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Original Research

The Establishment of Greenhouse Gas (GHGs) Emission Inventory for Strategizing the Solid Waste Management in Selangor, Malaysia

Norashikin Ahmad Kamal[1], Audra Stephanie Stephen[1], Sangmin Shin[2], Rohaslinda Ramele Ramli[3]*

[1]School of Civil Engineering, College of Engineering, Universiti Teknologi MARA, 40450, Shah Alam, Selangor, Malaysia
[2]School of Civil, Environmental and Infrastructure Engineering, Southern Illinois University, Carbondale, IL 62901, USA.
[3]College of Built Environment, Universiti Teknologi MARA, 40450, Shah Alam, Malaysia

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Abstract

Greenhouse gas (GHG) emissions are becoming increasingly concerning, with problems arising globally for the environment. There is an urgent need to have a clear picture of what is happening to the environment due to the GHGs emission from solid waste management (SWM). Thus, a GHG emissions inventory for SWM is needed to allow for the monitoring and control of further harmful emissions, allowing local authorities to provide solutions. This study aims to evaluate the processes and core parameters in SWM that contribute to emissions, and then calculate the GHG emissions for all processes. It specifically covers the solid waste management of eleven municipalities in Selangor, Malaysia, which aim to achieve sustainable city status. All related data and information in this study have been obtained from KDEB Waste Management, a company that manages waste for all twelve municipalities in Selangor State, along with secondary data that was found in previous studies. The data were analyzed using the LCA method in OpenLCA software. The results of this study suggest that the collection and transport processes contributed to the highest emissions and that additional low-carbon processes in solid waste management may help to reduce emissions. The research also recommends a thorough approach when selecting a suitable GHG-calculating tool.

Keywords: GHGs emission, solid waste management, sustainable cities

*e-mail: rohaslinda@uitm.edu.my
Tel. +60355436425; Fax: +60355435275

Introduction

Solid waste generation is known as one of the biggest contributors to GHG (greenhouse gas) emissions in Malaysia. The management of solid waste remains a challenge in Malaysia because the rate of waste generation is growing every year at an uncontrolled rate and beyond the management capabilities of the relevant authorities [1]. The SWM (solid waste management) cycle, including the generation of waste, transportation, and disposal, leads to GHG emissions [2]. There are a wide variety of mature and significant strategies available for mitigating emissions of GHG from waste. These technologies include landfilling with the recuperation of landfill gas; post-consumer recycling to prevent the production of waste; composting selected fractions of waste; and processes that decrease the output of GHG compared to landfilling [3].

Speedy urbanization, population growth, and industrialization make significant contributions to expanding waste production and changing waste properties [4]. This increase in solid waste is damaging to the environment, as the emission of GHG also increases. Increased GHG emissions into the atmosphere have led to the problem of global warming. According to [5], the [6] report states that the waste sector's contribution to overall GHG emissions worldwide is 3%. By contrast, 12% of total GHG emissions in Malaysia were contributed by the waste sector in 2011 [7].

Adequate waste management leads not only to reducing water or air pollutant and odor emissions, but also GHG emissions [8]. The evaluation of GHG emissions is based on the IPCC guidelines. The key rule was circulated and further revised in 1996. The latest IPCC guidelines were released in 2006. In order to gauge the GHG emission, release, and remove it from the atmosphere, the development of an inventory for solid waste management is necessary. A GHG inventory offers a high-level representation of the total emissions of an industry. In order to set and meet the pollution reduction goals, a well-designed and managed inventory should be used [9].

The establishment of an inventory for solid waste in Selangor is one means of minimizing pollution by analyzing and quantifying the amount of GHG emitted in every process of SWM. According to [2], reductions are made possible through inventory, as previous studies have summarized the different measurement approaches and their limits available for waste estimation–based carbon trading approaches and GHG pollution inventories. In addition, the inventory method measures emissions of carbon from the waste disposal process [2]. Since inventory techniques for solid waste management (SWM) have not been introduced in Malaysia, implementing this approach would be a wise move, given that Malaysia is one of the many Asian nations grappling with SWM challenges. Malaysia has participated in an annual workshop organized by the Greenhouse Gas Inventory Office of Japan (GIO) at the National Institute for Environmental Studies (NIES) since 2003, in collaboration with the workshop activity on improving the management of solid waste and reducing GHG emissions in Asia (SWGA). This workshop should improve the capacity for inventory compilation in NA I countries in Asia [8].

