Guidelines for Technology Selection for Sustainable Solid Waste Management in Ho Chi Minh City, Vietnam

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Preface

Improper solid waste management causes environmental impacts (water, air, and soil), affects human well-being, and also waste of natural resource. The amount of solid waste is growing rapidly in many of the developing countries with rapid urbanization.

Vietnam is one of the Southeast Asia's fastest growing economies. Vietnam's economic growth rate has been among the highest in the world. As of 2017, Vietnam had 95 million people and it is the World's 14^{th} most populous country. Ho Chi Minh City (HCMC) is a mega city and a large center of economic, cultural, education and training, science and technology of Vietnam. The total area of HCMC is 2,095 km^2, including 24 districts in which 19 are urban districts and 5 suburban districts with more than 9 million of people. From 1992 to 2016, the total amount of generated solid waste in HCMC has been significantly increasing from 424,860 tonnes to 3,028,040 tonnes/year (or 1,164 tonnes to 8,300 tonnes/day). At present, the solid waste management system in HCM City is not very effective as the major problems are that the separation of solid waste at source has not been implemented in the whole city, lack of professional ability of staff, and infrastructure for recycle, collection, transportation, and treatment of solid waste. With the vast population and amount of waste generation, it becomes very important to have appropriate waste management system suitable for local conditions.

The objective of the guideline "Guidelines for Technology Selection for Sustainable Solid Waste Management "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 guideline 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, a drastic reduction in the waste going to the landfill, and minimize environmental pollution. An example criteria and technologies selected based on the local conditions of HCMC, Vietnam 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 biodegradable 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 this guideline is to provide decision making tools for local authorities to adopt sustainable solid waste management in their local context. An example to follow the approach on selection of criteria and technology are provided for HCMC.

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 needed. Baseline data may include, but not limited to, waste generation and composition, available technology and skills, financial resources, stakeholder involvement, institutional framework, 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 of the waste will minimize amount of waste to be disposed into the landfill, which should be the least preferred option in 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 twelve fundamental management criteria for eight operation and utilization techniques. The twelve 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 twelve SWM criteria in terms of eight operation and utilization techniques to manage solid waste are presented in Table 1. The Table 1 demonstrates an overview of waste utilization methods used in cities worldwide and presents how each criterion relates to the operation and utilization technique in general. However, to specifically selecting the criteria for particular location, scoring system may be applied. Table 2 demonstrates how the twelve criteria and eight 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.

Table 1 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)

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.

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)
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 paired with different criteria that can be used as benchmark for a suitable SWM technique that will increase the effectiveness of SWM process and make it more sustainable.

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

As presented in Table 2, each criterion is assigned a value according to its score. This helps 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. Table 2 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 FOR SUSTANABLE SOLID WASTE MANAGEMNET IN HO CHI MINH CITY, VIETNAM

2.1 General Information of the Country

Vietnam is one of the Southeast Asia's fastest growing economies and the economic growth rate has been among the highest in the world. The population of Vietnam was 95.1 million as of 2017, and that made the country to be the World's 14th most populous country and the 8th most populous Asian country (Institute of Statistical Science, 2017).

The rapid growth of economic and population has led to increase amount of waste generation. Within a mere 8 years (2007 – 2015), amount of generated municipal solid waste increased from about 17.7 million tonnes to about 38.0 million tonnes per day (MONRE, 2016). The problems related to solid waste have pushed solid waste solid management to the forefront of environmental challenges.

2.2 General Information of Ho Chi Minh City)HCMC(

Ho Chi Minh City (HCMC) is a center of economic, cultural, education, training, science and technology. The city is also an international exchange hub, industrial center and multi-disciplinary services of the region and South East Asia. The total area of HCMC is 2,095 km, including 24 districts in which 19 are urban districts (District 1 to 12, Phu Nhuan, Binh Thanh, Thu Duc, Tan Binh, Tan Phu, Binh Tan, and Go Vap District), and 5 are rural districts (Hoc Mon, Binh Chanh, Nha Be, Cu Chi, and Can Gio District).

Population of HCMC increased from 2010 to 2016 by 12 % (Statistical office in Ho Chi Minh, 2017). The total gross domestic products (GDP) per capita of 2016 was 5,700 USD, increasing 73% when compared with 2010 (www. hochiminhcity.gov.vn).

Beside the accelerated economic growth, rapid urbanization, increasing population, and lack of infrastructure, the pollution especially due to municipal solid waste has become a major concern for HCMC.

2.3 Municipal Solid Waste Generation and Composition

Generation sources

Sources of solid waste generation in HCMC includes seven sources: (1) Household; (2) Hotel, motel, and restaurant; (3) Industries (factories and enterprises); (4) Healthcare (hospitals, dispensaries, private clinics); (5) Offices; (6) Public places; and (7) Market & service.

Proportion from different sources is as follows; household 58 %, markets & service 25%, public places 14.2%, and office 2.8%.

The total amount of generated domestic solid waste in HCMC has been significantly increasing from 1992 to 2016 (Figure 1). The amount of solid waste increased by 38% in 2016 as compared to 2006. In 2016, amount of collected solid waste was 8300 tonnes/day, which accounted for 21% of urban solid waste generated in the country.

