.

Most of the waste collected is currently in the mixed form as very minimal segregation takes place at the source of waste generation. The waste collected is then transported to a landfill site located in Gyelposhing, 30 km away from Mongar town. A new landfill is currently constructed. At the Gyelposhing landfill, a private firm “M/S We Care” waste management employs 2 workers to segregate the recyclable wastes, from the mixed waste disposed by the Mongar Municipality.

B. Waste generators and practices

- *Residential sector*

Some of the households compost their organic wastes, which is used in their garden. Among the six zones under the town area, household that carry out such activity mainly resides in the residential area of Trailing and Changshingpeg. Due to the lack of awareness among the public, few commercial establishments and residents carry out waste segregation at source in Mongar town. The valuable recyclables are either sold to informal waste collectors or to "M/S We-Care", who then transport to the neighboring Indian town of Jaigoan in West Bengal, where the recyclables are sold.

- *Commercial sector*

In Mongar town, there are a total of 271 commercial establishments that includes mainly hotels, restaurants and shops which are the major waste producers. The waste consists mainly of organic waste.

Currently, in Mongar town, the organic waste from some of these commercial establishments is given for free to farmers who have animal farms. The rest of the organic waste is disposed in landfill. At least one fourth of the commercial establishments in Mongar town separate the recyclables from other wastes, which are sold to the informal waste sector and "M/S We-Care". Rest of the commercial establishments does not undertake any segregation and therefore both recyclables and non-recyclables are dumped in the municipality waste collector trucks, which finally disposes in the landfill at Gyelposhing.

- *Hospital*

The biggest hospital in eastern Bhutan with a capacity of 150 beds is located in Mongar town. Although there is no incinerator for the treatment and disposal of medical wastes from the hospital, it is autoclaved before being disposed together with waste from Mongar town. Therefore, the medical waste is also currently being disposed in the same landfill at Gyelposhing. The hospital also generates other waste which includes food waste, dry waste, and recyclable waste.

- *Industrial sector*

Dzongkhag Administration in Mongar have allocated a separate area for industries in lower Trailing that include small scale industries such as furniture production, timber saw mills, motor vehicle workshop, recycling unit, incense production unit and steel fabrication. The waste generated from the industrial area is not treated and the effluent waste from the motor vehicle workshops is released into the environment without treating it. The furniture production unit and timber saw mill waste consists of sawdust and other wood waste, which is used as firewood by people.

- *Schools*

The Mongar lower secondary school under Mongar Municipality carries out segregation of recyclables while the Mongar higher secondary school undertakes composting and segregation of recyclables. Both schools have nature clubs that lead and carry out these activities. The members join together and collect the recyclables from the school premises as well as the students bring the recyclables to schools from their home. The recyclables are sold to "M/S We-Care". In the higher school, the organic waste generated in the kitchen is composted and the compost is used in the school agriculture garden.

The current practices of waste management are summarized in Figure 2. There are five pathways adopted for each waste stream as shown in the Figure. It can be seen that majority of waste generated end up in the landfill.