This study aims to evaluate the GHG emissions from each process in solid waste management in the cities of Selangor, Malaysia, as illustrated in Fig. 1. Selangor is the most populated state in Malaysia, with a diverse mix of urban and rural areas. Urban areas include Petaling Jaya, Shah Alam, and Klang, which are all densely populated and have a high level of economic activity. The rural areas, on the other hand, are mostly agricultural areas with smaller populations. With a population of approximately 6.5 million people, the state generates about 10,000 tons of waste per day, including domestic and bulk waste. The state has implemented various initiatives to manage and reduce waste, including waste segregation, recycling, composting, and landfilling, as well as programs to raise awareness about waste reduction and recycling. Thus, the findings from this study will be significant for public authorities in evaluating strategies for solid waste management for the future in order to achieve sustainable cities. This could also help public authorities achieve Sustainable Waste Management, as related to the related goals in the Sustainable Development Goals (SDGs) and also within the current global policy frameworks. Sustainable waste management is the process of collecting, transporting, processing, and disposing of waste in a way that minimizes negative impacts on the environment and human health while maximizing resource recovery and economic benefits.

The goal of sustainable waste management is to reduce the amount of waste generated, promote the reuse and recycling of materials, and ensure the safe disposal of remaining waste. Waste services prominently feature in the targets and indicators of both SDG 11 and SDG 12, notably with commitments to prevent, reduce, recycle, and reuse; as well as to properly collect and discharge urban solid waste and halve global food waste by 2030, and to properly handle and treat chemical and other hazardous waste through the entire life cycle in accordance with international standards by 2020. They also figure under the transformative commitments made by UN Habitat member states in the 2016 New Urban Agenda (NUA). This includes pledges to realize universal access to sustainable waste management systems, minimize landfills, and convert waste into energy, with special attention to coastal areas. However, there are still challenges to overcome in achieving sustainable waste management in Malaysia. One of the biggest challenges is a lack of public awareness and participation in waste management. Many people still do not fully understand the importance of proper waste management and the impact of their actions on the environment. Furthermore, there is a need for stronger enforcement of regulations to ensure that waste management practices are properly followed.

Fig. 1. Selangor's Location and Municipalities in Selangor.

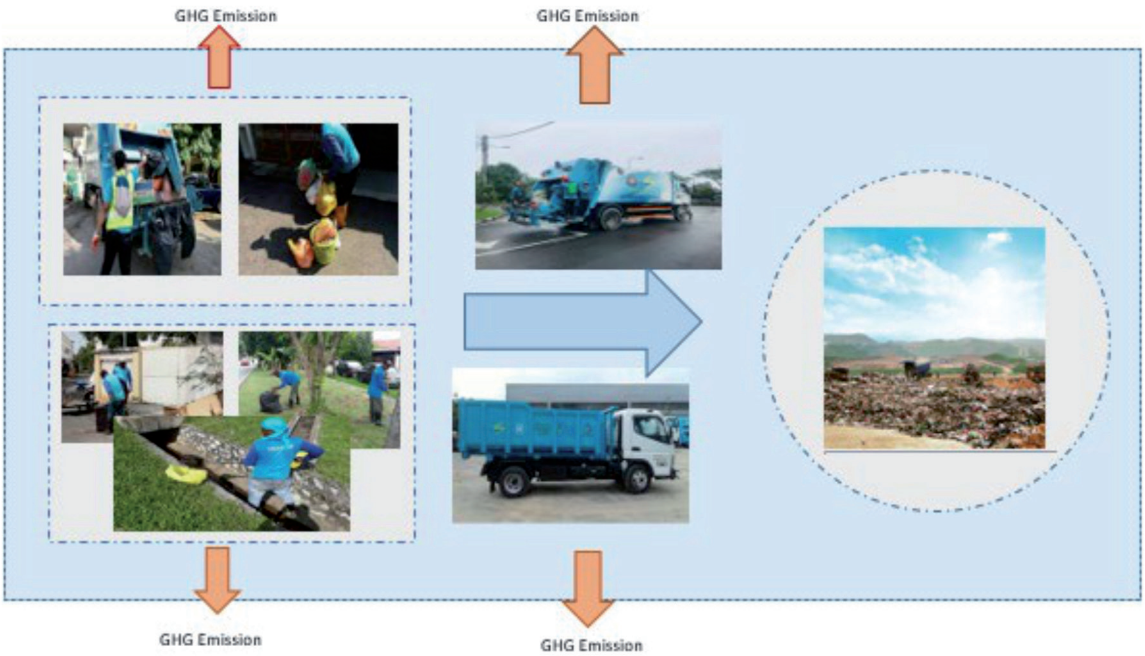

Fig. 2. Route of Data Collection based on the GHGs emissions.

Experimental Procedures

This section will outline the methods adopted for this research, including the collection of data and analysis.

