An assessment of the current situation and recommendation of management scenarios for municipal solid waste management in Ho Chi Minh city

Phuong Giang Le[1*], Hung Anh Le[2], Xuan Thang Dinh[3], Huu Hai Trinh[1]

[1]The Central Transport College VI, 189 Kinh Duong Vuong, Ward 12, District 6, Ho Chi Minh City, Vietnam
[2]Industrial University of Ho Chi Minh City, 12 Nguyen Van Bao, Ward 4, Go Vap District, Ho Chi Minh City, Vietnam
[3]Hoa Lu Center for Research and Apply Environment, 284/41/1 Ly Thuong Kiet, Ward 14, District 10, Ho Chi Minh City, Vietnam

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Abstract:

Ho Chi Minh city (HCMC) is currently facing a critical problem of the uncontrollable municipal solid waste (MSW). The most common waste disposal practice in the city is landfilling, but this is not a sustainable solution. From 2010 to 2022, the amount of waste generated has increased annually, from 6,000 tons/day to 9,200 tons/day, with an average growth rate of 6-8% per year. This study calculated the average emission factor of various districts in the city such as districts 1, 3, etc. at 0.83 kg/capita/day and district Binh Chanh, Cu Chi, etc. at 0.73 kg/capita/day and forecasted that the amount of waste will reach approximately 16,100 tons/day by 2050. Currently, 80-90% of collected MSW is landfilled, while only 10% is recycled. Composting and energy recovery practices are rarely used. This paper reviewed the current solid waste practice in HCMC and proposed four management scenarios to develop a sustainable solid waste management system. The first scenario is landfilling, which involves non-segregated waste disposal at the source. The second scenario is recycling, which involves segregating waste at the source for recycling, reuse, and waste reduction. The third scenario is composting, which requires using a mechanical-biological treatment plant for sorting, composting, and producing fuel from waste. The fourth scenario is waste-to-energy, which uses a waste incineration plant to generate energy from waste.

Keywords: **current status, municipal solid waste management, scenario, solution.**

Classification numbers: **2.2, 7**

1. Introduction

Currently, the development of industrialization has led to a surge in urbanization, resulting in the generation of more and more waste to the point of explosion. This problem causes major ecological changes in the direction of harming our planet. Environmental sanitation is a pressing concern in urban Vietnam. The increasing amount of household waste has put pressure on the government to solve the problem of waste disposal as landfills become overburdened. Technical solutions, both domestic and international, are being sought to comprehensively address these pollution sources, which are of interest across all industries and sectors.

While existing technologies such as burying, non-recovery incineration, composting, and recycling, have been suitable solutions in Vietnam in previous years, there is now urgent demand for household waste treatment across the entire country and especially in HCMC. These solutions have not been fully perfected, and secondary sources of pollution (odour control, leachate control, and minimization of landfill areas) have not been completely treated. In addition, landfilling takes up a considerable amount

*Corresponding author: Email: lephgiang@gmail.com

of land, wasting a large source of material that could be used for incineration and heat recovery or for generating energy from this process.

Around the world, several solid waste treatment technologies have been implemented such as anaerobic landfills with or without gas recovery and semi-aerobic landfills, which are a widely-used technology and the most popular worldwide [1-3]; composting, which is a waste recycling process based on biodegradation under anaerobic and aerobic fermentation conditions, producing stable and sterilized compost products [4]; burning with and without energy recovery [5, 6]; energy recovery waste incineration, which is a promising technology, especially for developing countries, that turns waste into a usable form of energy [5]; and the production of solid fuels and pyrolysis [5, 6]. Although many treatment technologies have been applied in solid waste management, not all have been successfully implemented [6]. The selection of treatment technology for each locality will depend on an assessment of advantages and disadvantages, site area, operation techniques, economy, and environmental factors. In Southeast Asian countries, where climate conditions are similar to Vietnam, the authors choose integrated treatment solutions in the context of increasing solid waste with economic development. For example, a study in Sepang city, Malaysia, has an organic solid waste composition of 73.2%, with high moisture content in their garbage. The authors suggested that an integrated treatment technology of recycling, composting, and incineration is the best and most suitable alternative for the Sepang area [7]. MSW is considered a renewable energy source in Thailand. Therefore, a study in Bangkok proposed two integrated solutions for sustainable MSW management: the first being composting and gasification in case there are market opportunities for compost products and the second being anaerobic and gaseous decomposition if more importance is given to biogas production and power generation [8]. MSW in the Philippines is treated in three forms: 57% landfilling, 32% incineration, and 11% recycling [9]. MSW in Malaysia is 80-95% landfilling and 5% recycling, while composting and energy recovery are rarely done [10]. The MSW treatment method in Iran is geared towards environmentally sustainable solid waste treatment technologies with segregation at the source, landfill with gas recovery, composting, and incineration for power generation [11].