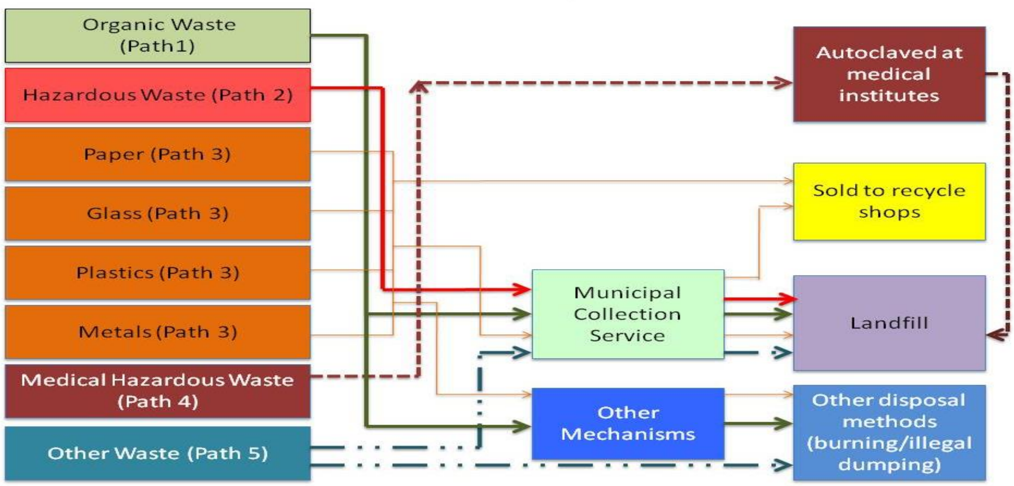


Figure 2 Summary of existing waste management practices

2.4 Municipal Solid Waste Generation and Composition

Mongar town generates a total of 0.95 tonnes of solid waste per day with a waste generation rate of 0.23 kg/person/day. The results of waste composition undertaken in May, 2015 for Mongar town is shown in Figure 3. It can be seen from the results that organic waste contributes around 50 % of the total waste. The medical waste generated in Mongar town accounted for 17.66 % as it is the only referral hospital for six districts. The recyclable components including paper, plastic, metals and glass is 24.8 %. The remaining waste, categorized, as 'others' comprises of rubber, wood and textiles is 7.54 %.

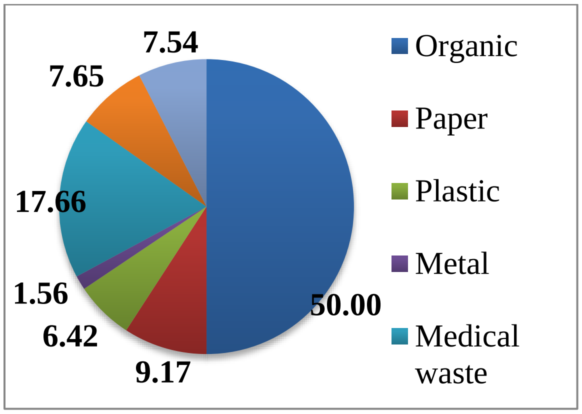


Figure 3 Waste composition at Mongar town

2.5 Challenges

Major waste management challenges are presented in Figure 4. Due to low level of awareness among the public, waste segregation is a big challenge. As such, most of the municipal waste is currently not separated at source. Further, absence of different bins for residents to store the recyclable waste and organic waste also hinders waste segregation. Although Mongar municipality has different colour coded waste bins for sale to the public, people are reluctant to purchase and use these bins due to the high cost (about Nu.2500 or 40 USD). This limited segregation could also be because when the municipal trucks collect the waste, both the recyclable wastes and organic waste are dumped together in the truck, which may have discouraged people from segregating the waste.