Data Collection

The data used in this research is obtained from previous studies and from one of the SWM stakeholders in Selangor, KDEB Waste Management (KDEBWM). The route of GHG emissions analysis considered for the collection of data in this study is illustrated in Fig. 2. The processes and core parameters in SWM were determined from the previous studies, while Table 1 shows the data collected from both previous studies and KDEBWM, based on the identified processes and parameters.

Data Analysis

The data obtained were analyzed by implementing the Life Cycle Analysis (LCA) method, using OpenLCA

Table 1. Processes and its core parameters.

Processes in SWM	Core parameter
Waste generation	Waste composition [11]
Collection and Transport	– Number of trips (lorry) – Distance travelled by lorries – Volume of fuels use (Source:KDEBWM)
Disposal (landfill)	Waste tonnage (Source: KDEBWM)

software [10]. Fig. 3 shows the framework of the software. The GHG inventory in this study is established using the LCA model, OpenLCA. The model consists of the processes, flows, and product systems of solid waste management. It also consists of a related impact assessment database that will be a guide or tool for quantifying the end emissions. The selected impact assessment is downloaded from OpenLCA Nexus, the source for LCA data sets and databases. OpenLCA is a well-recognized and handling-friendly software application that enables the user to estimate all LCA steps. Another benefit of this application is that it allows users to interact with other databases, such as the GaBi database, which is a comprehensive life cycle assessment (LCA) database that contains information on the environmental impacts of a wide range of products and processes. It includes data on the energy and material inputs, emissions, and waste outputs associated with each stage of a product or process's life cycle, from raw material extraction to disposal or recycling. The GaBi database is widely used by businesses, governments, and researchers to assess the environmental impacts of products and processes and to inform decisions about sustainable design and resource management. It is continually updated and maintained by Thinkstep, a sustainability consulting firm, and is considered one of the most reliable and comprehensive LCA databases available. Open LCA was first intended to determine the environmental effects of items and processes, but now the economic aspect has been added. It does include some functionality to incorporate economic aspects. For example, Open LCA has features for calculating the life cycle cost of a product or process, which can be used to evaluate the economic impact of different design or process choices. Furthermore, it contains an up-to-date feature introduction to the software. A comprehensive range of relevant, consistent LCI and sustainable datasets are also available globally [15].

The software is needed to create the flows, processes, and product systems of the processes identified in SWM (waste generation, collection and transport, and landfill) that are used to assess in a new database or exported database. When using OpenLCA, it is essential to obtain inventory data for the full supply chains in order to undertake life-cycle evaluations of a given item or service. Due to the quantity of data needed to conduct a thorough supply chain LCA survey, collecting and organizing data on an entire background system without access to a background LCI database is very difficult [16].

This study uses the Ecoinvent database because the database provides completely interconnected process unit delivery chains for all goods contained in it. The Ecoinvent database consists of a large collection of data about the inputs, outputs, and environmental impacts of many different industrial processes and products. It helps people understand how these processes and products affect the environment and identify ways to make them more sustainable. It is widely used by researchers, industry professionals, and policymakers

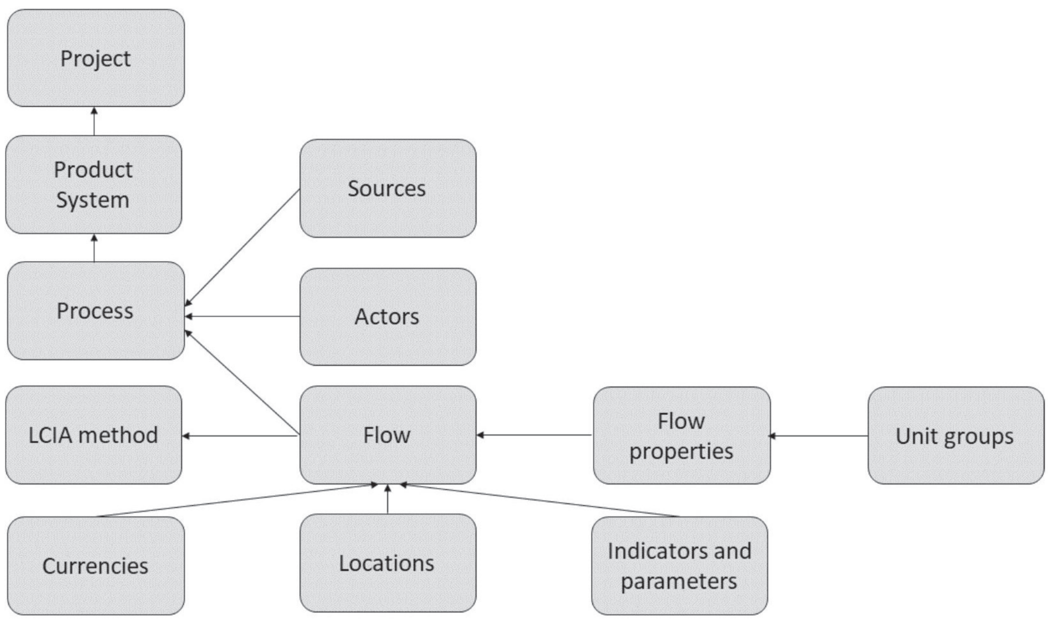

Fig. 3. OpenLCA framework (OpenLCA 1.7 user manual, 2017).

