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Assessment of greenhouse gas emissions from waste management in the shopping center: A case study of the Central Plaza Rattanathibet, Thailand

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ABSTRACT

Human activities contribute significantly to anthropogenic greenhouse gas (GHG) emissions, including waste management in shopping centers.This research aimed to investigate the waste composition and evaluate the GHG emissions associated with waste management in the Central Plaza Rattanathibet, Thailand. The study compared the Busines-as Usual waste management practices (Scenario 1: BAU) with a Zero Waste management approach (Scenario 2: ZW). In scenario 1: BAU, waste management solely relied on landfilling, whereas the ZW scenario in corporated four distinct waste management approaches: landfilling, composting, refuse-derived fuel (RDF 5), and recycling. The findings revealed that the shopping center generated1,967.47 tonnes of waste/ year in 2022. The waste composition was analyzed using the quartering method, and the five most prevalent types of waste were identified as food waste (39.28%), other waste (24.63%), plastic waste (15.52%), paper and board (10.48%), and glass (5.45%). Using the 2006 IPCC Guidelines for Greenhouse Gas National Inventories, BAU Scenario relied solely on landfilling for waste management, resulting in GHG emissions of 999.93 tonne CO_2eq/tonne of waste. In contrast,

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the ZW scenario in corporated four distinct waste management approaches: landfilling, composting, refuse-derived fuel (RDF 5), and recycling, which resulted in GHG emissions of -599.54 tonne CO_2eq/tonne of waste. This negative value indicates that the waste management practices in the ZW scenario resulted in a net reduction of GHG emissions compared to the BAU scenario. This reduction was achieved through the implementation of waste management practices such as RDF 5, composting, and recycling, which directly reduced GHG emissions in the ZW scenario.Additional, encouraging customers and staff to sort waste in the shopping center improves waste management. The GHG emissions data from this study are valuable for policymakers in the Nonthaburi municipality to address climate change and implement mitigation measures.

Keywords: Assessment; Greenhouse gas emissions; Municipal solid waste; Shopping center; Nonthaburi municipality

Introduction

Climate change is a global challenge with significant environmental consequences, including wildfires, water scarcity, droughts, rising sea levels, floods, melting polar ice, storms, and biodiversity loss [1]. Global warming, a component of climate change, is caused by increased levels of greenhouse gases (GHG) such as CO_2, NO_2, and CH_4. These elevated GHG levels disrupt the Earth's atmospheric balance, trapping heat and resulting in adverse effects [2]. Based on Thailand's Fourth National Communication report, the country recorded a total GHG emission of 372,648.77 GgCO_2eq in 2018. Notably, the energy sector emerged as the primary contributor to Thailand's GHG emissions, accounting for 257,340.89 GgCO_2eq (69.06%). This sector was followed by the agriculture forestry and other land use (AFOLU), industrial processes and product use (IPPU), and waste sector, which contributed 58,486.02 GgCO_2eq (15.69%), 40,118.18 GgCO_2eq (10.77%), and 16,703.68 GgCO_2eq (4.48%), respectively [3]. Currently, solid waste management is a big problem in Thailand. Due to the continuous development of the economy and the expansion of the urban community, resulting in an increasing amount of solid waste.From the assessment of the amount of solid waste in Thailand in 2018, it was found that there was about 27.80 million tonnes of solid waste or about 74,998 tonnes/day [4].Thailand currently has 70 landfill waste disposal sites and 1,707 dump sites [5]. Solid waste management through landfilling entails an anaerobic organic waste composting process and gas generation within the landfills. Therefore, waste management is one of the activities that is also an important variable in greenhouse gas emissions, no less than other aspects.One type of waste that can cause significant greenhouse gas emissions both globally and in Thailand is organic waste, particularly food waste. According to the Food and Agriculture Organization (FAO) of the United Nations, around one-third of all food produced for human consumption is wasted, and this contributes to approximately 8% of global greenhouse gas emissions.In Thailand, food waste is also a pressing issue. The improper disposal of food waste in landfills without proper waste management practices can lead to substantial methane emissions, adding to the country's overall greenhouse gas footprint [6].