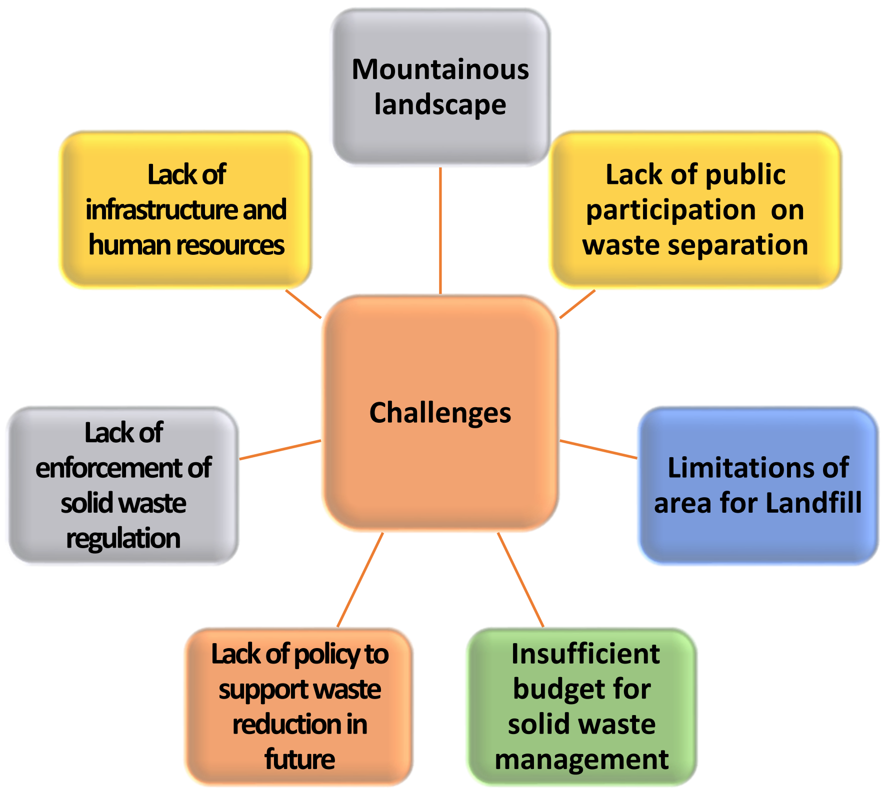


Figure 4 Challenges in existing waste management system

Inadequate financial resources, technical skills and lack of appropriate equipment also presents a major challenge in implementing solid waste management. The amount of revenue collected from the services provided by the municipality is less than the amount it invests in collection, transportation and disposal of solid wastes. Therefore, the current form of waste management is unsustainable in the long run.

A major impediment to achieving successful collection of waste is the lack of roads in some areas, while in other areas; poor condition of the roads makes it inaccessible during rainy season. Inadequate numbers of refuse collection vehicles and lack of adequate manpower also hampers collection efficiency. As a result, only about 80-85% of the waste generated within the municipality is collected daily.

2.6 Opportunities

The options for sustainable solid waste management are presented in Figure 5. These option includes:

1. *Reduce:* Educational campaigns, seminars, and academic involvement can be used for raising awareness and knowledge in SWM for the residents of Mongar District. The campaign can be implemented in various schools, institutions and the nearby community. Solid waste awareness campaign may include performing dances, short plays, VDO clips, posters or any other entertainment activities to attract a large number of people.
2. *Up cycle:* The waste stream in Mongar town contains approximately 50% organic waste. Thus, the conversion of organic waste to fertilizers through composting appears to be feasible. Organic waste in this context refers solely to the food and vegetable waste and do not constitute any agricultural wastes. Although, the composting technology is simple to be adopted by local people but it is done by few residents only at present.
3. *Material recovery:* There is a private firm "M/S We Care" operating since 2009, which collects recyclable from Mongar town, thus the dry waste can be separated and sold to the firm with some economic incentives to residents. At present, the company employs a small team of unskilled people, who manually segregate the waste into plastics, metals, papers, bottles and other recyclables from the Gyelposhing landfill.

As compared to Figure 2, it can be clearly seen from Figure 5 that majority of the waste can be intercepted after source separation and utilize instead of ending up into the landfill. It clearly indicated that for sustainable solid waste management, source segregation is key to success.

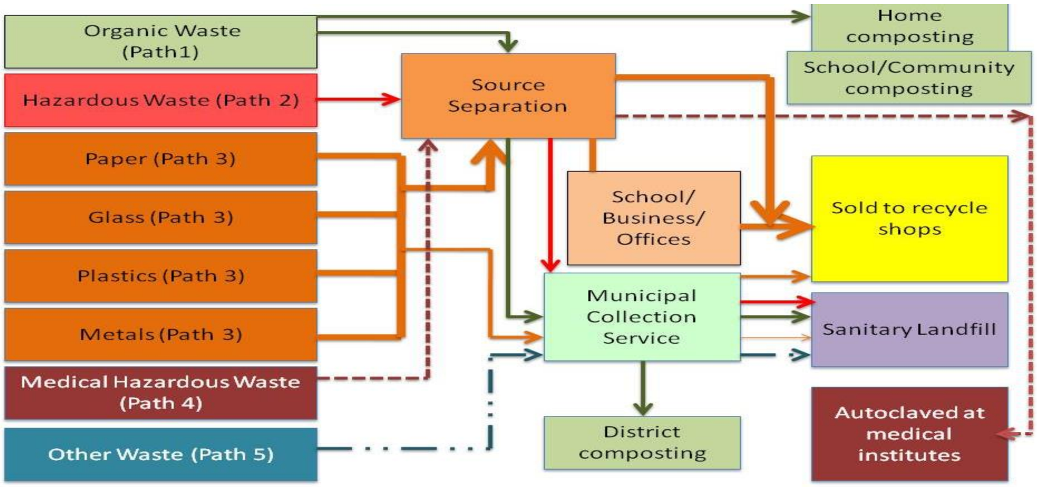


Figure 5 Sustainable solid waste management

CHAPTER 3 CRITERIA AND TECHNOLOGY SELECTION FOR MONGAR, BHUTAN

3.1. Selected Solid Waste Management Criteria

A sustainable technology is compatible with or readily adaptable to natural, economic, technical, and social environment that offers a possibility for further development. The sustainable technology can either be high-tech or low-tech as long as it is appropriate for the particular circumstances.