to make informed decisions. The data sets include all important environmental fluxes, such as the extraction of resources, land usage, and emissions, as well as all inputs and products of materials and energy from the activity. In the software input/output area for the specific foreground system, data obtained from KDEBWM is entered while using the background Ecoinvent [16].

Results and Discussion

In this study, the analyses are inclusive of: i) the GHG emission in the year 2020 based on field data; ii) emissions in 2015 and 2020 based on theoretical data; and iii) the GHG emissions from the three main processes (waste generation, collection and transport, and disposal) in SWM, whereby the highest emission among the processes is evaluated in this study, specifically focusing on the municipals in Selangor, Malaysia. Apart from that, the percentage of GHG emission reduction from 2015 to 2020 was also estimated. Estimating greenhouse gas emissions involves identifying the sources of emissions, collecting data to quantify the level of emissions, calculating the emissions using factors, verifying the results, and reporting the emissions data to relevant stakeholders. This process is complex and challenging, and several methods may be used depending on the circumstances.

GHG Emissions in 2020 Based on Field Data

The analysis of GHG emissions has been divided into two parts. In this first part of the analysis, GHG emissions are based on field data, in which only data from 2020 is used. The emissions data for 2020, which is obtained from KDEBWM, represent the emissions after solid waste management is managed by KDEBWM in the Selangor area. Fig. 4 shows the GHG emissions in 2020 for 11 municipalities in Selangor. Based on the figure, Subang Jaya City shows the highest carbon dioxide emissions, followed by Shah Alam City. This may be related to the high amount of waste generated in Subang Jaya city (refer to Fig. 3), which is the highest among all the other municipalities. According to [17], efforts to decrease municipal solid waste would significantly lower GHG emissions. With that being said, high waste generated could produce high emissions, which is in line with the results obtained in this field study.

Other than that, the number of populations can also affect the amount of GHG emitted into the air. The growth in population is directly increasing solid waste, and thus the waste increment contributed to the increase in greenhouse gas emissions. This finding is also in line with [18], which stated that waste rates increase as people expand every year due to unrestrained consumption, a spending mentality, and higher living standards.

GHG Emissions in 2015 and 2020 from Theoretical Data

The analysis of GHG emissions here is based on theoretical data for 2015 and 2020. The emissions in 2015 represent the emissions before KDEBWM took place on solid waste management in Selangor. The data used for this section are the population in 2015 and 2020 and the average waste per capita per day for each municipality. The number of populations is derived from a report on the National Strategic Plan for Solid Waste Management [19] and some from [13]. The estimated population for each municipality in 2015 and 2020 is shown in Table 2 and the location of each municipality is illustrated in Fig. 1. Fig. 5 illustrates the GHG emissions results between 2015 and 2020. Ampang Jaya, Kajang, and Subang Jaya cities show that GHG emissions are found