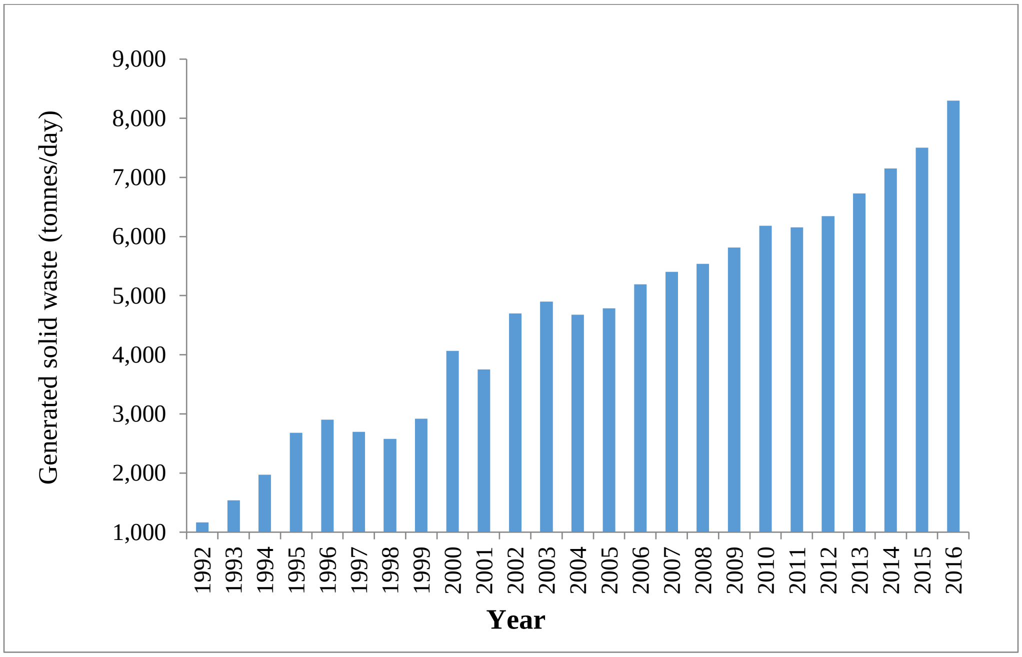

Figure 1 Amount of generated solid waste in HCMC from 1992 to 2016

(Source: DONRE, 2016)

Composition of solid waste: Composition of solid waste varies with the source of generation as follows:

i. *Households:*

The composition of solid waste generated from households consists of high biodegradable organic fraction (64.8 – 74.3%), and high moisture content (55-65 %). The bulk density of waste is in the range of 375 – 400 kg/m^3.

ii. *Schools*

Paper and plastics are the main components of solid waste. Paper content increased from 17.6% in 2009 to 35% in 2015, and plastic waste increased from of 25.9 % to 34.9 % in the same period. The biodegradable organic component was more or less the same with 28.7% in 2009 and 25.5% in 2015. The remaining components of solid waste are non-recyclable waste such as leather, textile, and Styrofoam.

iii. *Markets*

The main fraction of waste was biodegradable organic was 86.8% in 2009 and 87.8% in 2015. However, plastic content increased from 4.3% in 2009 to 7.5 % in 2015.

iv. *Offices*

Main composition of solid waste generated from offices in 2009 was biodegradable organic 43.7%, paper 19.4 %, and plastic 12.6%.

v. *Hotels, restaurants, and shopping centers*

Composition of solid waste generated from hotels and restaurants was biodegradable organic (66.2%), paper (8.8%), and plastic (8.1%), whereas the composition of waste from shopping centers was biodegradable organic (55.1%), plastic (14.7%), and paper (13.6%). Other fractions included nonferrous metal, glass, Styrofoam, clamshell, and soil.

2.4 Solid Waste Management System

A. Storage at sources

Separation of waste from household is not practiced at sources. Households have their own plastic or metal trash bins, or bamboo baskets. However, most of the residents use plastic bags to store waste before putting them in trash bins. Residents take the bins or plastic bags out so that collectors can easily collect them.

Markets have limited space and the space is used for storing the goods, therefore majority of small traders have very few locations to place waste bins. Most of the waste generated are disposed at market allies. After markets are closed, entire waste is collected. Trading activities and traffic congestion are complex problems that cause difficulties in storing waste. Improper disposal of the waste creates a mess on the street frequently.

In schools, offices, restaurants, and hotels, waste is stored in small bins before transferring into 240 liters bins. In public areas, on streets, and sidewalks, waste bins are not placed, or not insufficiently provided, or not functioning well.

B. Waste collection

The rate of solid waste collected from households in urban areas is 95%, and the remaining 5% is not collected properly. Rather than being collected by the district, the waste is left along the streets or dumped into common bins or thrown into canals. District's Public Services Companies sweep and collect waste on the streets, common bins, and dumping sites on the daily basis. In rural areas, the rate of waste collected from households is about 70% - 80%, the remaining waste (20-30%) is dumped into gardens or empty land.

Sweeping and collection of waste in public areas such as streets, roads, sidewalks, and manholes is the responsibility of District's Public Services Companies. The waste collection has carried out by two systems including public and private system as follows:

(1) The public system includes Urban Environmental One-Member Limited Company (CITENCO) and 22 of District's Public Services Companies. Tasks are to sweep all streets and roads, collect solid waste generated from markets, offices, shopping centers, public areas, and 30% generated from households located along main streets in the city and these are then transported to transfer stations, treatment complex, or sanitary landfills.