An assessment of the current situation and a proposal for solid waste management is a topic that attracts the attention of many scholars worldwide. UN-Habitat (2010) [12] showed that the biggest challenges faced by developing countries in solid waste management are the low collection rate and incorrect or unsafe MSW disposal methods. Malaysia has proposed reducing the amount of waste sent to landfills by sorting waste at the source, recycling, and using combustible MSW components as fuel to generate heat for power plants [13]. In a four-year study (2015-2019) on MSW management in Indonesia, the most optimal scenario was when the percentage of waste incinerated for electricity remained constant annually, but the percentage of 3R treatment increased, limiting the amount of waste sent to landfills. This study is highly feasible as Indonesia's waste is similar to Vietnam's, and reducing the amount of waste sent to landfills means a reduction in land investment costs and environmental pollution [14]. A sustainability assessment of the waste management system for Mexico City proposed a sustainable solution of incinerating waste to recover energy. These results confirm that Mexico city's decision to use waste incineration is a sustainable method from environmental, economic, and social aspects [15].

HCMC is the largest city in Vietnam in terms of population and scale of urbanization. It is also the centre of economy, politics, culture, entertainment, and education in Vietnam. The city is facing challenges in which the rate of waste growth is increasing rapidly [16], requiring an optimal waste management strategy. The trend of MSW generation over the period 2010-2020 shows that MSW is increasing by 3-8% annually [17].

Currently, in HCMC, 69% of MSW management is treated by sanitary landfill technology, 20% is used for composting, and 11% is incinerated, which cannot be a sustainable solution in the future [18]. Combustion helps to significantly reduce the volume, but the cost is high and the impact of discharging non-decomposing organic matter into the environment is unacceptable, therefore this is not a solid waste treatment option. Composting requires a lot of funding, time, and odour release into the surrounding environment. This practical recycling cannot remove all waste, as there will be a significant amount of waste backlog. The task of sustainable waste management is difficult because it requires consideration of the diverse factors mentioned above, namely, the social, economic, technical, and other concerns related to environmental conservation. Integrating waste management strategies that are environmentally friendly, economically affordable, and socially acceptable is an important step.

Since 1998, solid waste management has been addressed by the Party and the State in policies and directives, with Directive 36 of the Politburo-Central promoting the use of clean technology, minimising waste generation, and consuming fewer resources and clean energy [19]. Resolution 41/2002 encourages recycling and the use of recycled products, as well as the collection and treatment of used products [20]. Decree 38/2015 by the Prime Minister on waste and scrap management emphasizes the application of the 3R principles of waste reduction, reuse, and recycling, which play an important role in solid waste management [21]. Decision 491 by the Prime Minister approves the adjustment of the national strategy for integrated solid waste management until 2025, with a vision to 2050. Specifically, by 2025, 100% of solid waste will be source-separated and 100% of the total amount of solid waste will be collected of which 90% will be recycled, reused, energy-recovered, or used for organic fertilizer production [22]. Green growth strategies will be implemented with policies related to natural resource conservation and utilisation, renewable energy use, 3R in place of plastic bags, and sustainable production and consumption [22].

The proposal of the national strategy on 3R of waste management - reduce, reuse, and recycle, specifies the following issues: (1) Mechanisms to encourage reduction activities; (2) Policy development for the recycling market; (3) Development of appropriate tax structures for the industry; and (4) Mechanisms for establishing a recycling industry [16]. Additionally, the government should consider including the following activities in the strategy: (1) Integrating reduction activities at the source with community-wide efforts; (2) Introducing the concept of sustainable consumption in Vietnam through pilot projects; (3) Introducing clean development mechanisms in Vietnam through pilot projects; and (4) Sharing experiences in waste recycling into compost through associations and social organizations. In addition, recycling and recovery activities need to focus on the following issues: (1) Enhancing the recovery of used products for reuse for the same purpose or finding an alternative use; (2) Reuse mainly focusing on beverage containers and packaging materials, which are circulated through a closed-loop system, e.g., production - circulation - consumption - circulation - production; (3) Encouraging recycling facilities by collecting used products, processing or reprocessing them into original products or creating new products; (4) Effectively implementing reuse and recycling in industrial parks by establishing an information system to exchange waste, or, in some cases, waste that needs to be disposed of in one place can become input materials at another.

Thus, in addition to the decisions and decrees on solid waste management according to 3R, HCMC must have appropriate MSW management solutions. Therefore, the purpose of the paper is to propose solutions for domestic solid waste treatment in HCMC based on the current state of waste management, bringing a certain environmental and economic efficiency to the city.