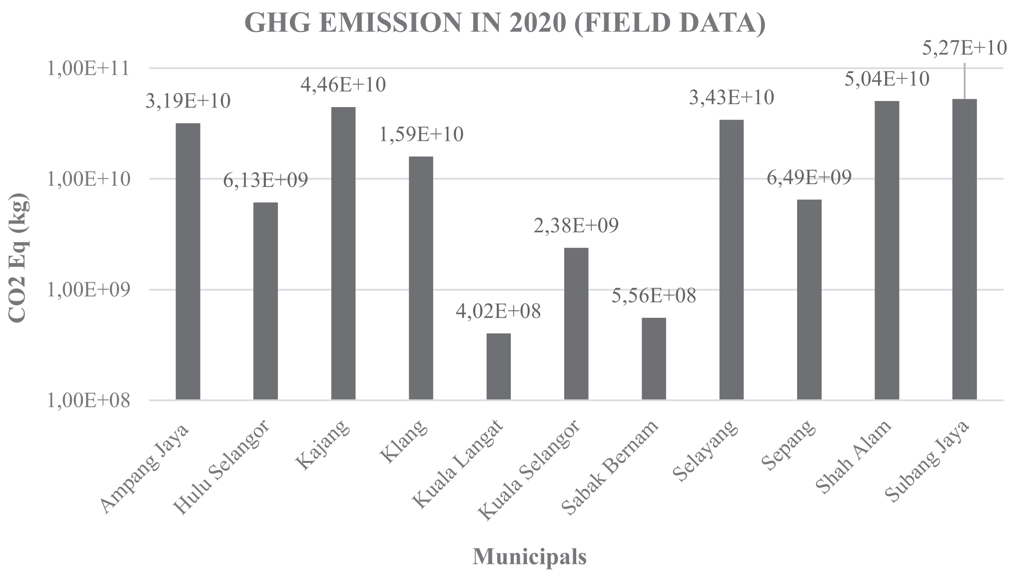

Fig. 4 The GHG emission in 2020 using field data.

Table 2. Population in 2015 and 2020 [12, 13].

DISTRICT	POPULATION	
	2015	2020
Ampang Jaya	675,253	800,000
Hulu Selangor	217,527	233,713
Kajang	810,000	1,584,000
Klang	945,516	1,015,234
Kuala Langat	223,830	323,400
Kuala Selangor	228,443	245,825
Sabak Bernam	97,407	150,000
Selayang	815,403	876,405
Sepang	254,828	274,729
Shah Alam	587,481	632,638
Subang Jaya	423,338	708,296

to have increased from 2015 to 2020. Factors that could lead to an increase in emissions by 2020 for the three municipalities are mainly due to the population numbers and high Gross Domestic Product (GDP). Even though Ampang Jaya's population is less dense than Kajang, Klang, and Selayang cities, significant solid waste output might be linked to economic and commercial activities for urban growth in the region [20]. The reduction that occurred for the rest of the municipalities may be related to the improvement in solid waste management by KDEBWM. [21] stated that KDEBWM is effectively managing solid waste in Selayang City with a reduction in the number of complaints.

The extensive technology and proper management deployed by KDEBWM could be a primary driver of the reduction in greenhouse gas emissions. KDEB employs compact refuse waste trucks completely equipped with GPS trackers for simple tracking of vehicles and improved waste collection planning (Closed-Circuit TV). In each compactor lorry, a rear camera is fitted to ensure safety, while automatic graying systems for car maintenance and avoidance of surveillance are implemented. In addition, rates of recycling and composting also cause reductions in GHG emission from solid waste management. In 2020, the recycling rate increased to 28.1% [13].

GHG Emission for each SWM Process

The GHG emissions of every process involved in solid waste management have been determined using OpenLCA software. The results of the emissions of waste generation, collection and transport, and disposal (landfill) are shown in Fig. 6, 7 and 8, respectively. For each of the processes, the greenhouse gases calculated are carbon dioxide, methane, and nitrous oxide. All of these gases are then combined into carbon dioxide equivalents (CO_2 Eq), whereby each gas is multiplied by its value of Global Warming Potential (GWP).

Comparing the three processes, the second process (collection and transport) produces the highest greenhouse gas emissions, followed by the third process (waste disposal), and lastly, the first process (generation of waste). These findings are also supported by a study conducted by [22], which found that the transportation sector generates the largest share of greenhouse gas emissions. However, there are also a few studies from other researchers that have found that landfills produce the highest emissions among the processes in SWM. The study in [23] proves that the highest amount of GHG can be found at the disposal stage, of which a total of 1.64 ppm CO_2 Eq was generated, whereby only methane gas was considered. That amount is in the range of the GHG emission obtained in this study for the disposal stage (0.024 ppm to 2.29 ppm CO_2 Eq). In this study, CO_2, CH_4, and N_2O gasses were considered in waste generation, collection and transportation,

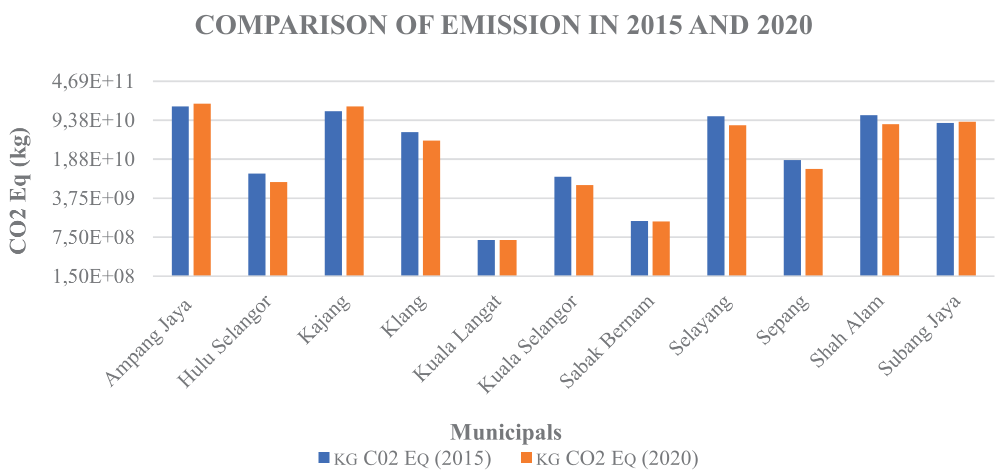

Fig. 5. GHG emission in 2015 and 2020.

