MINISTRY OF INDUSTRY AND TRADE
INDUSTRIAL UNIVERSITY OF HO CHI MINH CITY

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RESEARCH ON BUILDING A MUNICIPAL SOLID WASTE MANAGEMENT MODEL IN HO CHI MINH CITY

Major: Resource and Environmental Management
Code: 9850101

SUMMARY OF THE DOCTORAL THESIS

HO CHI MINH, 2024

The Thesis completed in

INDUSTRIAL UNIVERSITY OF HO CHI MINH CITY

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The Thesis can be referred at:

- Industrial University of Ho Chi Minh City
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LIST OF PUBLISHED WORKS

International Journal

1**. Phuong Giang Le**, Hung Anh Le, Xuan Thang Dinh, Kieu Lan Phuong Nguyen, "Development of Sustainability Assessment Criteria in Selection of Municipal Solid Waste Treatment Technology in Developing Countries: A Case of Ho Chi Minh City, Vietnam," *Sustainability.* ISSN: 2071-1050**.** *Vol. 15, 7917, 2023.* https://doi.org/10.3390/su15107917. (Q1)

National Journals

1. **Phuong Giang Le**, Hung Anh Le, Xuan Thang Dinh, Huu Hai Trinh, "An assessment of the current situation and recommendation scenarios for municipal solid waste management in Ho Chi Minh City," *VMOST Journal of Social Sciences and Humanities*,Vol. 65, pp. 45-56, 2023. DOI: 10.31276/VMOSTJOSSH. (ACI)

2. **Lê Phượng Giang**, Đinh Xuân Thắng, Lê Hùng Anh, "Chiến lược quản lý chất thải rắn bền vững cho Thành phố Hồ Chí Minh," *Tạp chí Môi trường và Đô thị*, số 148, ISSN: 1859-3674, 2022.

CHAPTER 1 INTRODUCTION

1. Rationale

Solid waste management is a critical issue for major urban areas in developing countries. Unsustainable production and consumption models, combined with the limitations of solid waste management systems, lead to resource wastage and cause harm to human health and the environment. Ho Chi Minh City (HCMC), the largest economic hub of Vietnam, faces significant challenges due to rapid economic growth. The influx of raw materials, transportation, and labor into the city, along with the booming service sector, has exceeded the city's natural carrying capacity, leaving severe environmental consequences that, in turn, negatively affect the speed and quality of development.

One pressing environmental issue that continues to draw attention from the community and policymakers is the increase in solid waste generation, particularly municipal solid waste (MSW), stemming from human activities and production and service sectors. Although the city has implemented numerous management solutions, their effectiveness remains limited. This is exacerbated by inconsistencies and shortcomings throughout the entire waste management system, from waste generation control, collection, and recycling to treatment. The classification of MSW for recycling purposes is still at a very low level. Hygienic waste treatment at landfill sites also faces significant inadequacies, even at some facilities marketed as modern. Most MSW is disposed of via landfilling, which overburdens landfill sites, wastes resources, and creates environmental issues.

Additionally, limitations in the waste management system—from policy and system planning to implementation—have delayed addressing the environmental impacts of development or mitigating obstacles to sustainable development. These factors pose long-term challenges to the city's sustainability. Analyzing the factors that influence the effectiveness of MSW management and treatment to propose comprehensive solutions is a crucial requirement for environmental management in particular and development management in general in HCMC.

The research topic, "*Research on building a municipal solid waste management model in Ho Chi Minh City*" is both an appropriate and essential direction. Its goal is to establish a suitable MSW management system, focusing on the safe and efficient selection of waste treatment solutions that align with the city's conditions and other system components, forming a key aspect of the MSW management model.

2. Objectives and research contents

2.1 Objectives

The thesis proposes a suitable management model and optimal technology for each stage, from waste sorting to treatment. The research focuses on comprehensive solutions to enhance waste management efficiency and ensure sustainable environmental protection.

2.2 Research contents

1. Overview of related research issues.

2. Assess the current status of MSW management in HCMC; Mainly focuses on evaluating treatment technology.

3. Develop a set of criteria;

4. Use a set of criteria, apply the AHP approach and the normalization approach to determine weights and score scales; Choose appropriate treatment technology.

5. Propose suitable treatment technology for MSW management model in HCMC.

3. Research questions

This study will focus on addressing the following questions: (1) What is the relationship between municipal solid waste treatment technologies and the effectiveness of the municipal solid waste management model in HCMC? (2) How do the criteria for evaluating the sustainability of municipal solid waste treatment technologies impact the success of the municipal solid waste management model in HCMC? (3) Which municipal solid waste treatment technology will be the most optimal when applied to the municipal solid waste management model in HCMC**?**

4. Object and research scope

- The research object is MSW generated from households

- Time limit: The research was conducted from 2019 to 2022, this is the period before and after expanding the administrative boundaries and establishing Thu Duc City.

- In this thesis, the treatment segment is selected for the MSW management model for a number of reasons as follows: (1) Treatment can be considered one of the final segments of the MSW management cycle. This segment greatly affects the environment and people's health; (2) Processing is the segment where managers show the strongest involvement; (3) Although the MSW management system in HCMC has been planned and implemented in stages such as classification, collection and transportation in an organized manner, the treatment segmentation is still ongoing encounter difficulties and challenges.

5. Scientific and practical significance

5.1 Scientific significance

The thesis synthesizes and builds a set of criteria and evaluation through the AHP approach and normalization approach to select treatment technology for the MSW management model in HCMC. The results of this research can be used and referenced for related research.

5.2 Practical significance

The research results of the thesis have shown an overview of solid waste characteristics, MSW management in HCMC as well as the methodology and process of developing a set of criteria and AHP application process and normalization the selection of treatment technology for the MSW management model in the study area.

The research results of the thesis provide scientific foundations to help managers apply a set of criteria in selecting waste treatment technology for the MSW management model, which can be widely applied to urban areas in Vietnam.