2. Methods

One of the biggest challenges in this study is the limitation of data. There are many sources of data on the current status of solid waste management in the study area, but they are not continuous over time and space and are not regularly updated. For example, in the HCMC Environmental Status Report for 2019, the data on components and quantities remained the same (citing data from 2010-2015). The data sources are also inconsistent with each other, meaning that data on the same location and at the same time may differ, making it challenging to select and analyse data in this study. Therefore, in this paper, we re-evaluate the current status of MSW management in HCMC, which is the basis for forming the most sustainable and optimal treatment options.

2.1. Method of data collection

The data is collected from the following sources: (1) National State of the Environment reports of the Ministry of Natural Resources and Environment; (2) Environmental Status Report of HCMC Department of Natural Resources and Environment; (3) Environmental report of Urban Environment Company; and (4) the Statistical Yearbook.

2.2. Method of investigation

Determine the number of survey forms: To better understand the situation in the research area and related subjects, the study conducts surveys and field investigations in districts and towns throughout HCMC. Using a survey questionnaire for field investigations is suitable for many subjects and has high accuracy in research. The number of survey questionnaires is based on the total number of households in HCMC (Table 1), calculated using Yamane's formula (1967) [23]:

$$n = \frac{N}{1+N(e)^2}$$

where n: the required number of questionnaires for the survey; N: total number of households (N_{2020}=2,559,817 households); e: expected percentage error (5%).

For example, the study area in Thu Duc city, with 16 urban districts and 05 suburban districts, has 2,559,817 households [24]. Thus, the number of questionnaire samples for the whole study area is 400 votes. With *e* being 0.05 acceptance error, a total of 420 questionnaires were sent out for evaluation.

2.3. Method forecasting

To forecast the total amount of MSW generated in the study area until 2050, this study relies on the forecasted population in the area. The population forecast is estimated using the improved Euler formula:

$$N_{i+1} = N_i + r \times N_i \times t$$

where: N_{i+1}: the current population of the year being calculated (people); N_i: the current population of the city (people); t: the time difference between years; r: the population growth rate, with r=1.02% (2020), r=0.95% (2021-2050).

The amount of generated solid waste from household activities is calculated as:

$$R_{MSW} = N_{i+1}.g.365/1000 \text{ (tons/year)}$$

where R_{MSW} is the amount of generated solid waste during the period being considered (tons/year); N_{i+1} is the population in the period being considered (people); g is the waste disposal standard (kg/capita/day).

The amount of collected MSW is calculated as:

$$R_{collect} = R_{MSW} \times P$$

where P is the collection rate (%/year).

2.4. Method of determination of waste generation

A random 10 households were selected for each district. Carry-out bags for garbage collections were weighed on a scale at the same time the next day for a total of three times a week for one month. After collection, the garbage was dumped on the tarpaulin for sorting, determining the volume of each type of balanced garbage, and recording the results on a prepared form.

A record of the weight of the garbage and the demographic number of each household was used to calculate the waste generation by:

$$\text{Waste generation} = \frac{\text{Household garbage weight}}{\text{Demographics}}$$

2.5. Method of determining waste composition

Sampling in the districts was conducted and 200 kg of garbage was analysed according to Environmental Protection Agency (EPA) (2002) [19]. The method was as follows (Fig. 1):

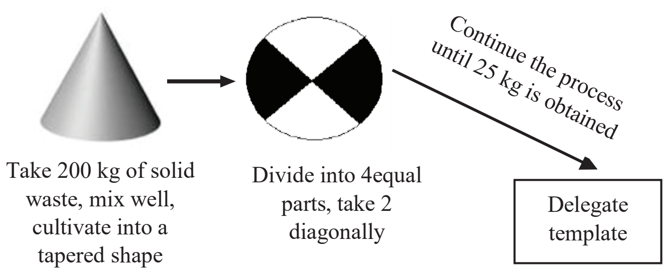

Fig. 1. Solid waste sampling method.

In each district, garbage was collected and sorted 3 days per week over 4 weeks and assessed according to the following equation:

$$\text{Ingredients \% by type} = \frac{\textit{Weight by type}}{\textit{Total waste of sampling}} \text{ x } 100\%.$$

Generally, the entire assessment process for the recommendation of scenarios for MSW management is shown in Fig. 2.

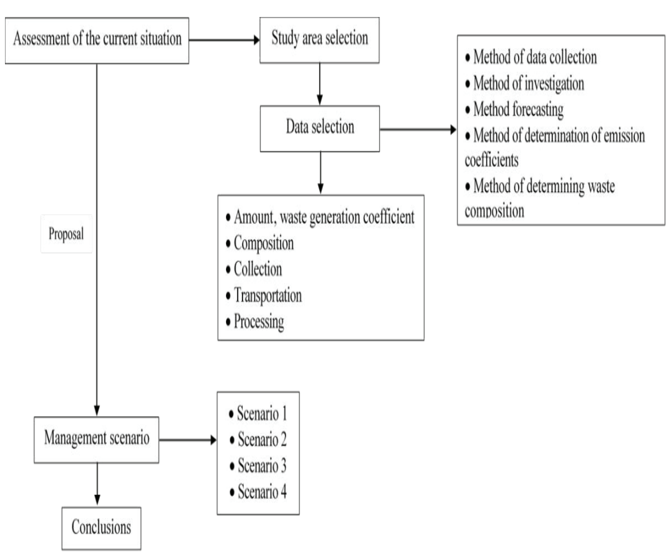

Fig. 2. Overview of the study procedure.