(2) The private system includes individual collectors, collecting unions, and cooperatives. The private system has responsibility for collecting 70% of solid waste generated from households (alleyway) and domestic solid waste generated from enterprises by contracting with the People's Committee of Wards.

There are more than 200 small loading capacity trucks (550 kg), about 1,000 of homemade vehicles (3 or 4 wheels), and more than 2,500 of 660 liters pushcarts are used for collection activity. Approximately 4,000 private collectors and 1,500 of collectors in the District's Public Services Companies and cooperatives are employed.

C. Waste transfer and transportation

In terms of waste collection and transporting of domestic solid waste from rendezvous points to transfer stations, and then waste transportation to landfill or the composting processing plants, there are 3 companies that are responsible for implementation: CITENCO (53%), Districts' Public Service Companies (30%), and Cong Nong Cooperative (17%). The average distances of transportation from the districts of HCMC to Da Phuoc sanitary landfill are 30-50 km, and to Vietstar composting Plant is 50.17 km.

In waste transferring and transporting system, there are 891 meeting points and 33 transfer stations locating in 22 districts in HCMC (DONRE, 2015). Locations of meeting points are often changed due to bad sanitation conditions. In the future, urban meeting points tend to gradually reduce and will be replaced by transfer stations with proper technologies. Transfer station is the place that has gathered solid waste from small loading capacity vehicles and then loads them to larger vehicles (capacity of 10-15 tonnes) or hook lift before transporting to waste treatment complex or composting plant.

The collection and transportation system has more than 570 vehicles with capacity ranging from 0.5-14 tonnes, in which have 53 hook lifts, 421 compact garbage trucks.

D. Recycle, treatment and disposal

Since 2008, waste disposal has been socialized by business capital of local companies and foreign. According to DONRE (2016), currently used waste treatment technologies are sanitary landfills (68.6%), composting (24.6%), recycling (1.1%), and incinerator (5.7%).

Recyclable waste is collected by a collection network around the city. However, most of junk shops and recycling enterprises are small scale located in residential areas. As the applied recycling technology is backward and due to inconsistent amount of recyclable waste, quality of the recycled products is not high.

Approximately 90% of recyclable waste collected is paper, plastic, and metal. Recycling activities has been developed and has brought economic benefits to the residents. Most of the workers working in recycling enterprises have low educational level. Hence, it is challenging to apply new technologies for recycling industry.

HCMC has about 740 private recycling enterprises with 67 recycle plastic, 15 of glass, 9 of metal, 7 of paper, and 2 of rubber recycling enterprises. Accordingly, there are a large number of workers working in recycling businesses.

Flow of solid waste from generators to treatment and disposal site in HCMC is presented in Figure 2.