6. New science points

Theoretically: Based on the survey of waste properties, the thesis has constructed a set of criteria, applied and combined the AHP approach and normalization approach to evaluate the selection of waste treatment technology for the MSW management model. Environmental, economic, and social aspects are all considered and evaluated.

Practically: The thesis has successfully applied the methods and criteria developed to evaluate the optimal selection of waste treatment technology for HCMC and proposed their application to other areas with similar conditions.

Structure of the thesis: The thesis includes 5 chapters: (1) Introduction, (2) Literature review; (3) Content and research methods; (4) Results and discussion; (5) Conclusions and suggestion accompanied by a list of published works, references and appendices. The content of the thesis is presented in 145 pages including 14 figures, 19 tables and 121 references. The appendix has 55 pages including 4 appendices.

CHAPTER 2 LITERATURE REVIEW

2.1 Overview of municipal solid waste management

The integrated MSW management model is the selection and application of appropriate technologies and management programs to achieve specific goals of solid waste management. That management model must be suitable to local conditions, ensure harmony and balance from an economic, social, financial, environmental, and institutional perspective, and must be able to maintain itself in a sustainable manner long periods of time without depleting resources [18].

2.2 Overview of the Current Status of municipal solid waste management in the worl and Vietnam

In developed countries, the MSW management system is well planned and organized, waste is classified at source, reducing the amount of landfilled waste by modern treatment, and burning waste to generate electricity has been implemented for a long time [20, 21]. In developing countries, treatment technology is still traditional, mainly burying and recovering and recycling plastic, metal, and paper [22]. The goal is to innovate waste treatment technology, recover energy, save resources, reduce land fund for waste treatment, limit emissions, and minimize environmental pollution [23].

The MSW management system in Vietnam has its own characteristics and experiences. MSW treatment technology is still mainly handled by two methods: burial and incineration [46]. Some recycling methods such as composting, energy recovery, recycling and reuse have gradually been applied instead but still have many limitations [47].

The MSW management system in HCMC is facing a number of challenges: (1) Waste classification at source is also facing difficulties due to technical infrastructure from the collection, transportation and transfer system. and handling is not synchronous, people do not cooperate, many spontaneous rendezvous, transit, and transportation locations appear, causing pollution; (2) Garbage treatment technology has too high a landfill rate. Due to lack of classification, the compost is of poor quality, there is no output for the product, burning the risk of environmental pollution has not yet had a specific form. It is possible to burn waste to generate electricity [11].

2.3 Overview of criteria set for treatment technology

The study reviewed more than 30 foreign studies related to the set of criteria to evaluate the MSW management system. In general, studies conduct analysis of technical, environmental, social and economic aspects to select appropriate MSW treatment technology for each locality [68]. Using a set of criteria helps optimize waste management, minimizing negative impacts on the environment and the community [69]. However, the set of criteria for MSW management to select treatment technology from Vietnam, the number of studies is still very limited.

24 Overview of the AHP approach for the set of criteria

Research around the world has applied the AHP approach to evaluate MSW treatment technology, helping them choose optimal treatment technologies for the management system through the participation of relevant parties and forming a unified chain [90]. The research only found a few documents using the AHP approach to select treatment technology from Vietnam. Through research, it is found that the cost and environmental impacts of treatment technologies dominate the authors' selection criteria. While technical (reliability, feasibility, applicability) and social (employment, public health, community acceptance) criteria were not considered in the majority of studies.

2.5 Overview of normalization approach for the set of criteria

Normalization is the process of establishing and enforcing regulations, standards or processes that organizations or individuals need to follow to ensure quality, uniformity and comparability between products, services or procedure. The main goal of normalization is to create a uniform basis to ensure consistency, reliability and quality assurance [95]. Researchs evaluate a process or social, economic, or environmental aspect using many different indicators, often measured in different units [96].

CHAPTER 3 CONTENT AND RESEARCH METHODS

3.1 Research content of the thesis

Research content includes: (1) Survey of waste properties; (2) Proposing a set of criteria; (3) Use a set of criteria, apply the AHP approach to evaluate, determine the highest weight, and select the optimal technology; (4) Use a set of criteria, apply a normalization approach to evaluate, determine the highest scoring scale, and select the optimal technology; (5) Propose suitable treatment technology for MSW management model in Ho Chi Minh City. The research contents of the thesis are presented in detail in Figure 3.1

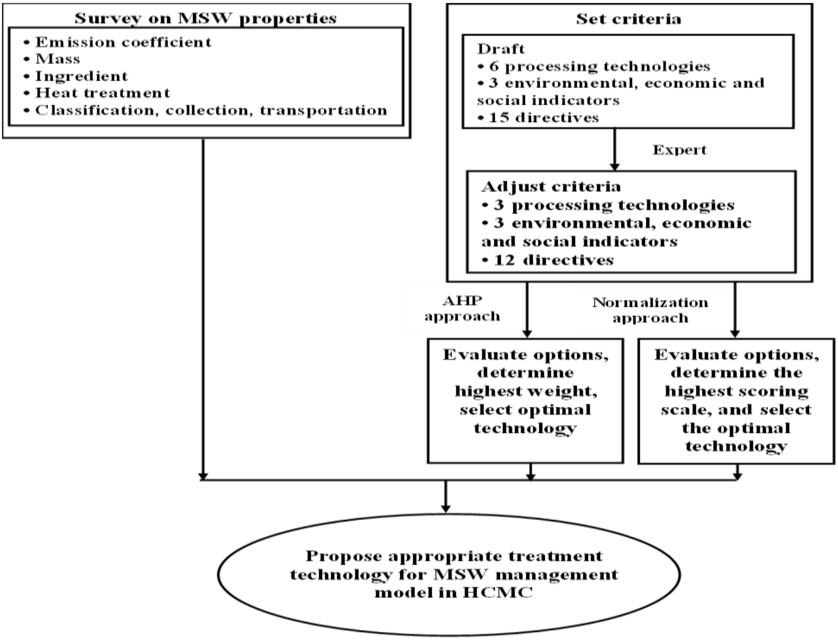

Figure 3.1 Research diagram

3.2 Research methods

3.2.1 Methods of investigation, survey and data collection

Secondary data includes published documents, newspapers, magazines, books, and materials of relevant research authors; solid waste treatment plants and landfills.