3. Results

3.1. The current status of MSW management in HCMC

The quantity of MSW generated: Based on the survey results from the HCMC Department of Natural Resources and Environment (DONRE) in 2023, the quantity of MSW in the city's area over the years is shown in Fig. 3.

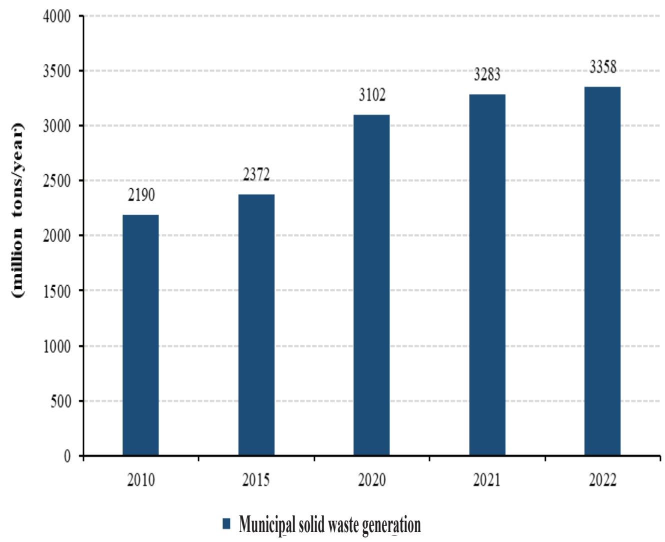

Fig. 3. The quantity of MSW in HCMC over the years. Source: HCMC DONRE (2022) [24].

In terms of scale, the period from 2010 to 2015 saw an annual increase of 2-4% in waste production. From 2015 to 2022, the quantity of waste increased rapidly with an annual growth rate of 6-8%. This situation is attributed to the rapid pace of urbanization and high population density, coupled with the lack of awareness among citizens in waste segregation for reuse and recycling at the source. As a result, the city is facing a rapid increase in waste, which is placing significant pressure on the environment.

The quantity of waste generated in each district and county is determined by weighing the waste from each discharge source. The method for determining the amount of waste is presented in detail in the research methodology section.

From the quantity of waste surveyed from the districts over three days/week carried out for one month, the average volume of waste of each waste discharge unit generated in a day is also known as the emission factor. The calculation results are shown in Fig. 4.

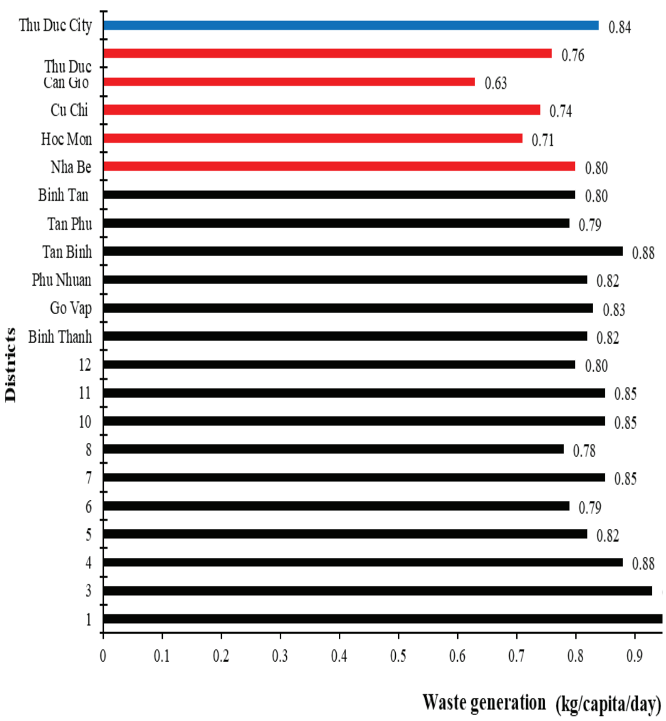

Fig. 4. Waste generation per district. Source: Authors' calculation.