In Mongar district, almost 50% of waste is organic (Figure 3). Therefore it is possible to segregate the waste into biodegradable (wet) and recyclable (dry) waste at household in core town area. At present, only some households do the separation at source. The total amount of organic waste collected per week from commercial area can be as high as 400 – 450 kg.

The dry waste consists of 90% recyclables and 10 % non-recyclables. For separated recyclables from the households, school, and business, the “M/S We Care” collects directly from generators. Parts of the recyclables are collected from the landfill site. Land and the facility is leased by municipality to the company for the operation of the facility showing the existing public private partnership. This provides employment opportunity to the youth, increase the life span of the landfill as recyclables are diverted. Markets for the recyclables are good enough to cover the operation cost.

Based on the above mentioned waste characteristics and local infrastructure and facilities available, the technology that is applicable for case of Mongar includes composting, anaerobic digestion, material recovery and sanitary landfill. Regarding the criteria, 10 criteria were selected from the list in Chapter 1. The selected technology and criteria are shown in Table 3 for commingled waste and Table 4 for the segregated waste.

Table 3 Assessment of material recovery approach and technologies for commingle waste

Criteria	**Composting (windrow aerobic)**	**Anaerobic Digestion (AD)**	**Sanitary Landfill**	**Materials recovery for reuse and recycle**	**Landfill (Existing practice)**
(1) Solid waste characteristics					
- Separated solid waste at source	-	-	-	-	
- Commingled waste	1	1	5	1	1
(2) Waste quantity:	3	1	4	3	1
(3) Time consuming for entire process	2	2	5	3	5
(4) Ease of use	5	3	3	3	5
(5)Amount of valuable final products	4	4	1	3	1
(6) Initial investment	4	3	3	3	4
(7) Operating cost	4	4	2	4	5
(8) Land requirement:	4	3	1	3	1
(9) Possible adverse impacts					
- Odor	2	2	2	2	1
- Wastewater	2	2	1	4	1
- Dust and air pollution	2	4	1	4	1
(10) Public acceptability	4	4	1	2	1
Total score for each waste utilization technique	**37**	**33**	**29**	**35**	**26**

Note: Influence of impact of each criterion: 5 = most favorable, 4 = favorable, 3 = Neutral, 2= less favorable 1 = not favorable

Table 4 Assessment of material recovery approach and technologies for segregated waste

Criteria	**Composting (Windrow compost)**	**Anaerobic Digestion (AD)**	**Sanitary landfill**	**Material recovery for reuse and recycle**	**Landfill (Existing practice)**
(1) Solid waste characteristics					
- Separated solid waste at source	5	5	4	5	1
- Commingled waste	-	-	-	-	
(2) Waste quantity:	5	5	4	4	1
(3) Time consuming for entire process	2	3	5	5	5
(4) Ease of use	5	3	3	5	5
(5)Amount of valuable final products	5	5	1	5	1
(6) Initial investment	4	2	3	3	4
(7) Operating cost	3	3	2	3	5
(8) Land requirement:	4	3	1	3	1
(9) Possible adverse impacts					
- Odor	2	2	2	2	1
- Wastewater	2	2	1	4	1
- Dust and air pollution	2	4	1	4	1
(10) Public acceptability	4	4	1	2	1
Total score for each waste utilization technique	**43**	**41**	**28**	**45**	**26**

Note: Influence of impact of each criterion: 5 = most favorable, 4 = favorable, 3 = Neutral, 2= less favorable 1 = not favorable

3.2 Waste management priority in local context

If the waste is not segregated it is difficult to justify appropriate technological solution for solid waste management in Mongar as shown in Table 3. Composting and recycles still seems to be preferred options based of the composition of the waste and the existing private sector, "M/S We-Care". At present, there is no sanitary landfill in Mongar. However, if the sanitary landfill will be constructed in the future, it is still the least preferred option for the commingle waste. This is due to the mountainous terrain and the pristine forest ecosystem that makes it difficult to obtain the available land for sanitary landfill construction and also would lead to higher transportation cost.

When the waste is segregated, the appropriate technology can be clearly distinguished (Table 4). Composting and Anaerobic Digestion score higher due to the nature of the waste generation and also because of segregation. Since the waste is separated, good quality of recyclable materials can be collected and sold at better price. Sanitary landfill is still the last preferred choice for the same reasons as mentioned above. The biogas for such small amount of the waste generated is not economical and viable for both the cases. However, sanitary landfill is still required for the residual waste.