The household survey method is applied to assess the current situation of MSW management regarding collection, classification, and health affected by processing facilities.

+ Determine the number of survey and interview forms [120]:

$$n = N /(1 + N (e)^2)$$

n: Number of ballots to be determined for investigative research;

N: Total number of households (N_{2020}=2,559,817 households);

e: Expected error in percent (5%).

According to the 2019 household census data [121], the study area has 2,559,817 households. Thus, the number of survey questionnaires is 420.

3.2.2 Method for determining emission coefficient

Each district studied distributed bags to 420 households to store trash and weighed them at the same time the next day (weighing 3 times/week x 1 month).

$$\text{Emission coefficient} = \frac{\text{Household garbage weight}}{\text{Demographics}} \text{ (kg/capita/day)}$$

3.2.3 Method of determining waste composition

Sampling in the districts was conducted and 200 kg of garbage was analysed according to EPA, 2002 [122]. The method was as follows:

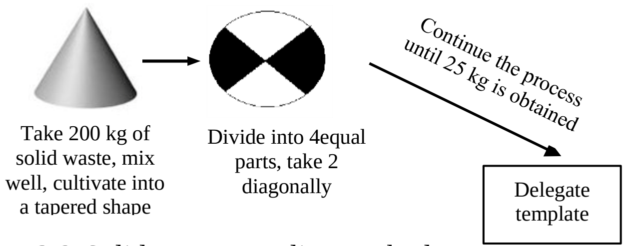

Figure 3.2 Solid waste sampling method

3.2.4 Method for determining the calorific value of waste

* Determining moisture content: $x_w = \frac{m_r - m_s}{m_r} . 100\%$

* Determine calorific value:

$$Q=0,556 \text{ x}\{145C + 610 (H_2 – 1/8 O_2) + 40S +10N; \text{ (kCal/kg)}$$

3.2.5 Analytic Hierarchy Process approach (AHP) [123]

The approach to selecting MSW treatment technology in Ho Chi Minh City is the AHP approach . The AHP process in this study includes 4 steps:

- Step 1: Build a matrix to compare the importance of each pair between groups of economic, social, and environmental criteria to determine the weights of criteria.

- Step 2: Build a matrix to compare the importance of 12 indicators with economic, social, and environmental criteria to determine the local weights of indicators.

- Step 3: Calculate the global weight of criteria by multiplying the weight of the criteria, which is the result of Step 1, and the local weights of the indicator, which is the result of Step 2, to obtain the composite weights of criteria in the AHP method.

- Step 4: The composite weight is calculated by multiplying the weights of criteria obtained from Step 1 by the weight of each technology determined in Step 4.

3.2.6 Normalization approach

In this study, the normalization approach is a combination of expert and community surveys. Because the indicators in the evaluation criteria are measured in different units, the study normalization these indicators within a value range of 1–5. This normalization was invented by American social scientist Rensis Likert in 1932 [124].

The steps are as follows:

- Step 1: Evaluate the importance of the criteria to determine points through a questionnaire. Each expert assigns importance to an indicator based on their expertise and experience.

- Step 2: Scale the feature range from 1 to 5.

- Step 3: Evaluate the results of component indices according to Formula (2.12-2.14) [119].

Economic index:

$$I_{eco} = \frac{\sum_{i=1}^{4} I_i}{4} \quad (2.12)$$

Social index:

$$I_{soc} = \frac{\sum_{i=5}^{8} I_i}{4} \quad (2.13)$$

Environmental index:

$$I_{env} = \frac{\sum_{i=9}^{12} I_i}{4} \quad (2.14)$$

- Step 4: Calculate the composite index for each treatment technology based on the results obtained from Step 3. The composite index (I_{com}) includes three component indexes: economic, social and environmental. The calculation is presented in Formula (2.15) [119].

$$I_{com} = \frac{I_{eco} + I_{soc} + I_{env}}{3} \quad (2.15)$$

CHAPTER 4 RESULTS AND DISCUSSION

4.1 Results of surveying the nature of MSW in Ho Chi Minh City

4.1.1 Results of determining emission coefficients by districts

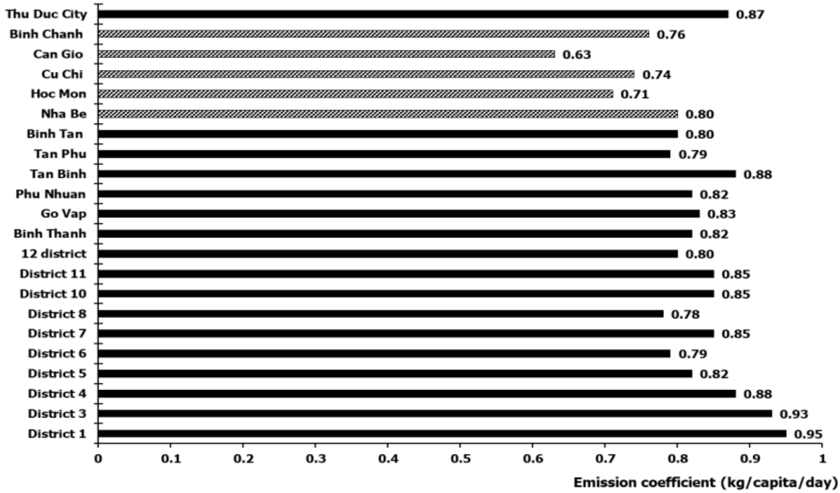

Figure 4.1 Results of the survey on emission factors by urban district, district

Figure 4.1 illustrates the uniformity of the emission factor. Although there are certain differences across areas, the results indicate that the emission factor does not vary significantly between districts, averaging 0.83 kg/capita/day. This may reflect a level of consistency in how residents handle waste, but it could also highlight weaknesses in the implementation of waste segregation at the source or differences in population structure and types of economic activities. Thus, the average emission factor in 2021 is 0.91 kg/capita/day.