The results of Fig. 4 can be seen that the waste generation of the districts does not have a big difference, an average person is about 0.83 kg/capita/day. However, in the central districts (districts 1, 3, 4, 7, 10, 11, Tan Binh) the waste generation (0.85-0.95 kg/capita/day) is higher than remaining suburban districts (0.78-0.83 kg/capita/day). However, there is a significant difference of about 0.3 kg/capita/day when comparing the discharge levels between the central and suburban districts. Thus, on average, the quantity of MSW discharged is estimated at approximately 0.81 kg/capita/day, and this data is also used as a basis for forecasting future waste generation volume. To compare the waste generation of HCMC to other regions, this study collected inherited information on the waste generation of several cities in the country [16], as shown in Fig. 5.

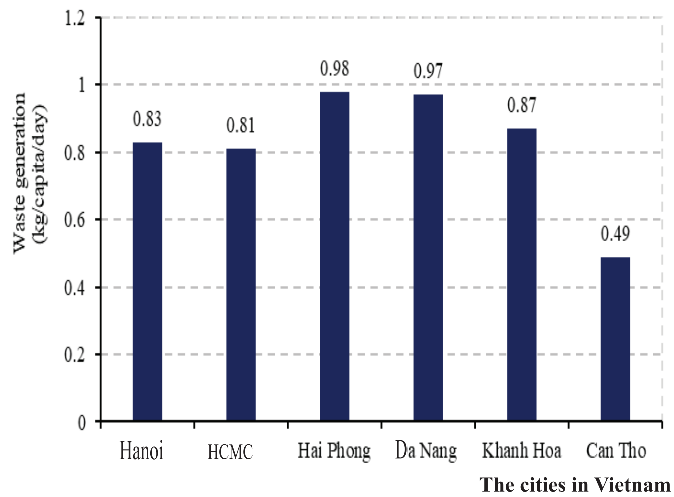

Fig. 5. Waste generation comparison chart of various cities in Vietnam. Source: Authors' calculation.

Based on Fig. 5, HCMC and Hanoi exhibit similar waste generation rates due to similar levels of urbanization and industrialization. Conversely, waste generation in Hai Phong, Da Nang, and Khanh Hoa is high due to the rapid development of industrial parks, coastal urban areas, and tourist destinations that attract a large number of domestic and foreign tourists. Although Can Tho is a large city in the Mekong delta region, its waste generation is relatively low compared to other urban areas. This is because the region's river tourism has not yet fully developed, and many agricultural occupations are under cooperatives. Furthermore, the infrastructure has not yet implemented or upgraded a new highway in the town, and investment in the province remains limited. Thus, the standard of living in Can Tho is not as high as in other cities, which results in a lower waste generation rate.

Composition of MSW: Fig. 6 provides the waste component results for the entire city by indicating the weight ratio of each type of waste to the total weight of the waste. This allows us to determine the percentage ratio of each waste component in HCMC.

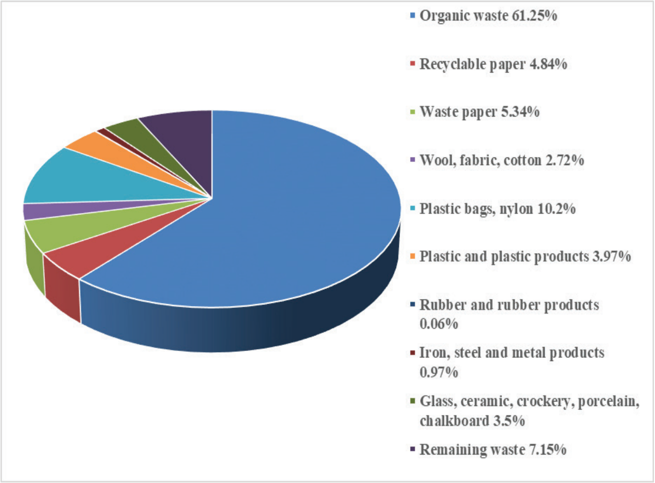

Fig. 6. Solid waste composition in HCMC. Source: Authors' calculation.

The waste composition of the city is diverse and comprises ten different types of waste, with organic waste being the most common due to its biodegradable nature. Other common types of waste include nylon bags and paper. This research categorized the waste components according to Decision No. 12 of the People's Committee of HCMC dated May 17, 2019, which mandates the classification of MSW at the source and proposes effective waste treatment measures. Thus, this work categorizes the waste components into three main types: organic waste group, comprising 61.25% (leftover food and fruit and vegetable peels); recycling, reusing waste group, comprising 31.6% (plastic bags, other plastics, rubber, paper, bottles, and jars); and the remaining waste group, comprising 7.15% (chemical containers, broken fluorescent bulbs, and expired medicines) of the total waste.