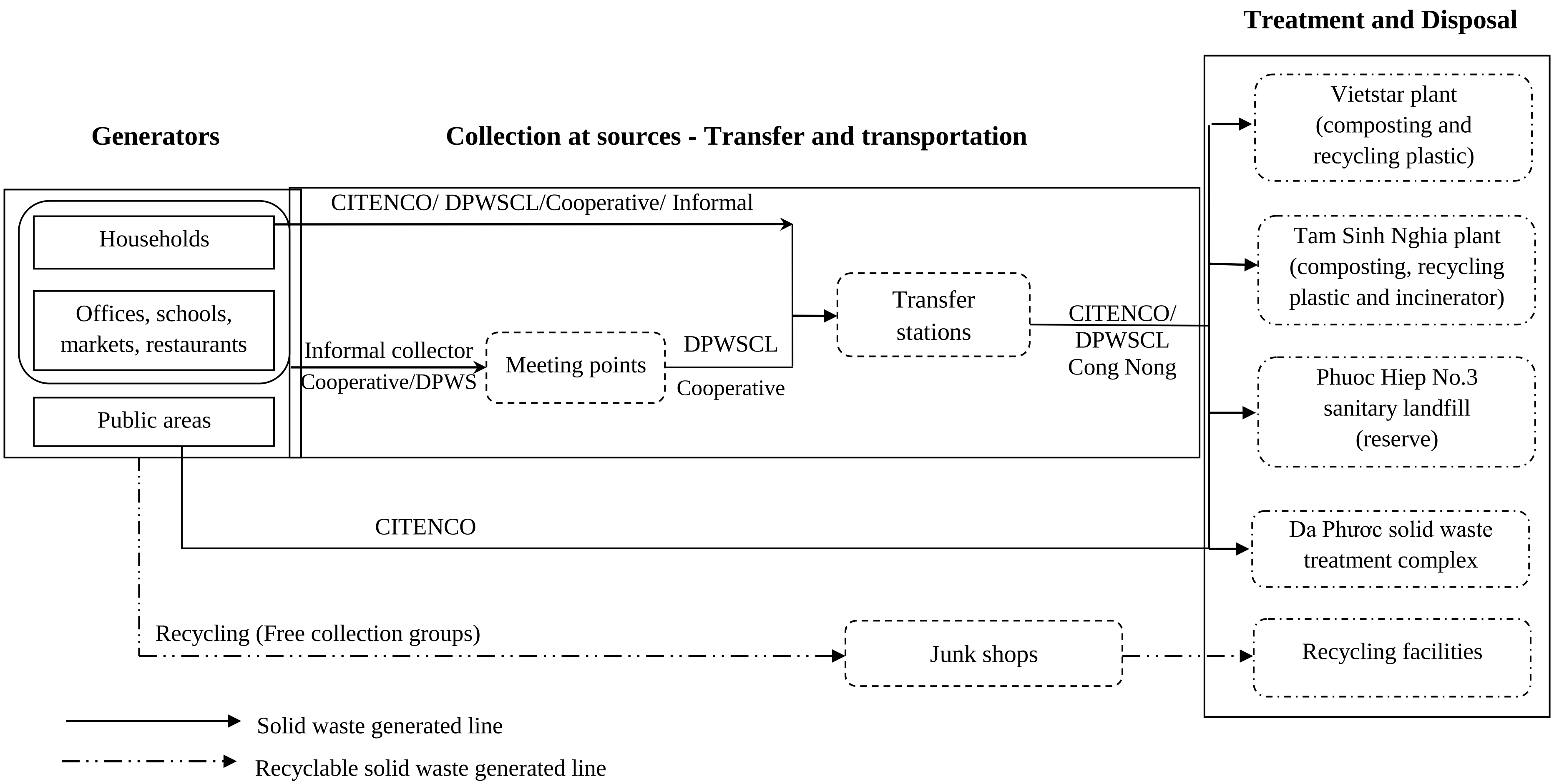

Figure 2 Flow of solid waste from generators to treatment and disposal site in HCMC

2.5 Challenges

Major waste management challenges are presented in Figure 3. 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. When the informal sector collects the waste, both the recyclable wastes and organic waste are dumped together in the containers, which may have discouraged people from segregating the waste.

Financial constraints, lack of human resources and limited availability of technology 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 paid in collection, transportation and disposal of solid wastes. Therefore, the current form of waste management is unsustainable in the long run.

Figure 3 Challenges in existing solid waste management in HCMC

2.6 Opportunities

The investigation results on situation of solid waste management in HCMC from 2009 to 2016 show that many opportunities for sustainable solid waste management in HCMC exist as listed below.

- The potential agricultural demand for organic fertilizers and soil conditioners in the surroundings of HCMC is very high and exceeds the actual production capacity. With high biodegradable organic fraction (64.8-74.3%), composting technology and anaerobic digestion technology with collection of biogas is the most sustainable technology for utilization of solid waste. Non-recyclable waste with high calorific values is suitable for incineration or RDF technologies with energy recovery system.
- The network for recycling activities in HCMC is very large including 740 private recycling facilities to recycle about 15-20 % of MSW collected. Recyclable components including paper, plastics, and metals can be recycled to create new products. It is an important sector in the solid waste management system of HCMC.
- In order to obtain pure biodegradable organic and remain fractions, solid waste separation at source or SWSAS plays an important role in the integrated SWM in HCMC. Separating MSW at source can be applied at various levels through media campaign and educational programs. In Vietnam, there are many social organizations such as Women's Union, Young Communist League, Veterans' Union, HCM young pioneer organization; these social organizations can play the leading role in the implementation of the SWSAS program.
- Vietnam has a policy to increase the use of green energy. The unit price for electricity produced from biogas is 7USD/kW and from incineration is 12 USD/kW. This policy can encourage the use of waste treatment technologies such as anaerobic digestion technology with biogas collection and incineration technology with energy collection.
- HCMC has established policies to support the SWSAS program and encouraging the investment on technologies for recycling solid waste with energy recovery.

For example, the options for sustainable solid waste management in HCMC are presented in Figure 4.