4.1.2 Results of determining the volume of MSW by districts

Table 4.1 Volume of MSW generated by districts

District	Population (people)	Waste Quantity	
		Tons/day	Tons/year
District 1	142,625	135,494	49,455,219
District 3	196,433	182,683	66,679,182
District 4	4203,006	178,645	65,205,527

District 5	187,510	153,758	56,121,743
District 6	258,945	204,567	74,666,791
District 7	324,620	275,927	100,713,355
District 8	451,290	352,006	128,482,263
District 10	372,450	316,583	115,552,613
District 11	332,536	282,656	103,169,294
District 12	520,175	416,140	151,891,100
Binh Thanh District	490,618	402,307	146,841,967
Go Vap District	677,000	561,910	205,097,150
Phu Nhuan District	182,477	160,580	58,611,612
Tan Binh District	470,350	385,687	140,775,755
Tan Phu District	464,493	366,949	133,936,557
Binh Tan District	874,000	699,200	255,208,000
Nha Be District	175,360	140,288	51,205,120
Hoc Mon District	422,471	299,954	109,483,360
Cu Chi District	403,038	298,248	108,860,564
Can Gio District	74,960	47,225	17,237,052
Binh Chanh District	706,000	536,560	195,844,400
Thu Duc City	1,157,998	882,002	321,930,602
Tổng	8,944,152	7,279,368	2,656,969,225

Based on data on waste volume and population in districts, it can be clearly seen that there is an uneven distribution among districts. Central districts have a higher population and waste volume than suburban districts such as Can Gio district and Cu Chi district. This uneven distribution is due to the concentration of population and economic and industrial activities in central districts, leading to more waste generation.

4.1.3 Results of determining MSW components

Table 4.2 MSW composition in Ho Chi Minh City

Waste composition	Percentage
Organic waste	58.9÷80.7
Recycled and reused waste	
Paper	1.5÷8.1
Plastic	0.7÷9.4
Nylon	1.3÷15.2

Glass	0.5÷9.1
Carton	0.8÷11.9
Metal	0.3÷3.9
Remaining waste	
Styrofoam	0.2÷4.2
Bandages	0.2÷8.9
Fabric	0.4÷3.7
Porcelain	0.2÷2.3
Wood	0.3÷3.7
Hazardous waste	0.1÷0.2

The results of waste composition analysis are different from the results of the HCMC Department of Natural Resources and Environment in 2021 because they depend on the sources of data collected when making the report. Specifically, the organic content in 2021 ranges from 61 to 88.9% [121], while the organic content determined in the study ranges from 58.9 to 80.7%.

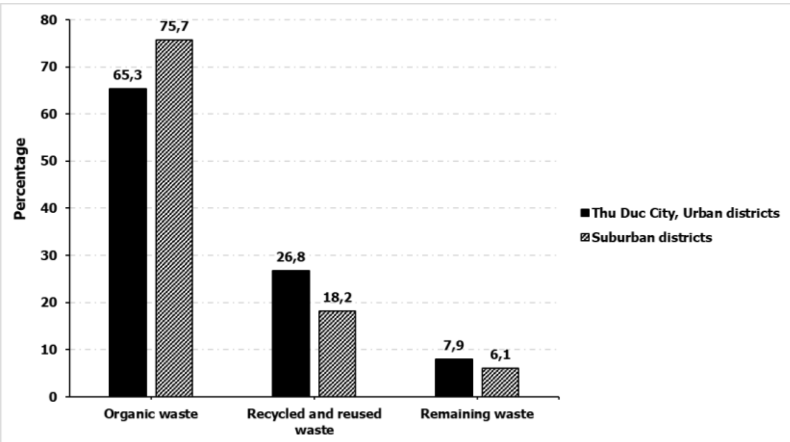

Figure 4.2 Ratio of MSW components in districts

In the study area, the proportion of biodegradable waste in urban districts is lower (65.3%) than in suburban districts (75.7%) where there is more production from agriculture (Cu Chi district, Hoc Mon district), seafood processing (Can Gio district). However, in urban districts areas where fast food, offices, and restaurants tend to be used, the content of recycled and reused waste (26.8%) will be higher than other suburban districts (18.2%). This is important data showing the need to determine appropriate and effective treatment technology in each district in HCMC.

4.1.4 Results of determining waste calorific value

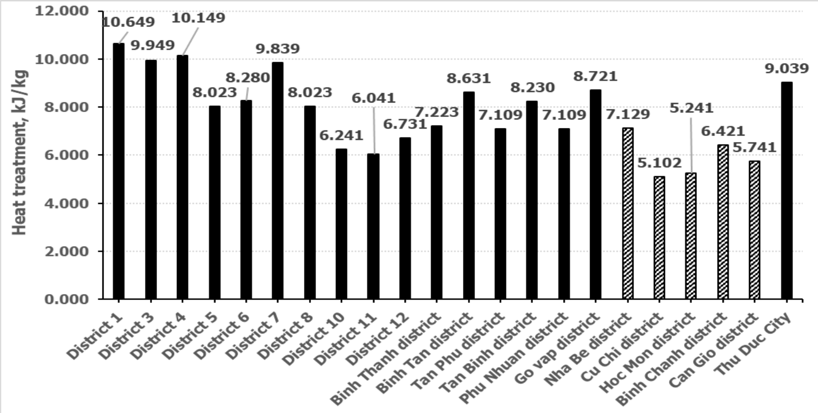

Figure 4.3 Heat value results of MSW in districts

Results of measuring absolute humidity and analyzing the calorific value of MSW components in districts show that humidity ranges from 53-77% and an average calorific value of 7,710 kJ/kg (Appendix 2). The waste sample in District 1 has the highest calorific value (10,649 kJ/kg), the lowest is the waste sample in Cu Chi district (5,102 kJ/kg). The calorific value of waste the urban districts are 1.5 - 2 times higher than the calorific value of waste in suburban districts. Based on calorific value, it will help research and select suitable MSW treatment technology for HCMC.