Shopping centers are hubs for consumption, leisure, and entertainment, making them significant waste generators. Central Plaza Rattanathibet, in Nonthaburi Province, Thailand, is a sizable shopping center covering an expansive retail and rental area of 105,000 square meter and 77,008 squaremeter, respectively [7]. Effective waste management in the shopping center becomes crucial to prevent improper disposal, which could lead to the emission of GHG and contribute to climate change. The responsibility for waste management at Central Plaza Rattanathibet lies with in the Nonthaburi municipality. Thus, waste management in the shopping center is an essential source of GHG emissions, which requires attention in GHG emission reduction policies. Furthermore, optimizing waste management practices in this shopping center would pave the way for improved waste management overall, ensuring that all types of waste are appropriately handled and reach their intended destinations. Good waste management practices can have significant benefits in reducing GHG emissions, particularly methane emissions, which play a critical role in climate change. On the other hand, poor waste management can lead to increased GHG emissions, contributing to global warming.

This research aimed to analyze the waste composition and estimate the amount of GHG emissions from the community wasteof Central Plaza Rattanathibet. In addition, it is expected that the results of this assessmentwould demonstrate opportunities, guidelines and lesson learned in connection toGHG emissions reduction for Nonthaburi Municipality and agencies involved in waste management.

Methodology

1. Case study description

Central Plaza Rattanathibetis a large shopping center in Mueang Nonthaburi District, Nonthaburi province(13.86654° N, 100.49721° E), a highly urbanized province with roughly a million population. The gathering of many people creates a multitude of activities that can lead to environmental problems, particularly issues related to waste management. To illustrate, it has approximately 1,122.34 tonnes of solid waste/day, which the local government agency collects and transports, but private companies employ some areas to operate [8]. This shopping center is also the outstanding department store of the province and has waste management under the responsibility of Nonthaburi municipality. It has a total retail area of 105,000 square meters and a rental area of 77,008 square meters[7]. Moreover, this shopping center is a multi-activity mall that contributes significantly to waste generation. The shopping center consists of Robinson department stores, Index Living Mall, OfficeMate, BnB home, cinemas, and retail stores.

2. Sampling of waste composition

The quartering method is used in solid waste management to obtain representative samples from a larger waste stream. It involves dividing the waste material into quarters, typically by physically segregating it into four equal parts.

A large sample of waste is initially collected to perform the quartering method. This sample is then spread into a flat heap or placed in a designated container. From there, the waste is divided into four equal sections by drawing two perpendicular lines or physically separating it into four smaller piles. Two opposite quarters are discarded; the remaining two are combined and mixed thoroughly to create a composite sample [9]. In this study, we studied the total waste composition for 7 days so that the study covered the waste composition that occurred both weekdays and weekends.

The primary objective of employing the quartering method is to ensure that the composite sample obtained accurately reflects the characteristics and composition of the entire waste stream. This sampling technique is commonly employed in waste analysis and characterization studies, where representative samples are crucial for further analysis and decision-making about waste management practices.

3. GHG Emission Estimation

The concept of baseline emissions in this research refers to the initial or existing level of greenhouse gas (GHG) emissions associated with waste management practices in a specific setting, such as a shopping mall. It represents the emissions that would occur without any specific mitigation measures or interventions to reduce GHG emissions from waste management.

The mitigation aspect of this research involves evaluating the impact of implementing different waste management approaches (composting, refuse-derived fuel, and recycling) compared to the baseline scenario of landfilling alone. The study aims to measure how these waste management practices influence the reduction or avoidance of GHG emissions. By comparing the emissions under the baseline scenario (landfilling) with emissions under the different waste management approaches, the research assesses the effectiveness of each strategy in mitigating GHG emissions and contributing to climate change mitigation efforts. To demonstrate, composting with a biodigester produces compost and fermented water, serving as a soil enhancer. Additionally, single-use plastic/textileand wood waste can be processed to create refuse-derived fuel 5 (RDF 5). RDF 5 is a fuel made from non-recyclable waste, and it can be used as an alternative to fossil fuels in certain industries, such as cement manufacturing.The RDF 5 is utilized in a cement factory located in Saraburi province. Moreover, the process involves segregating recyclable waste from general waste, enabling the recycling of materials as substitutes for raw materials.

This research used the IPCC 2006 guidelines to quantify greenhouse gas emissions from waste management [10]. The equations and schemes employed in the model, including those relevant to the present study, are described in the following section.

3.1 Transportation

The calculation of the GHG of waste management included the transportation of waste to landfill. We calculated the amount of carbon dioxide emissions from the combustion of fuels used in waste transportation using the following equation:

$$Emissions_T = Fuel\ (Unit)/Waste\ (tonnes) \times Energy\ (MJ\ /unit) \times EF\ (kgCO_2/MJ) \quad (1)$$

Where $Emissions_T$ is emissions from transportation ($kgCO_2$/tonne of waste transported); Fuel is the amount of fossil fuel consumed in transportation (Liters); Waste is the amount of MSW transported (tonne of MSW); Energy is the energy content in of fossil fuel(MJ /unit); EF is the emission factor of fossil fuels ($kgCO_2$/MJ).