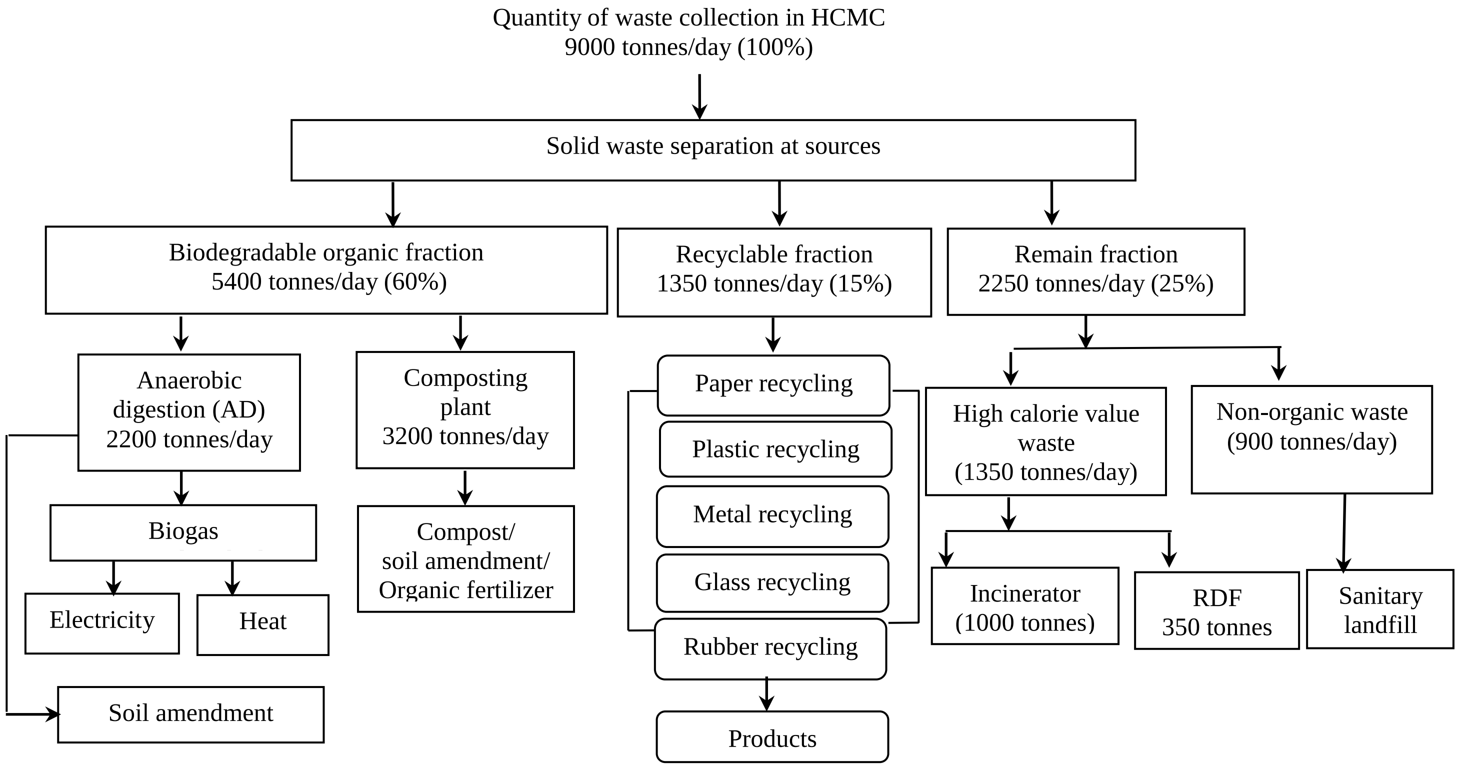

Figure 4 Options for sustainable solid waste management in HCMC.

CHAPTER 3: CRITERIA AND TECHNOLOGY SELECTION FOR HO CHI MINH CITY, VIETNAM

3.1 .Selected Solid Waste Management Criteria

The goal of assessing the sustainability of solid waste treatment technology is to choose technologies that can be applied based on HCMC's condition. This can be based on the criteria system which will help responsible solid waste management authorities to decide which technology should be adopted.

Selection of criteria will depend on many factors such as natural, economic, technical, and social environment. In Vietnam, the selection of technology also considers the National strategy on integrated management of solid waste.

As mentioned in Table 1, out of the eight technologies for solid waste operation and utilization techniques and 12 criteria for selection of sustainable techniques for SWM, for HCMC five of the eight solid waste treatment technologies are selected. These technologies are (1) composting; (2) anaerobic digestion; (3) sanitary landfill (with landfill gas collection) or bioreactor landfill; (4) incinerator; (5) refuse derived fuel (RDF) or solid recovered fuel (SRF). The selection of these technologies is based on their wide application in many countries as well as in HCMC (composting, sanitary landfill, and incinerator). Three remaining technologies are not compatible with economic, technical, and human resource condition of HCMC. Pyrolysis and gasification are advanced technologies, difficult to operate, and costly, while the MBT technology does not give a final disposal solution for treated waste.

Five technologies were compared based on 11 criteria as mentioned in Table 1, in which the multisector involvement criterion was rejected because it was considered the least important one in the HCMC's condition. The calculation was performed using scoring system of 1 to 5 scores (5 = most favorable, 4 = favorable, 3 = Neutral, 2= less favorable 1 = not favorable).

The assignment of score to each criterion is based on consultation with expert, performance, on-site survey, and results of environmental monitoring. The sum of scores for each technology can be used as a "Sustainability Index" (SI) of technology. If the technology has the high score, the sustainability is the high and vice versa.

Based on current situation of solid waste management in HCMC, two scenarios are given. Results of assessment of sustainability of solid waste treatment technologies are presented in Table 3 for commingled waste and Table 4 for segregated waste.

Table 3 Assessment of sustainability of treatment technologies for commingled waste (Scenario 1)

Criteria	**Composting (windrow)**	**Anaerobic digestion (AD)**	**Sanitary landfill with collection of biogas**	**Incinerator with energy collection**	**RDF or SRF**
(1) Solid waste characteristics					
- Separated solid waste at source	-	-	-	-	-
- Commingled waste	2	2	5	3	3
(2) Waste quantity:					
Large amount (large community to city levels)	3	1	3	3	1
(3) Compliance with standard/regulation of National technology of Vietnam	5	5	5	5	5
(4) Time consuming for entire process	2	3	5	5	3
(5) Complexity and required skills	5	3	4	2	3
(6) Demand for final products	2	2	2	2	2
(7) Initial investment	4	2	3	1	2
(8) Operating cost	2	2	5	1	2
9) Land requirement: - Large scale	2	3	1	4	3
(10) Possible adverse impacts					
- Odor	2	2	1	2	2
- Wastewater	2	2	1	4	3
- Dust and air pollution	2	3	1	2	3
(11) Public acceptability	2	2	1	2	2
Total scores	**35**	**32**	**37**	**36**	**34**

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

As shown in Table 3, total scores of five (5) technologies assessed are not much different. For commingled waste, the technology's sustainability index shows the sanitary landfill with collection of biogas (37 points) as the most suitable technology, followed by incinerator with energy collection (36 points), composting (35 points), RDF or SRF (34 points), and anaerobic digestion (32 points), respectively.