4.1.5 Determination results on the situation of classification, collection and transportation of MSW

In the research area, Thu Duc City and other urban districts, the majority of households still put their trash together in nylon bags, accounting for 77.5%, with 22.5% sorted. Because there is still land for agricultural production in the suburban districts, waste from leaves, vegetables, shrimp and fish shells are kept by people for composting; plastic and nylon bottles for sale, the classification rate is quite high.

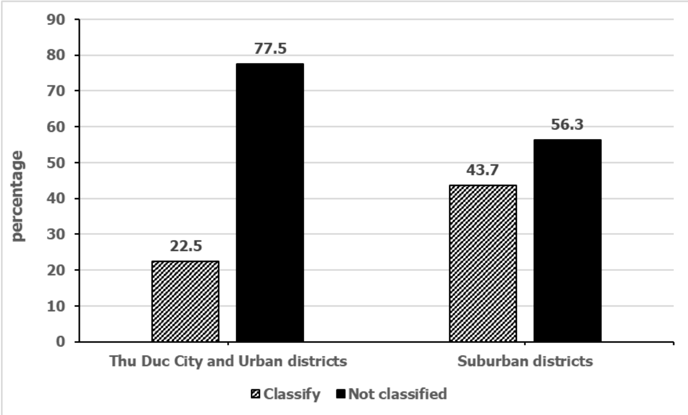

Figure 4.4 Results of waste classification in Thu Duc City and the districts

4.2 Results of developing a set of criteria for evaluating MSW treatment technology

Table 4.3 Set of criteria for selecting treatment technology for MSW management model

Criteria	Indicator	Description	Unit
Environmental	Air pollution	NH_3 concentration H_2S concentration Dust concentration	mg mg µm/m^3
	Greenhouse gas emissions	Amount of greenhouse gas emissions into the atmosphere	kg CO_2e/year
	Water pollution	BOD5 concentration COD concentration Amoni concentration	mgO_2/l mgO_2/l mg/l
	Land quota	Land use quota for treatment activities Heavy metal pollution: As, Cr, Pb	m^2/tonne mg/kg
Economic	Investment cost	Infrastructure Investment	VND million/tonne
		Equipment Investment	VND million/tonne
	Operation and maintenance costs	Maintenance costs	VND million
		Material costs	VND million
	Treatment cost	Unit price for waste treatment	VND/tonne

	Revenue/Benefit	Revenue from sales of electricity generated. Revenue from sales of composting	VND million VND million
Social	Community health	Number of people affected	person/year
	Job creation	Number of employees Income	person/tonne VND million/month
	Support policy	Support policies for waste treatment Support policies for selling compost Support policies for selling electricity	VND/tonne VND/tonne VND/kWh
	Community consensus	Number of lawsuits in a given year.	number of cases/year

4.3 Results of applying the AHP approach in determining weights to evaluate the sustainability of MSW treatment technology

4.3.1 Weighting results between index groups

Table 4.4 Weighting results of index groups

Criteria	Economic	Social	Environmental	Weight
Economic	1.00	1.26	0.98	0.355
Social	0.79	1.00	0.73	0.275
Environmental	1.02	1.37	1.00	0.370

The weight of the indicators for priorities from environmental experts accounts for 37%, which is considered the most influential factor in building a solid waste management system in the study area, followed by economic indicators. Economic index 35.5% and social index 27.5% have the least influence on this process.

4.3.2 Weighting results between indicator groups

4.3.2.1 Environmental directive group

Table 4.5 Weighting results of indicators belonging to the environmental index

Environmental index	Air pollution	Greenhouse gas emissions	Water pollution	Land quota	Weight
Air pollution	1.00	2.62	3.65	4.17	0.513
Greenhouse gas emissions	0.38	1.00	2.50	2.34	0.252
Water pollution	0.27	0.40	1.00	1.34	0.128
Land quota	0.24	0.43	0.75	1.00	0.108

Results Table 4.5, air pollution is ranked highest, greenhouse gas emissions into the environment affect the ranking for natural habitat and biodiversity.

4.3.2.2 Economic directive group

Bảng 4.6 Weight results of indicators belonging to economic index

Economic Index	Investment costs	Operation and maintenance costs	Treatment cost	Revenue	Weight
Investment costs	1.00	2.00	4.85	4.56	0.500
Operation and maintenance costs	0.50	1.00	3.59	3.43	0.306
Treatment cost	0.21	0.28	1.00	1.09	0.098
Revenue	0.22	0.29	0.92	1.00	0.096

Investment costs play an important role and are highly appreciated, accounting for half of the total other costs, showing that landfills consume a large amount of land, and building an MBT plant to operate waste incineration to generate electricity does not take up much space. The land is as large as a landfill but consumes quite a lot of money for factory investment. The cost of operating and maintaining machinery and equipment has an important influence on treatment selection and implementation, ensuring compliance when operating safe and sustainable waste treatment plays an important role.

4.3.2.3 Social directive group

Table 4.7 Weighting results of indicators belonging to the social index

Social index	Community health	Job creation	Support policy	Community consensus	Weight
Community health	1.00	1.41	2.05	1.16	0.328
Job creation	0.71	1.00	1.65	1.01	0.253
Support policy	0.49	0.61	1.00	0.67	0.162
Community consensus	0.86	0.99	1.49	1.00	0.257

Collaboration from the community in any decisions such as where to locate waste treatment facilities is important and must be adopted through policies. However, experts' opinions have proven that no matter how powerful a policy is, it will not be accepted if it does not have community consensus.