The composition of waste in the study area is similar to that of developing countries in the ASEAN region, which is mainly organic waste with an average of over 50% [25]. In Sepang, Malaysia, organic solid waste constitutes 73.2% of the total waste with a high moisture content of 80-95%. Only 5% of waste is recycled, while no energy recovery or composting is carried out [26]. In Indonesia, 60% of MSW is organic waste, followed by plastic (14%), and paper (9%) [27]. The composition of MSW in Thailand is mainly organic waste at 64% of the total waste, paper at 8%, plastic at 17.6%, and metal at 2%. Of the total waste, 17.65% is recycled, 25.66% is sent to landfills, 1.52% is burned, and only 1.82% is composted [28]. Thus, countries with developing economies have a high proportion of organic waste, which is similar in composition to that of Vietnam. Vietnam still treats their waste in the traditional way: landfilling and recovering/recycling of plastics, metals, and paper. Composting technology is suitable for Vietnam's amount of organic waste, however, it is still a waste of resources.

Current status of MSW collection segment: A survey of waste collection and cleaning in districts and towns was conducted by the public sanitation team of the utility service company and community waste collection groups. In 2022, the waste collection rate in HCMC reached 90%. However, like other developing cities, the waste collection rate in HCMC varies by location. Specifically, the collection rate in 13 inner city districts is 100%. Meanwhile, it is 80-90% in 6 outer suburban districts and 70-80% in rural districts [24]. In reality, the amount of collected waste is still low, and most of it is still uncontrolled and not properly disposed of. In fact, the amount of waste collected is still low, mostly from households that do not transfer it directly, but instead leave it out in public waste containers or dump waste into the city's canals. Sometimes, households will self-treat by burying waste in the garden or dumping it in vacant lots in suburban districts such as Cu Chi and Can Gio [16, 24].

Current status of MSW transportation segment: Collection and transportation networks for solid waste are operated by the Urban Environment Company, Public Service Companies, and the Agricultural Transport Cooperative. The network collects and transports MSW from designated points to transfer stations and then to processing clusters located within the city. Although the MSW transfer station system has been established, most transfer stations are temporary or have not received enough investment to meet environmental protection requirements. They also face difficulties in terms of location, scale, and distance, which affect the surrounding environment.

Current status of MSW treatment segment: Like many cities in Asia, disposal of solid waste in landfills is the predominant form of waste disposal in HCMC. The MSW in the city, after being collected, is brought to four solid waste treatment centres as shown in Fig. 7.

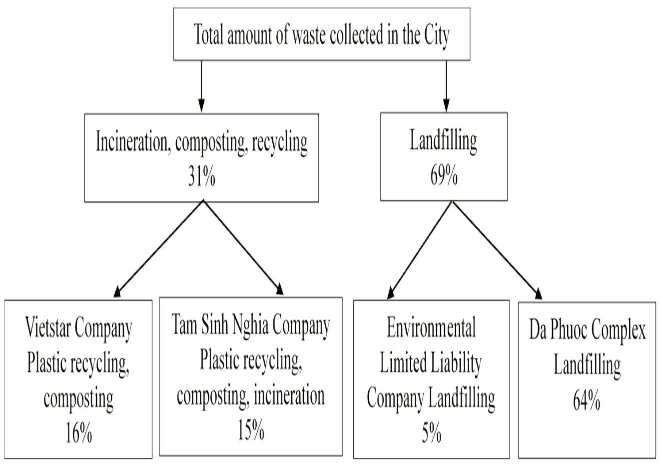

Fig. 7. Solid waste treatment flowchart in HCMC.

Currently, the majority of waste treatment technology in the city comprises landfill (69%), while incineration, composting, and recycling methods account for the remaining 31%. The Da Phuoc landfill is the primary urban solid waste treatment facility, receiving nearly 70% of the total waste. However, according to a survey conducted by the author's team, almost 80-90% of the collected solid waste was sent to landfills, with only 10% being recycled, and composting and energy recovery practices being rare. The reason for this issue can be explained as follows: firstly, the waste is not sorted at the source, resulting in compost product containing impurities, being of low quality, and difficult to consume. Secondly, the construction and operation of a waste incineration power plant are high, while funding sources are limited [29].

3.2. Forecasting the quantity of MSW in HCMC until 2050

Population growth poses a significant challenge in managing the increasing quantity of garbage generated in the city. This study estimated the quantity of MSW that could be generated by 2050, as shown in Fig. 8. Based on forecast data on population growth, GDP forecast increases, and report in the "HCMC solid waste planning 2019", per capita emissions tend to steadily increase at a rate of 0.02-0.03 kg/capita/day [30]. This result is consistent with research from other developing countries such as Malaysia [31] and Thailand [32]. Therefore, the study relies on this data as the basis for forecasting future waste generation.