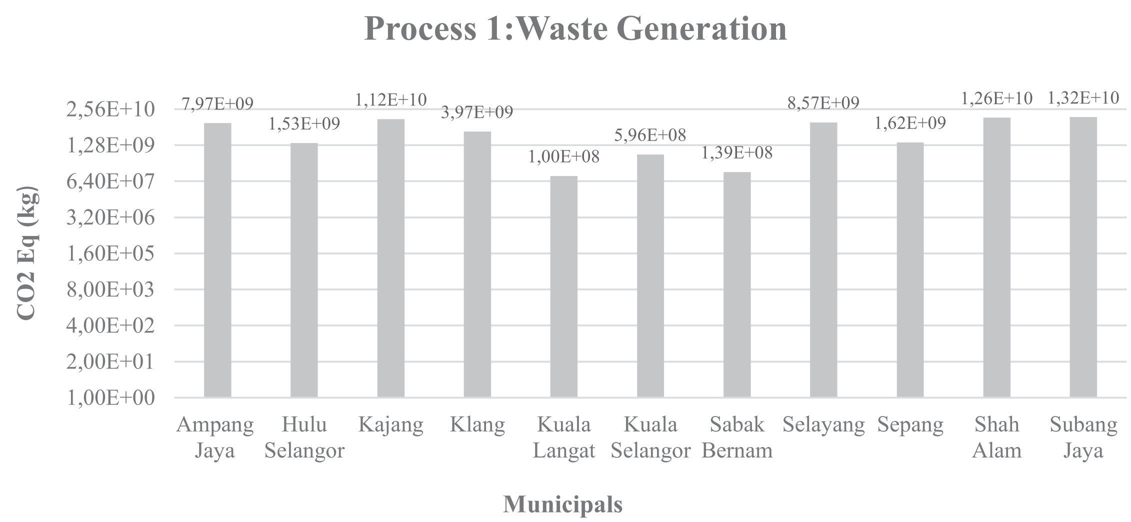

Fig. 6. GHG emission from Process 1.

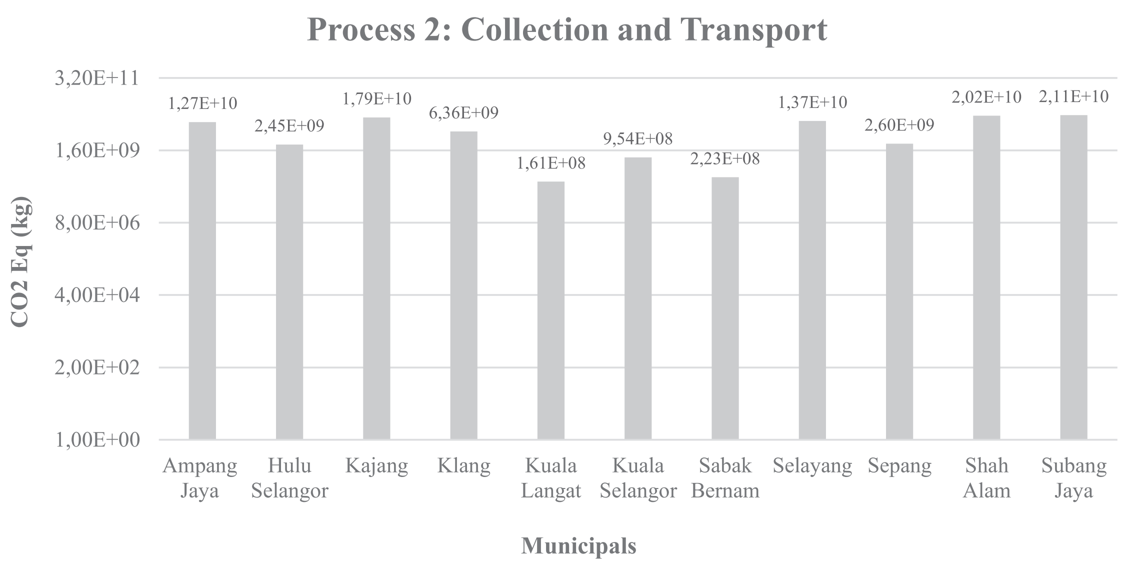

Fig. 7. GHG emission in Process 2.