As mentioned in chapter 2 the composition of commingled solid waste in HCMC also contains certain amount of household hazardous wastes (HHW) and many non-recycling components. In addition, the composition of solid waste in HCMC has high biodegradable organic fraction (64.8-74.3% of wet weight) and high moisture (55-65%) so that sanitary landfill (with collection of biogas) is a sustainable technology for solid waste management in HCMC at present. Amount of non-recycling fraction (about 25% including plastic, diaper, textile, rubber & leather, styrofoam, wood) with high calorific value have increased significantly and the biodegradable organic fraction has decreased from 2009 to 2015. Due to lack of available land, incineration technology was ranked the second with the possibility of energy recovery. However, high moisture content of the solid waste and the highest investment and operation costs may limit the use of this technology.

The composting technology is ranked the third because the waste is commingled and therefore the separation step has to be carried out before the waste is composted and this step is labor intensive. At present, quantity of solid waste at two composting plants takes at 35-64% and the remaining non-compostable (taking 36-65%) are buried at sanitary landfill or burned by incinerator. In addition, quality of compost using commingled waste is low because the end product is mixed with scrap glass and plastics making it difficult to consume. The RDF technology ranked the fourth. The anaerobic digestion technology has the lowest score due to uncertainties regarding investment and operation costs, low energy prices, damaged reputation due to unsuccessful plants as well as this technology need the source sorted organic. These results are consistent with the set targets for management of solid waste in HCMC as according to National strategies on integrated management of solid waste.

Table 4 Assessment of sustainability of treatment technologies for separated solid waste (Scenario 2)

Criteria	Composting (window compost)	Anaerobic digestion (AD)	Bioreactor landfill (Sanitary with recovery biogas)	Incinerator with energy collection	RDF or SRF
(1) Solid waste characteristics					
- Separated solid waste at source	5	5	5	5	5
- Commingled waste	-	-	-	-	-
(2) Waste quantity					
Large amount (large community to city levels)	5	5	5	4	4
(3) Compliance with standard/regulation of National technology of Vietnam	5	5	5	5	4
(4) Time consuming for entire process	2	3	1	5	4
(5) Complexity and required skills	5	3	4	2	3
(6) Demand for final products	4	4	1	4	3
(7) Initial investment	5	3	4	2	3
(8) Operating cost	5	3	4	2	3
(9) Land requirement - Large scale	2	3	1	4	3
(10) Possible adverse impacts					
- Odor	2	2	1	2	2
- Wastewater	2	2	1	4	3
- Dust and air pollution	2	4	1	2	3
(11)Public acceptability	2	3	1	3	3
Total scores	**46**	**45**	**34**	**44**	**43**

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

Table 4 shows that total scores of all technologies in scenario 2 is higher than scenario 1 because solid waste is separated at source to form clean biodegradable organic, recyclable, and remaining fraction. The assessment of treatment technologies for separated solid waste shows that the composting technology (46 points) is the most applicable, followed by anaerobic digestion (45 points), incinerator with energy collection (44 points), RDF or SRF (43 points), and bioreactor landfill or sanitary landfill (34 points), respectively.

The potential demand for organic fertilizers and soil conditioners in the surroundings of HCMC is very high and exceeds the actual supply. With source separated clean biodegradable organic fraction, the composting technology is the most suitable because of its simplicity, low cost, and high demand of composting products. The anaerobic digestion can produce green energy and soil conditioner from biodegradable organic fraction and it is ranked the second after composting technology because of its higher complexity and cost compared to the composting technology. The bioreactor landfill or sanitary landfill with collection of biogas require large amount of land, generate leachate and emit odor and thus it has the lowest score. Components of remaining solid waste after separation (plastic, diaper, textile, rubber, leather, etc) with high calorific value can be incinerated with energy collection and thus obtains higher score compared to RDF technology.

3.2 Waste Management Priority in Local Context

By assessing the sustainability of solid waste treatment technologies from two scenarios, scenario 2 have specific advantages such as low operation, high quality of composting product, more efficient land use, lower environmental impacts and higher production of biogas, energy collection in comparison with the Scenario 1 so that the scenario 2 will be selected for integrated solid waste management in HCMC. These results are in consistent with situation of solid waste and the set targets for management of solid waste in HCMC. In addition, it is clear that one technology would hardly achieve efficiency of solid waste management in HCMC. The need for combination of multiple technologies yields integrated solid waste management system leading to zero waste for sustainable resource utilization in HCMC. Ideally, the composting technology followed anaerobic digestion technologies is found to be the most sustainable for solid waste in the HCMC. Incineration with energy collection is essential only for non-recycling solid waste (with high calorific value) and residual solid waste will always be needed for landfilling.

By separating solid waste at sources (application of scenario 2), the City will be able to:

1) Utilize 70 to 80% of city’s solid waste, among which about 60-70% can be used for producing compost and anaerobic digestion for generating energy. Remaining 10-20% can undergo recycling.
2) Decrease pollution caused by odor and leachate from landfills.
3) Raise people’s awareness on environmental protection.

To achieve zero waste management, the results of the two exampled scenarios show that waste separation at source is an essential factor that prevents waste entering landfills. Implementing waste separation allows the collection of great amount of recyclable waste that can be converted into useful materials. In addition, unmixed waste helps waste collectors save time during collection process substantially, and save cost for HCMC's waste management.