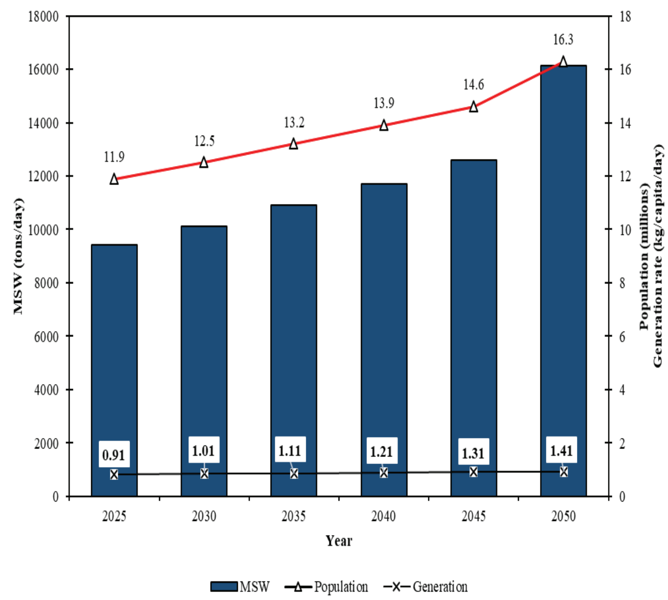

Fig. 8. Forecasting the quantity of MSW generated to 2050. Source: Authors' calculation.

Referring back to Fig. 3, in the year 2022, the total amount of MSW generated is approximately 3.3 million tons/year, which is equivalent to 9,200 tons/day. It is projected that by 2050, the total amount of MSW generated will be approximately 5.8 million tons/year, equivalent to 16,100 tons/day. It can be seen that, along with population growth, the amount of MSW is expected to increase almost twofold compared to the current amount generated as this increase depends heavily on the economic growth rate.

3.3. Proposed management scenarios

To meet the growing demand for waste management in the city due to urbanization, an optimal waste management scenario needs to be chosen. The current waste management model has many limitations, and therefore, a waste treatment planning direction until 2025 and a vision until 2050 have been proposed. To achieve this, advanced and modern treatment facilities are suggested to reduce landfills, conserve land resources, recover energy and biomass, and reduce greenhouse gas emissions. The proposed aim is to reduce the landfill rate to no more than 10% by 2050 [33, 34].

In building a scenario for HCMC, the study relies on integrated solid waste management, which considers the entire waste management cycle, from generation to final disposal. The proposed scenario aims to optimize resource recovery, minimize waste generation, promote sustainable economic development, and reduce the negative impact of waste on communities and the environment. The four scenarios proposed by our research group for a sustainable solid waste management system are based on the principles of integrated solid waste management.

Scenario 1: Non-classification of waste at the source: Scenario one (Fig. 9) is based on the reality in many urban areas, where a significant proportion of waste is sent to landfills, such as Hanoi (89%), Da Nang (90%), and Can Tho (80%). Despite having regulations for waste classification at the source, the proportion of sorted waste is still low. For example, in HCMC, 69% of solid waste is treated through landfilling without being classified at the source, and recycling and material recovery are still informal. Although the city has implemented waste classification at the source, there has been little progress, and most people still mix different types of waste. The landfills in the study area are open-air sites that have leachate treatment but do not collect gas. In this scenario, waste collection units at containers do not sort waste, and transfer stations are used to store and transport waste to landfills.

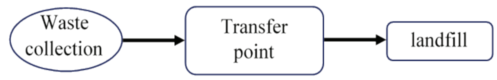

Fig. 9. Waste flow diagram of Scenario 1.

Scenario 2: Waste sorting at the source for recycling, reuse, and waste reduction: Scenario two aims to improve the current waste collection system by sorting recyclable waste at households based on the city's waste classification program, which divides waste into burnable and non-burnable categories (Fig. 10). This sorting method is already used in some localities, such as Can Tho and Hanoi. Under this scenario, all collected waste will be treated at sanitary landfills, and full compliance with environmental regulations will be ensured. By sorting waste at the source, this scenario aims to reduce the amount of generated solid waste and promote recycling and reuse of waste. All waste will be disposed of at sanitary landfills to ensure safe and sustainable waste management practices.

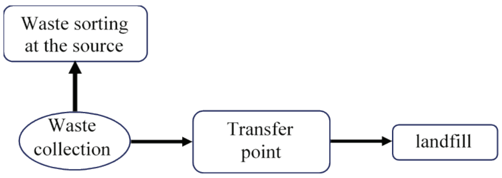

Fig. 10. Waste flow diagram of Scenario 2.