The government policies also are trying to force the residence, government offices, schools, hospitals, and business enterprises to segregate the waste as they have the motto to have clean Bhutan and to preserve the natural resources.

Based on the assessment score, possible technological solution, priority-wise are presented in Figure 6. It is clearly visible that the segregation of the waste in dry and wet categories is must for sustainable solid waste management, as the waste can be intercepted for recovery of materials and composting and the minimal amount goes to the sanitary landfill.

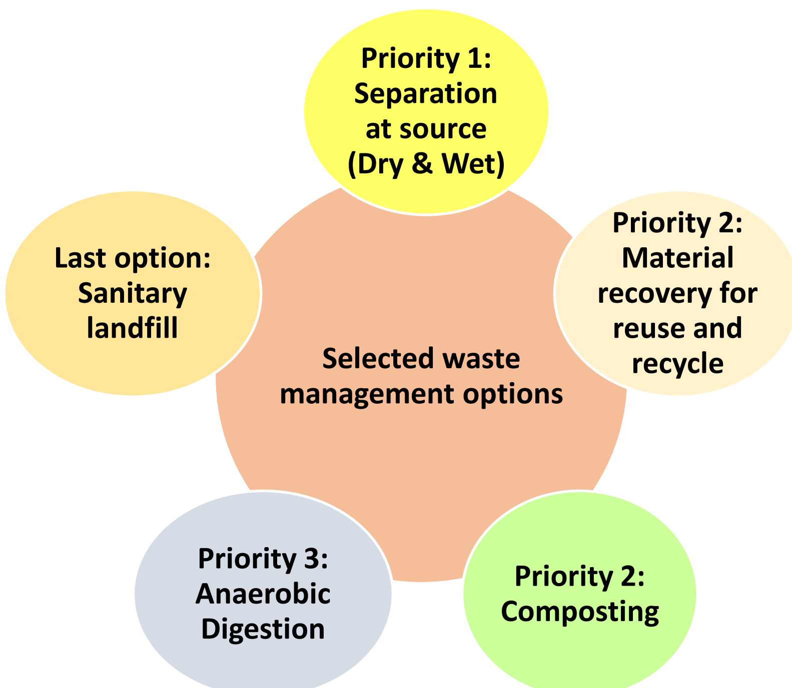


Figure 6 Selected waste management options

CHAPTER 4: CONCLUSIONS AND RECOMMENDATIONS

In order to make an appropriate decision, it is important to adopt the following steps shown in Figure 7.