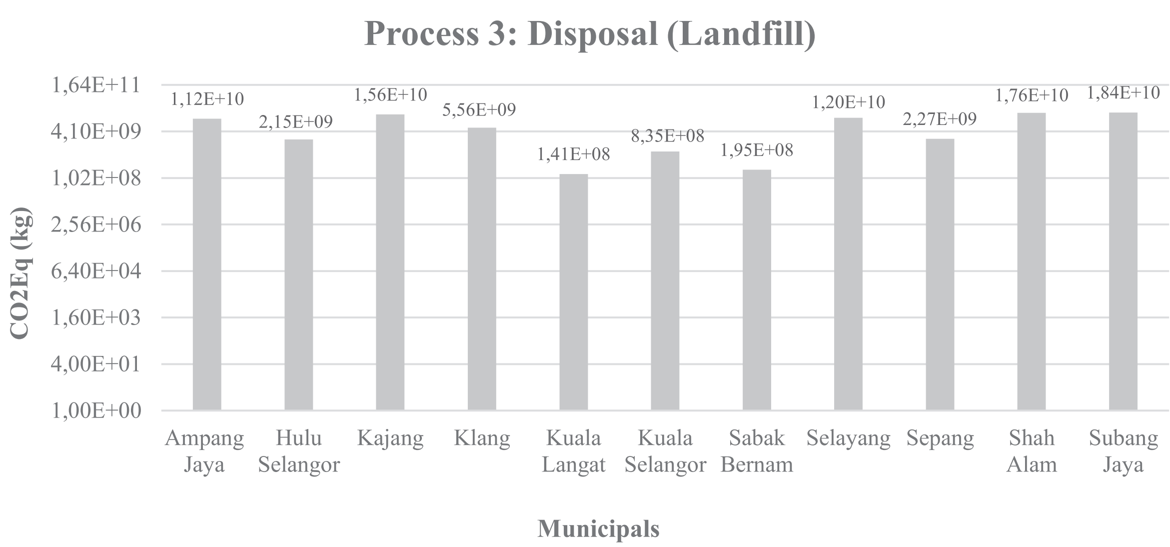

Fig. 8. GHG emission in Process 3.

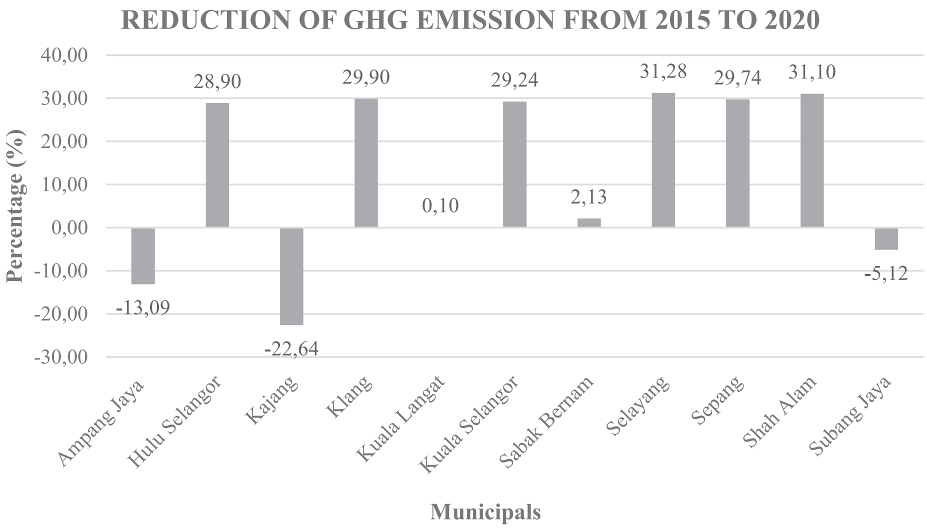

Fig. 9. Reduction of GHG emission from 2015 to 2020.

and landfills. The differences in gas consideration might be a factor contributing to the different findings from the other researchers. In addition, [24] revealed that the GHG emissions from collection and transport were the smallest, while landfills were the highest emitters when compared with incineration and composting. In different scenarios of SWM by other studies, the results of GHG emissions vary from one another. A study by [23] presents waste prevention strategies through SOW (Source-Separated Organic Waste) composting, a diversion from disposal to create climate change benefits. In that case study, the GHG emission from a Baseline scenario (100% landfilled) and Scenario 1 (22% organic waste composted) were compared. It was found that the Baseline scenario and Scenario 1 achieved total CO_2 emissions of 1,636.18 and 1,399.52, respectively. This verifies that the GHG emission can be reduced by including initiatives such as composting and recycling in the SWM.