4.3.3 The result of the combined weight of the criteria

Table 4.8 Composite weight for the component criteria

Criteria	Weights of Criteria (wi)	Indicator	Local Weights of Indicator (wj)	Composite Weights of Criteria W = wi * wj
Environmental	0.370	Air pollution	0.513	0.190
		Greenhouse gas emissions	0.252	0.093
		Water pollution	0.128	0.047
		Land quota	0.108	0.040
Economic	0.355	Investment costs	0.500	0.178
		Operation and maintenance costs	0.306	0.109
		Treatment cost	0.098	0.035
		Revenue	0.096	0.034
Social	0.275	Community health	0.328	0.090
		Job creation	0.253	0.070
		Support policy	0.162	0.045
		Community consensus	0.257	0.071

Among economic indicators, investment costs (wj=0.500) and operation and maintenance costs (wj=0.306) have the most obvious impact on treatment technology. In terms of social aspects, there is not much difference between the directives. Public health (wj=0.328) is the greatest concern when operating a treatment facility, followed by community consensus, job creation, and policy indicators. Air pollution (wj=0.513) and greenhouse gas emissions (wj=0.252) play the most important roles in MSW treatment technology in terms of environmental criteria. This means that the quality of emissions from the treatment system needs to be well managed before being released into the environment.

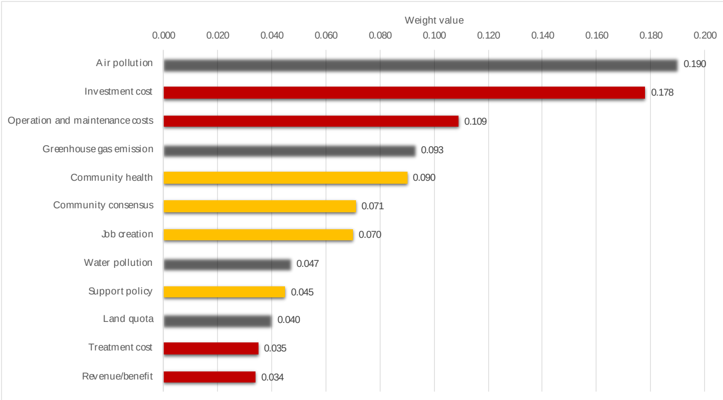

Figure 4.5 The impact of indicators on the sustainability of Ho Chi Minh City's waste treatment technology

Figure 4.5 depicts the combined weights of 12 indicators belonging to 3 criteria in descending order of the level of influence of the indicators on MSW treatment technology in HCMC. Indicators belonging to environmental, economic and social criteria are marked in green, purple and orange respectively. Air pollution, investment costs and operation and maintenance costs are the top three indicators with weights of 0.190, 0.178 and 0.109 respectively. They also represent the top concerns of local leaders and communities when deciding on MSW treatment technology.

4.3.4 Weighted ranking results of treatment technologies

Table 4.9 Composite weights of three treatment technologies

Criteria	Landfilling	Composting	Waste to Energy
Economic	0.105	0.058	0.191
Social	0.026	0.142	0.107
Environmental	0.041	0.114	0.215
Weight	0.172	0.314	0.514

The results of calculating the combined weight of the three treatment technologies are presented in Table 4.9. Waste incineration technology (0.514) has the highest weight, followed by composting (0.314) and landfilling (0.172). This shows that burning waste to generate electricity is the most preferred MSW treatment technology for the current situation of the city. Composting is also an interesting alternative to landfill technology which is not an effective solution for the current management system in HCMC.

4.3.5 Sensitivity analysis

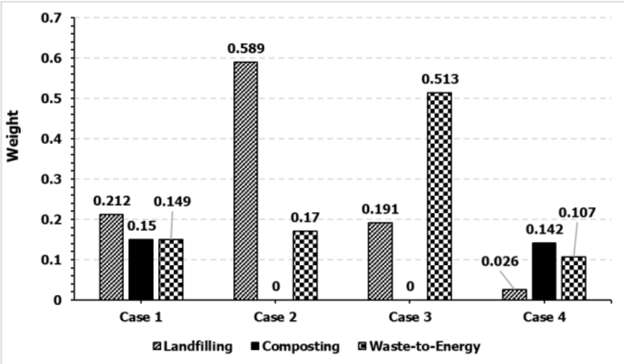

Figure 4.6 Sensitivity analysis for four cases

Case 1: All indicators have equal weight (10%). The sensitivities of the options are quite close, suggesting that they are not very sensitive to changes in the weighting coefficient.

Case 2: The environmental index group has a weight of 100%, and the other index groups have a weight of 0%. In this case, the sensitivity of landfilling is very high, very sensitive to changes in the weighting coefficient, while Incineration for Power Generation is not so sensitive and Composting does not change.

Case 3: The economic index group has a weight of 100%, while the other index groups have a weight of 0%, the sensitivity of waste incineration to generate electricity is high, but not very high compared to landfilling in this case. 2. Landfilling is also quite sensitive, while composting remains unchanged.

Case 4: The social indicator group has a weight of 100%, while all other indicator groups have a weight of 0%, Landfilling has the lowest sensitivity, composting has a higher sensitivity, and incineration has Generator waste has average sensitivity.

This result shows that there is a change, but not a significant change, in the rating of the processing technology that results are considered reliable.