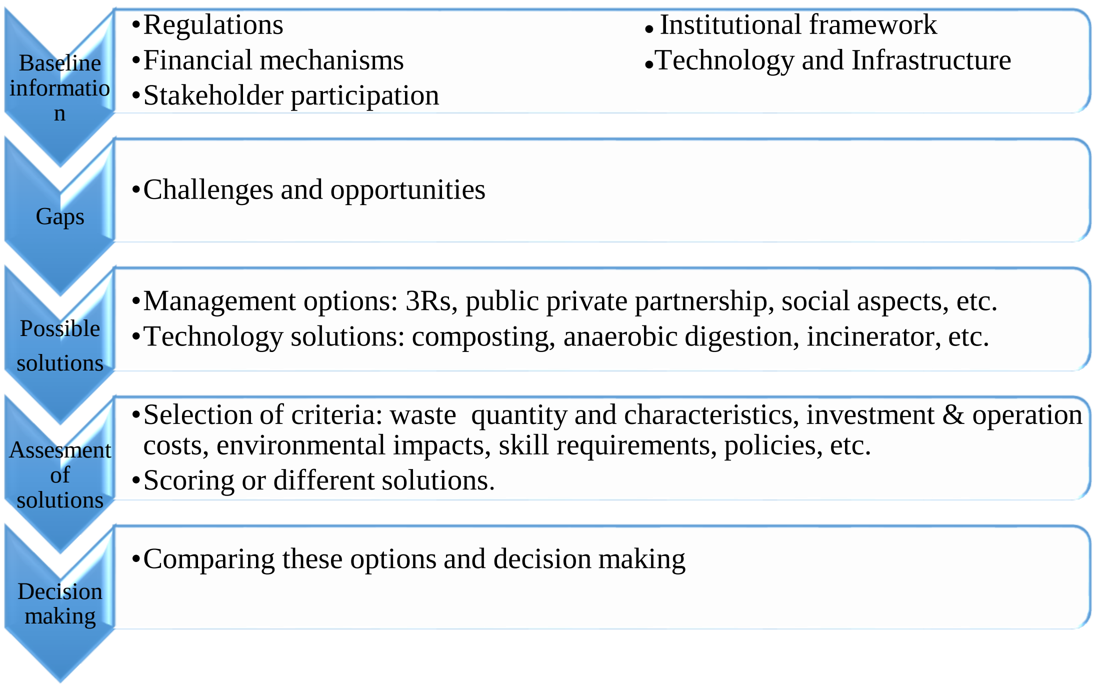


Figure 7 Steps for decision making process

The selection of the criteria should be based on the local conditions, and other cities may need to modify accordingly based on the local policy, regulations, waste generation and characteristics, infrastructure, and technological skills of human resources. In developing countries, it is important that the technologies should be simple and can be easily adopted by local people.

Additional interventions are required for successful solid waste management as presented in Figure 8.

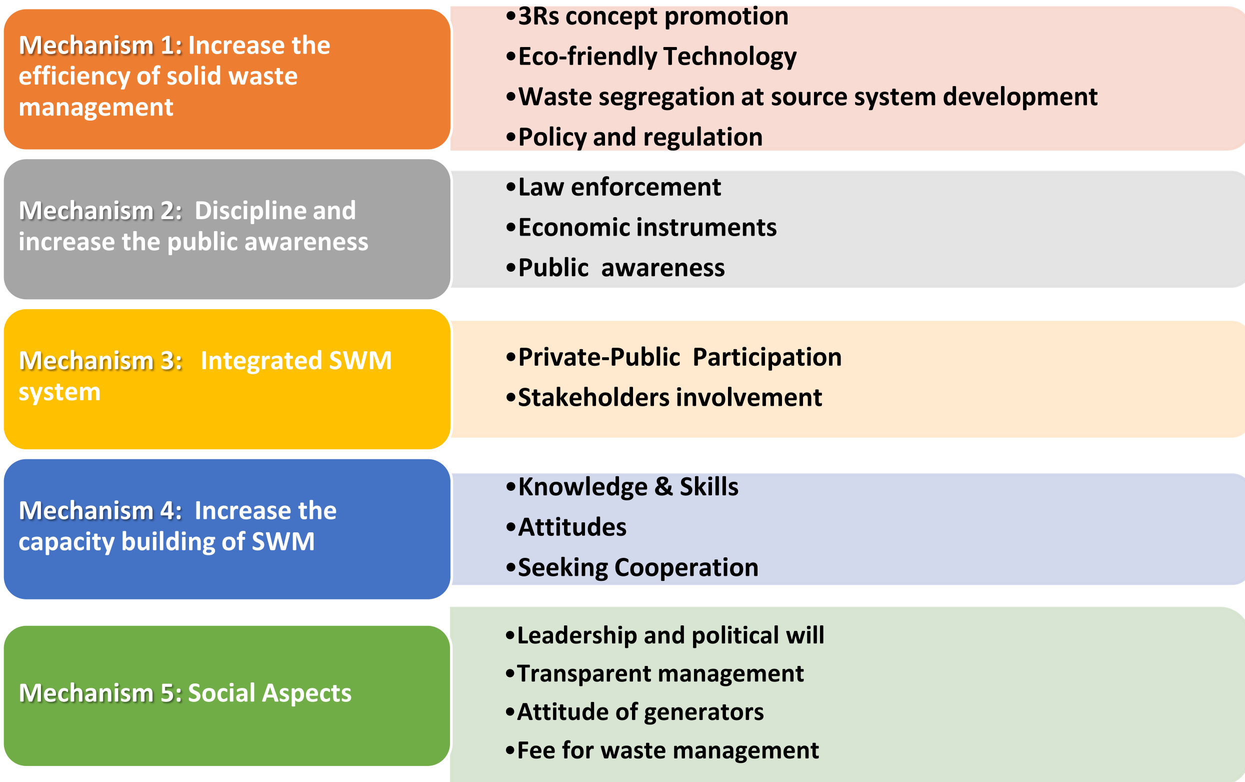


Figure 8 Suggested mechanisms for sustainable solid waste management

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