Scenario 3: Mechanical-biological treatment plant for sorting, composting, and producing refuse derived fuel: Scenario three addresses the challenge of managing waste in areas with numerous rendezvous and transit points, which can cause environmental pollution (Fig. 11). Implementing recycling, reduction, and reuse strategies in these areas is particularly difficult. To achieve the 3R goal of waste management, this scenario proposes converting waste into energy in the form of refuse-derived fuel. This scenario combines integrated processing, where a mechanical-biological treatment plant sorts, recycles, and composts waste simultaneously. The waste is sorted and separated into ferrous metals, organic, and inorganic components. The inorganic component, which includes plastic, paper and cardboard, textiles, wood, and rubber, is processed to remove refuse-derived fuel and used as fuel for incineration or other thermal energy uses. Organic waste accounts for over 70% of the waste and is primarily processed biologically to produce compost. Biogas is the main product in the composting plant.

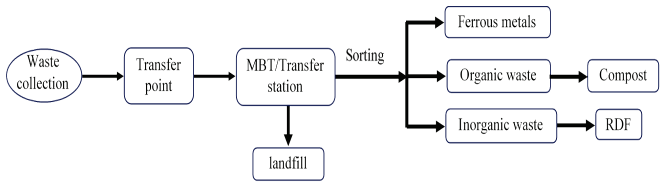

Fig. 11. Waste flow diagram of Scenario 3.

Scenario 4: Incineration plant waste to energy: The treatment of municipal waste has become a challenge for many localities due to overloaded landfills and outdated incinerators that pose environmental pollution risks and health hazards to the community. To address this issue, this study proposes a scenario that involves converting waste into sustainable energy, in line with the city's integrated waste management policy. This approach focuses on high-tech applications and aims to reduce the landfill rate to less than 10% after treatment by 2050, which is consistent with the trend that developing countries are pursuing, as well as international conferences on global climate change such as COP26 in November 2021, where countries committed to reducing emissions and using renewable energy in the future.

Scenario shown in Fig. 12, the waste-to-energy (WtE)/incineration plants include transfer stations where the waste is transported directly to the incinerator for energy recovery with emission control. Eliminating transfer stations will reduce environmental pollution and transportation costs.

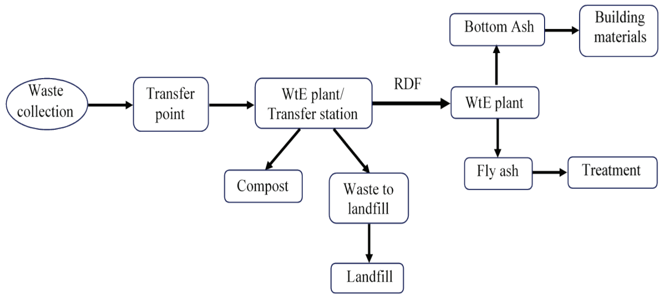

Fig. 12. Waste flow diagram of Scenario 4.

Using four previously proposed scenarios, the research team will establish criteria using the Analytic Hierarchy Process (AHP) in the next study, which is a tool of the Multi-Criteria Analysis method to evaluate scenarios. This evaluation will compare the economic benefits, the impact of waste treatment on the environment, and the social benefits of specific waste treatment scenarios for HCMC. The results obtained from this evaluation will assist decision-makers in selecting a sustainable waste management system.

4. Conclusions

HCMC is a metropolis of Vietnam, characterized by fast-paced economic growth and rapid industrialization and urbanization. However, this continuous development has come at a significant cost to the environment, with serious negative impacts resulting from human activity. The results of this investigation show that the current technology and strategy for managing MSW in HCMC are outdated, with most of the unsorted waste being landfilled, resulting in secondary pollution and consuming a considerable amount of land. The waste collection system is also inefficient, with open-air bins concentrated in residential areas, causing pollution and affecting people's daily lives. Therefore, the city needs to adopt a sustainable solid waste management model, innovate waste treatment technology, recover energy from waste, conserve resources, reduce the land used for waste treatment, limit emissions, and minimise environmental pollution. It is essential to realize that sustainable economic development requires a balance between economic growth and environmental protection.

This study evaluated the MSW management system in HCMC and provided solutions for sustainable solid waste management. Through the survey process, this study calculated the average emission factor of Districts 1, 3, etc. as 0.83 kg/capita/day and the districts of Binh Chanh, Cu Chi, etc. as 0.73 kg/capita/day. Therefore, on average, the estimated amount of solid waste generated per day in the research area is about 0.81 kg/capita/day, which also serves as the basis for predicting the amount of solid waste to be generated in the future. This study proposed four scenarios for effective sustainable waste management, considering the environment, society, and economy.

To find the most optimal technology from the proposed scenarios, the next research direction is to comprehensively evaluate the four scenarios (burying, recycling, composting, and incineration for electricity generation) using an analytical hierarchical process (AHP). This evaluation will involve experts who will provide their opinion on the most optimal technology. The results will assist planners in making informed decisions on waste management strategies, policies, and investments in new waste treatment facilities in HCMC and neighbouring areas.

CRediT author statement

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COMPETING INTERESTS

The authors declare that there is no conflict of interest regarding the publication of this article.

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