Based on the assessment score, possible technological solution, priority-wise are presented in Figure 5. It is clearly visible that the segregation of the waste 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.

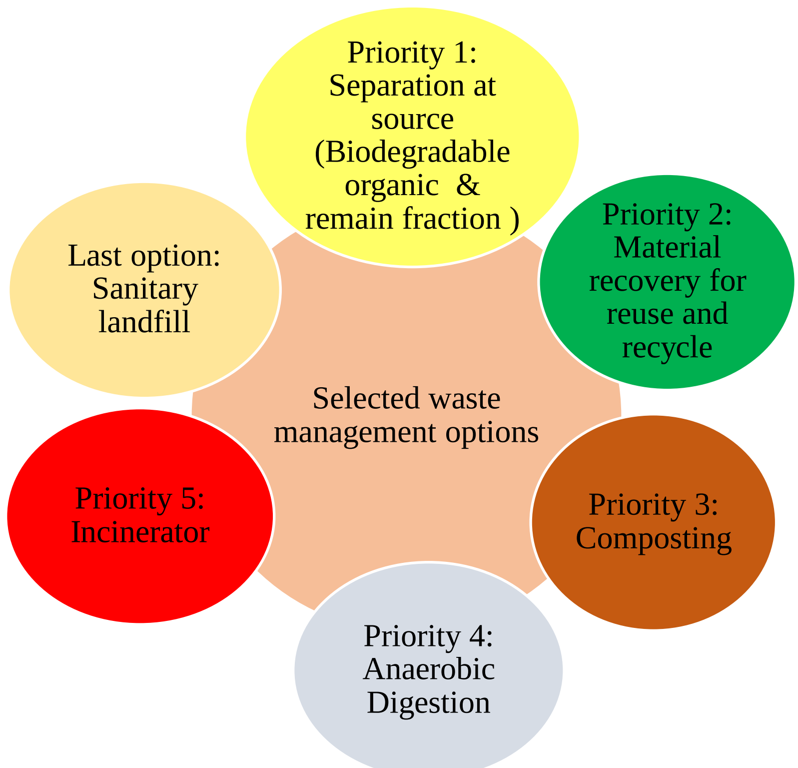

Figure 5 Selected waste management options

CHAPTER 4 :CONCLUSION AND RECOMMENDATIONS

The goal of assessing the sustainability of treatment technology is to choose technologies that can be adopted in local condition. The assessment of sustainability of solid waste treatment technology is based on criteria system which will help responsible solid waste management authorities to decide which technology is appropriate. In order to make proper decision, it is important to adopt the following steps as shown in Figure 6.