4.4 Results of applying a normalization approach for evaluating the sustainability of MSW treatment technology

4.4.1 Component index results for three treatment technologies

Table 4.10 Results of evaluating component indexes according to MSW treatment technology

Criteria	Landfilling	Composting	Waste to Energy
1. Economic	**25.20**	**30.20**	**24.50**
1.1 Investment costs			
+ Infrastructure investment	149	172	109
+ Equipment	124	153	124
1.2 Operation and maintenance costs	145	152	121
1.3 Operation and maintenance costs			
+ Maintenance and servicing costs	114	167	112
+ Raw material costs	124	117	106
1.4 Revenue/Benefit			
+ Revenue from sales of electricity generated.	106	125	136
+ Revenue from sales of composting	106	149	142
2. Social	**25.86**	**31.33**	**38.33**
2.1 Job creation			
+ Number of employees	172	170	157
+ Income	153	159	149
2.2 Community consensus	107	160	163
2.3 Support policy			
+ Support policies for waste treatment	121	-	-
+ Support policies for selling compost	-	147	-
+ Support policies for selling electricity	-	-	149
2.4 Community health	94	148	149
3. Environmental	**21.67**	**29.33**	**42.33**
3.1 Air pollution			
+ NH_3 concentration	108	148	177
+ H_2S concentration	93	168	173
+ Dust concentration	92	140	183
3.2 Water pollution			
+ BOD_5 concentration	110	130	166

+ COD concentration + Amoni concentration	115 115	123 158	159 159
3.3 Greenhouse gas emissions	116	135	171
3.4 Land quota + Land use quota for treatment activities + Heavy metal pollution - As + Heavy metal pollution - Cr + Heavy metal pollution - Pb	 112 113 105 113	 167 112 167 167	 172 174 165 164

The results in Table 4.10 show that waste-to-energy incineration and landfilling technologies have higher costs. Revenue is more likely to be realized through the sale of compost and electricity when applying composting and energy recovery incineration technologies, making them more feasible compared to landfilling. Additionally, the number of lawsuits filed annually and the number of people affected by waste-to-energy incineration plants are also lower compared to landfills.

4.4.2 Summary index results for three MSW treatment technologies

Table 4.11 Evaluation results of aggregated indicators according to MSW treatment technology

Criteria	Landfilling	Composting	Waste-to-Energy
Economic	25.20	30.60	24.50
Social	25.86	31.33	38.33
Environmental	21.67	29.33	42.33
Composite indexes	24.24	30.29	35.05

Thus, it can be seen that evaluating treatment technology for the MSW management model, the aggregate indexes of each technology are different. The difficulty being encountered is that there are few environmental experts' options for landfilling and composting, while waste incineration for power generation is economically underestimated, the main factor being the cost of investment and operating too high, but this result also reflects positive changes in the environment and public health.

4.4.3 Process statistical results to determine the representativeness of the

results

4.4.3.1 Kruskal-Wallis test

In this study, testing the differences between treatment technology groups in the Kruskal-Wallis test for the MSW management model in HCMC was performed to determine whether there is a significant difference in scores. number. In addition, the Kruskal-Wallis test was used to determine whether the opinions of 50 experts responding to the questionnaire were statistically significant or not. The results of the Kruskal-Wallis test run on R software are detailed in Appendix 4.4.

Table 4.12 Kruskal-Wallis analysis results for 03 treatment technologies

	Synthetic		
	Landfilling	Waste to Energy	Composting
Mean (SD)	2.14 (0.919)	3.03 (1.175)	2.65 (1.089)
Median [Min, Max]	2.00 [1, 5]	3.00 [1, 5]	3.00 [1, 5]
Check total ratings	p-value < 0.00000000000000022		

With a very small p-value, there is enough evidence to reject the hypothesis of no difference between treatment technologies. This shows that there are significant differences in scores between treatment technologies. The waste management model with the highest average score is waste incineration technology (3,028), followed by composting (2,650) and the lowest is landfilling (2,139). The dispersion of scores within groups is expressed in standard deviations with waste incineration for power generation having the highest standard deviation (1.175) and landfilling having the lowest standard deviation (0.919).

4.4.3.2 Anova post hoc testing

In this data source, although the Kruskal-Wallis test was used to evaluate the differences between groups, the Anova post hoc test still provided some significant information at the 95% confidence level.

Table 4.13 Anova post hoc analysis results for three treatment technologies

Technology	**Average value difference**	**Lower confidence interval**	**Upper confidence interval**	**Adjusted p-value**

1. Waste to Energy - Composting	0.05043478	-0.0597653	0.16063487	0.5308719
2. Landfilling - Composting	-0.20869565	-0.3188957	-0.09849557	0.0000276
3. Landfilling - Waste to Energy	-0.25913043	-0.3693305	-0.14893035	0.0000001

Comparison between waste incineration technology and composting technology shows no significant difference, p=0.5308719 > 0.05. This result does not have enough evidence to confirm a meaningful difference between these two technologies.

Comparison between landfill technology and composting technology; Landfill technology and waste incineration technology both show a significant difference, p<0.05, there is enough evidence to confirm the meaningful difference between the two technologies.

After analyzing the Kruskal-Wallis test and Anova test for 50 expert assessments with a scale of 1 to 5, the results show that there is a significant difference in the average scores between treatment technologies. Therefore, the Kruskal-Wallis and Anova tests in this study confirm that the assessments of 50 experts are statistically significant, determining the representativeness of the results according to the normalization approach.

4.5 Results of evaluating AHP approach and normalization approach

From the results of Figure 4.7, it can be seen that both AHP methods and standardization through expert evaluation have similar choices. Thus, both methods choose waste incineration to generate electricity as the top priority technology.