Reduction of GHG Emission from 2015-2020

The reduction of GHG emission from 2015 to 2020 is based on the collected theoretical data. The results that are illustrated in Fig. 5 indicate a high increment in emissions in 2020 compared to 2015 for the Kajang area and a number of negative reductions, followed by Ampang Jaya and Subang Jaya cities. These negative reductions could be related to the increase in populations in the respective municipal city and the distance to the landfill, which contributed to high emissions for the collection and transportation phases.

Fig. 9 also shows that the Selayang area had the highest reduction of greenhouse gas emissions, followed by the Shah Alam area. This result is in line with the current management of solid waste in these areas. Initiatives such as low-carbon building, shifting in transportation modes, landscape waste composting, recycling campaigns, green transport infrastructure, landscape competitions, and more are done by the Shah Alam City Council. Additionally, the Shah Alam City Council aimed to reduce GHG with a minimum 3% yearly target from 2015 to 2019, with the final mission of achieving a national carbon reduction of 45% by 2030. The reduction of GHGs emission in Klang (29.9%) indicates that the city council's efforts in dealing with carbon emissions have been worth the time and cost. The Klang City Council implemented green programs such as a green data center, building an energy efficiency campaign, rainwater harvesting, composting, and tree planting. These data centers utilize various technologies and strategies to reduce energy consumption, minimize carbon footprints, and decrease waste generation. Moreover, five local councils in Selangor had been selected to adopt a Low Carbon City Framework (LCCF) by 2017, in line with the state's vision to ensure Selangor takes the lead in low-carbon city initiatives. The five selected councils were the Petaling Jaya City Council (MBPJ), Shah Alam City Council (MBSA), Subang Jaya Municipal Council (MPSJ), Klang Municipal Council (MPK), and the Sepang Municipal Council. According to [25], the selected low-carbon zones need to reduce GHG emissions through efforts in energy and water efficiency, low carbon mobility, waste reduction in landfills, and increased green spaces. This finding supports the percentage reductions obtained for the Klang, Shah Alam, and Sepang municipalities.

Conclusions

This study has established an inventory of GHG emissions for waste management in Selangor by identifying the specific processes involved in waste management that contributed to GHG emissions. In every process, the core parameter involved is determined to obtain data for the calculation stage of the GHG emissions. The core parameter for the waste generation process is waste composition, whereas, for the collection and transport process, the parameters include the volume of fuel, the distance traveled by truck, and the number of trips, and lastly, for landfills and waste tonnage. The GHG emissions for all municipalities in Selangor have been quantified by implementing a life cycle assessment (LCA) method using OpenLCA.

It has been found that the collection and transport processes emit the highest CO_2 Eq emissions compared to waste generation and disposal processes. This result is also supported by the findings from [26], whereby the GHG emissions from source-segregated and partially co-mingled municipal solid waste were evaluated. The transportation process is revealed to emit the most tons of CO_2 Eq, at nearly 15,000, as compared to intermediate facilities, residual treatments, direct landfills, recycling, and organic treatments in that study. However, most studies show the opposite results, with landfills as the highest CO_2 Eq emitters. The GHG model used in this study (OpenLCA) is operated based on databases available online in accordance with international standards, commonly the European standard. Hence, the results obtained are based on broad estimations.

The reduction of GHG emissions from 2015 to 2020 in Selangor shows CO_2 Eq savings for 8 of the municipalities, while the other 3 show no reduction. Alternatives towards achieving low-carbon city status via the implementation of green activities include tree planting, recycling, and composting [27], all of which have contributed to CO_2 Eq savings. There are also extensive initiatives related to low-carbon cities conducted in other cities (Kajang, Ampang Jaya, and Subang Jaya) that have negative reductions in GHGs. However, the negative reductions are probably due to factors such as the distance to the landfill from cities, which may increase the GHGs emission for that particular area.

In selecting a model for measuring GHGs from solid waste management, a few considerations are needed. It is crucial to determine the availability and quality of data, the purpose behind quantification, and the acceptance and applicability of model assumptions or inputs. Standardizing the method for quantifying the emissions for all the municipalities or cities is also important for making accurate comparisons and further analysis and decision-making.

The most suitable instruments for successfully targeting major emission sources along the route to a low-carbon future can be selected through a more comprehensive study of various quantification methodologies for municipal emissions. Further studies using sophisticated carbon footprint calculators would benefit from the data obtained.

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Conflict of Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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