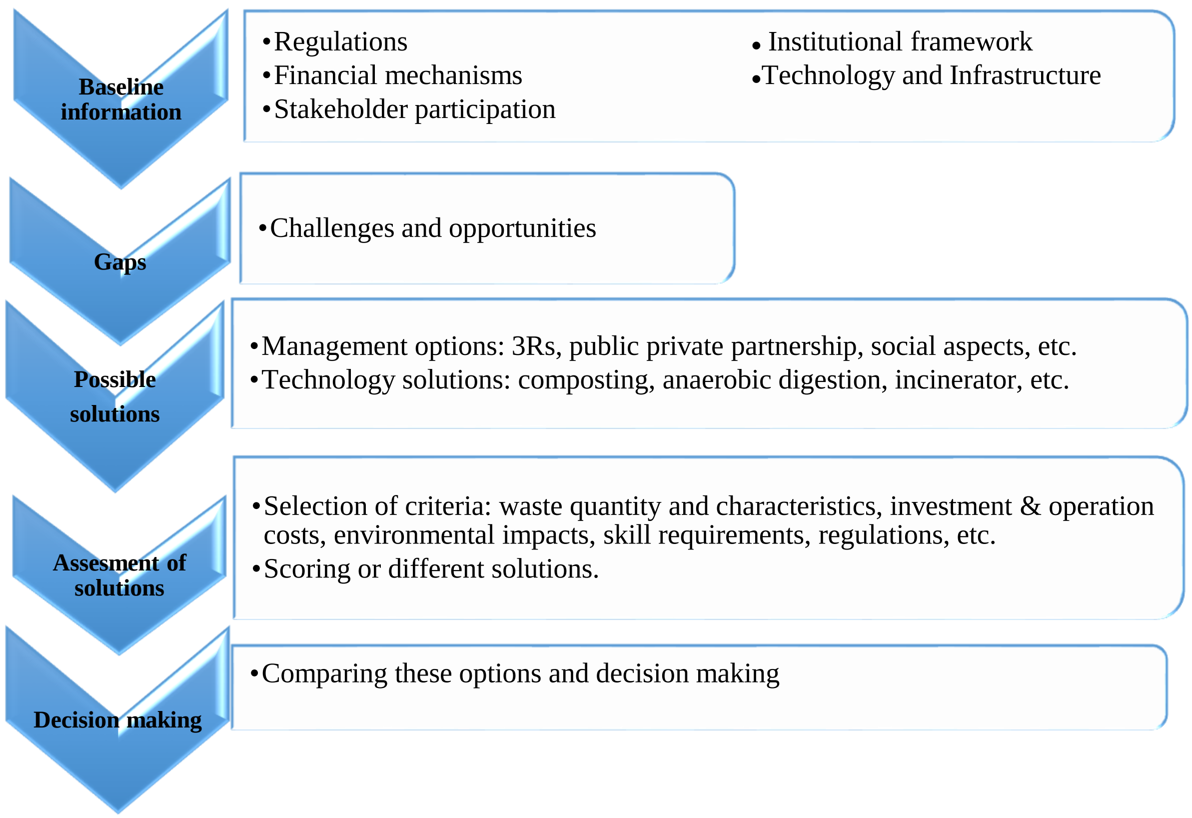

Figure 6 Steps for decision making process

The selection of criteria will depend on many factors such as the natural, economic, technical, environment and social. There are no standard criteria for selection of treatment technology, and the criteria should be modified based on conditions of each locality. In developing countries, a sustainable technology should be low cost (investment and operation costs), technically and legally feasible, ensuring pollution treatment efficiency and community acceptability. Additional interventions are required for successful solid waste management as presented in Figure 7.

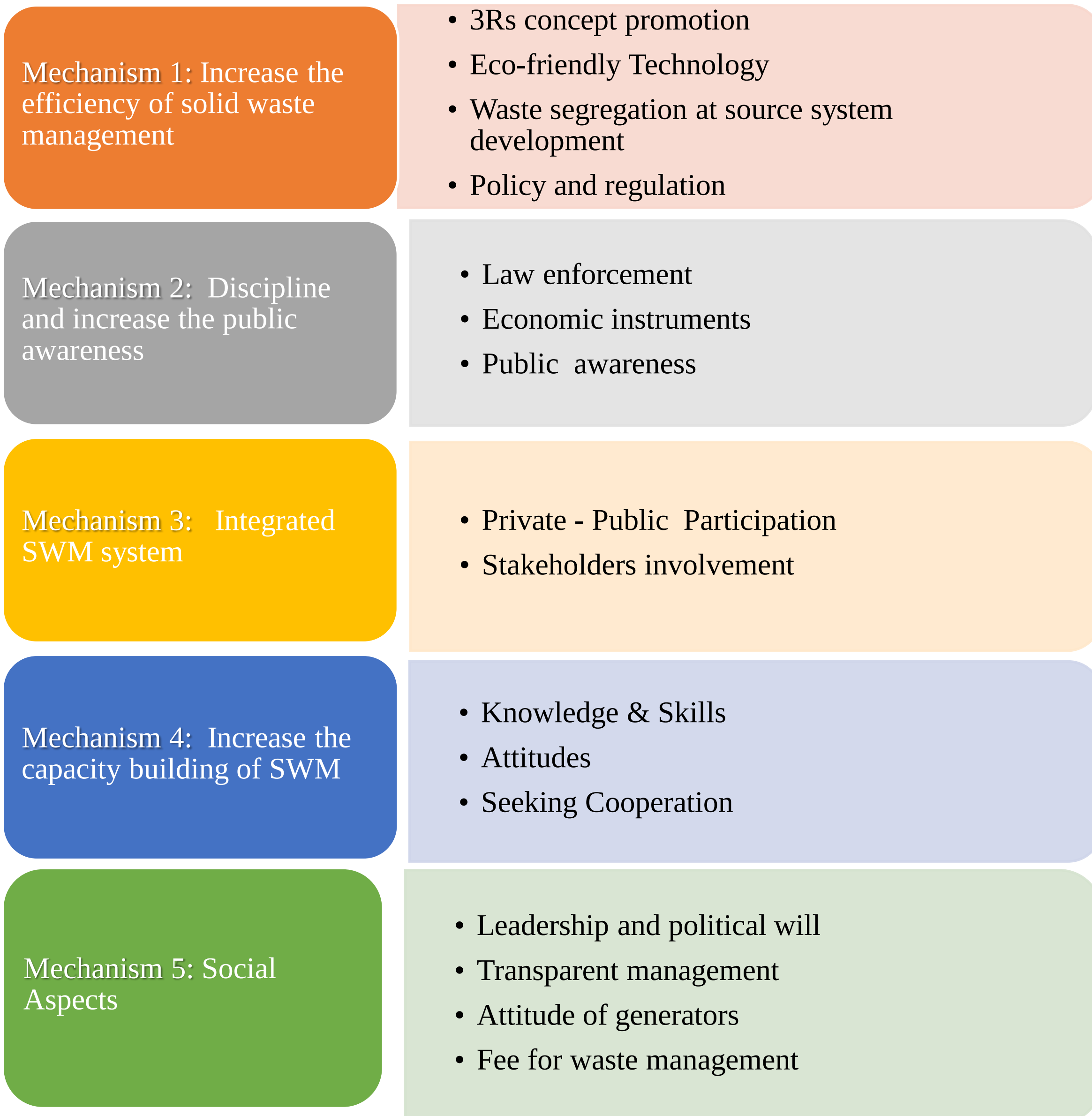

Figure 7 Suggested mechanisms for sustainable solid waste management

REFERENCES

[1] Do Ngat (2017). World Population Statistics in 2017, Institute of Statistical Science. Ha Noi.

[2] Ministry of Natural Resources and Environment (2016). National State of Environment: Urban Environment, Ha Noi.

[3] HCMC DONRE (2016). Report on results of work in 2016 and work planning in 2017, Division of Solid Waste Management.

[4] 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] Statistics Yearbook (2010, 2016). Population and labour, Statistical Office in Ho Chi Minh City.

[6] http:// www. hochiminhcity.gov.vn