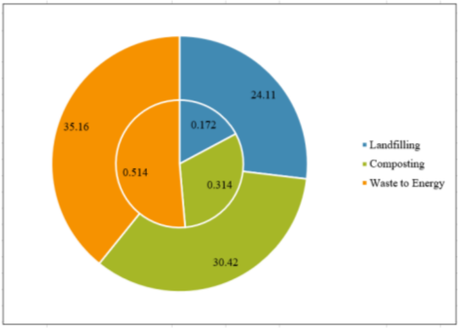

Figure 4.7 Summary of selection of MSW treatment technology using AHP approach and normalization approach

4.6 Proposed treatment technology for MSW management model in Ho Chi Minh City

The results of the experimental study indicate that the optimal choice of treatment technologies for HCMC is a combination of waste-to-energy incineration, composting, and landfilling for waste that cannot be processed through composting or incineration. The waste treatment process for the municipal solid waste management model in HCMC is as follows:

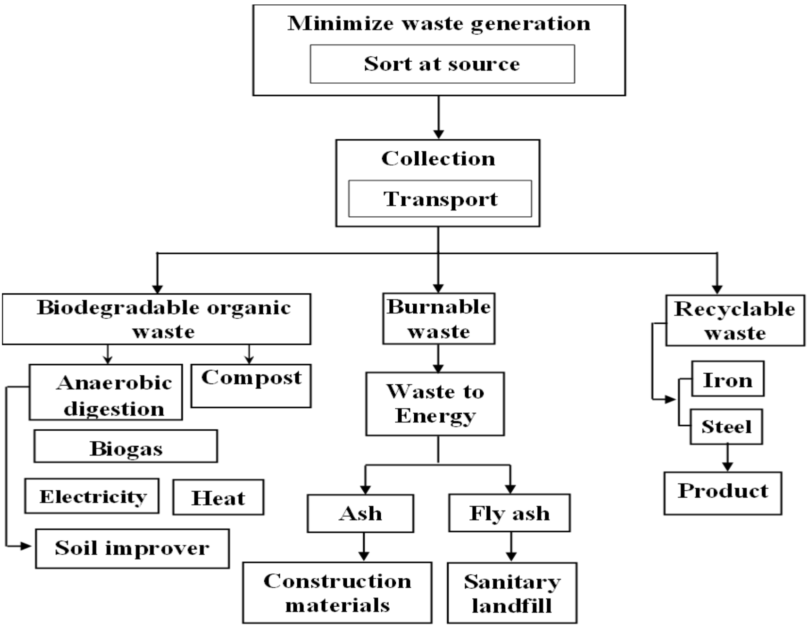

Figure 4.8 Proposed technology processing model for the CTRSH management system in Ho Chi Minh City

Based on the proposed model, eliminating landfill disposal in the future will lead to a gradual reduction in the land area allocated for traditional landfills. Instead, the existing landfill areas can be reallocated for other purposes, such as constructing waste-to-energy (WTE) plants and compost production facilities. The long-term goal is to completely phase out landfill use, optimize land utilization, and move toward more sustainable and efficient waste management solutions.

To rezone the Da Phuoc landfill for repurposing its land, gradually reducing traditional landfill areas, and converting the site into a WTE plant, compost production facility, and public space after environmental remediation, the following factors should be considered:

- Waste-to-Energy area

Allocate a portion of the area to build modern WTE plants. These facilities should be designed to process waste volumes in alignment with the future reduction in landfill usage, equipped with advanced emission treatment systems that meet environmental standards. Based on forecasted waste volumes from central districts and Thu Duc City. Phase 1 (2025–2030): Forecasted waste of 5,122 tons/day in 2025 and 5,384 tons/day in 2030. Propose the construction of two WTE plants, each with a capacity of 2,000 tons/day. Phase 2 (up to 2050): Increase to four plants with a total capacity of 7,527 tons/day, addressing future waste volumes effectively.

- Compost production area

Designate a separate area for processing organic waste into compost. This area should include systems for sorting organic waste at the source and advanced composting equipment. Forecasted waste volumes from suburban districts and the remaining urban districts, with lower daily per capita waste generation rates (0.63–0.79 kg/person/day), consist of high organic content (78.4–80.7%) and low calorific value (5,102–6,421 KJ/kg). Biodegradable organic waste is more suited for composting, particularly in suburban areas with available land (e.g., Cu Chi and Hoc Mon districts). Compost production also supports agricultural needs. Currently, organic waste suitable for composting at compost processing plants accounts for 35–64%, with the remaining waste (non-usable) accounting for 36–65% of the total waste received. Based on the forecasted waste volumes for the suburban districts and remaining urban areas:

+ 2025: 5,425 tons/day × 60% (organic content) = 3,255 tons/day

+ 2030: 5,702 tons/day × 60% (organic content) = 3,421 tons/day

+ 2050: 8,117 tons/day × 60% (organic content) = 4,870 tons/day

From the actual daily waste volumes, the following plant capacities are recommended: Phase 1 (2025–2030): 4,000 tons/day; Phase 2 (2030–2050): 5,000 tons/day

CHAPTER 5 CONCLUSION AND SUGGESTION

5.1 Conclusion

1. The study has effectively addressed the thesis on assessing the current state of municipal solid waste (MSW) management, providing comprehensive data and detailed analysis of variations in emission factors, waste composition, and calorific value across different areas of the city, while also forecasting future waste generation. These findings offer a thorough understanding of the MSW situation, forming the basis for developing effective management and treatment solutions.

2. The evaluation criteria have been comprehensively developed and effectively applied. The use of the AHP method and normalization has helped identify optimal MSW treatment technologies for HCMC. The results provide a solid foundation for proposing a management model that combines Waste-to-Energy technology and compost production, supported by statistically significant evaluations.

3. The study has addressed the thesis on developing a sustainable MSW management model for HCMC. The proposed model integrates Waste-to-Energy

and composting technologies with a specific development roadmap spanning from 2025 to 2050, optimizing the MSW treatment process for the future. This approach not only provides a strategic direction for HCMC but also serves as a scalable solution for urban areas in Vietnam with similar MSW conditions.

5.2 Suggestion

1. To effectively deploy waste incineration technology to generate electricity in HCMC, a mechanism for selling generated electricity and connecting it to the national grid should be researched. This process is necessary to attract investment and facilitate the adoption of advanced waste treatment technologies, which will be crucial in solving the looming waste crisis in future city.

2. In Suburban districts, small-scale composting (backyard composting) should be the focus of the future model because large-scale composting takes a lot of capital, energy and time.