3.2 Landfilling

GHG emissions from MSW landfills were calculated from the First Order Decay (FOD) equation when the amount of biodegradable organic carbon accumulated in landfills and the latest year of waste are known. Moreover, we calculated GHG emissions from MSW landfills only for methane (CH4) emissions, which are caused by the decomposition of organic waste in landfills under anaerobic conditions.

The equations used to calculate first-order decay methane emissions according to the 2006 IPCC Guidelines are shown in Equations 2 to 6.

1) The amount of biodegradable organic carbon in solid waste at the disposal site (SWDS) in year T

$$DDOC_{mdT} = W \times DOC_x \times DOC_f \times MCF \quad (2)$$

Where $DDOC_{mdT}$ is the mass of decomposable DOC deposited(Gg); W is the mass of waste deposited (Gg); DOC_x is degradable organic carbon in the year of deposition; DOC_f is the fraction of DOC that can decompose (IPCC recommendation value is 0.5); MCF is CH_4 correction factor for aerobic decomposition in the year of deposition; T is inventory year.

2) The amount of biodegradable organic carbon (but not degraded) accumulated in the disposal area at the end of year T

$$DDOC_{maT} = DDOC_{mdT} + (DDOC_{maT-1} \times e^{-k}) \quad (3)$$

Where $DDOC_{maT}$ is the mass of decomposable; DOC accumulated in the SWDS at the end of year T (Gg), $DDOC_{mdT}$ is the mass of decomposable; DOC deposited into the SWDS in year T (Gg), $DDOC_{maT-1}$ is the mass of decomposable; DOC accumulated in the SWDS at the end of the year (T-1) (Gg); k is reaction constant, $k = \ln(2)/t_{1/2}$ (y^{-1}); $t_{1/2}$ is half-life time (y); T is inventory year.

3) The amount of biodegradable organic carbon and methane in year T

$$DDOC_{decompT} = DDOC_{maT-1} \times (1 - e^{-k}) \quad (4)$$

Where $DDOC_{decompT}$ is the mass of decomposable DOC decomposed in the SWDS in year *T* (Gg); $DDOC_{maT-1}$ is the mass of decomposable; DOC accumulated in the SWDS at the end of the year (*T*-1) (Gg); k is reaction constant, $k = \ln(2)/t_{1/2}$ (y^{-1}); $t_{1/2}$ is half-life time (y)

4) The amount of methane produced by the reduction decomposition of organic carbon

$$CH_{4\ generated\ T} = DDOC_{decomp\ T} \times F \times \frac{16}{12} \quad (5)$$

Where $CH_{4\ generated\ T}$ is the amount of CH4 generated from decomposable material; $DDOC_{decompT}$ is the mass of decomposable DOC decomposed in the SWDS in year T (Gg); F is the fraction of CH_4in generated landfill gas (volume fraction); 16/12 is molecular weight ratio CH_4/C (ratio).

5) The amount of methane gas released from waste disposal sites

$$CH_{4\ Emission\ T} = [\Sigma_X CH_{4\ generated\ x,T} - R_T] \times (1 - OX_T) \quad (6)$$

Where $CH_{4Emissions}$ is CH_4emitted in year T (Gg); T is inventory year, x is the waste category or type/material; R_T is recovered CH_4in year T (Gg); $OX_T$is oxidation factor in year T (fraction).

3.3 Recycling

In the case of the shopping center, GHG emissions from the recycling activities were estimated using the following equation:

$$Emissions_{Recycling} = (FC \times NCV_{FF} \times EF_{CO2}) + (EC \times FE_{el}) \quad (7)$$

Where $Emissions_{Recycling}$is the emissions of GHG from recycling (tonne CO_{2eq}/tonne of recyclables waste); FCis the fuel consumption apportioned to the activity type (mass or volume/tonne of recyclables waste); $NCV_{FF}$is the net calorific value of the fossil fuel consumed (MJ/unit); $EF_{CO_2}$is the emission factor of CO2 by combustion of fossil fuel (kg CO_2/MJ); ECis the electricity consumption for operation activities (MWh/tonne of recyclables); EF_{el} is the emission factor of country grid electricity production (kg CO_2/MWh).

3.4 Refuse Derived Fuel (RDF 5)

$$Emissions_{RDF} = (FC \times NCV_{FF} \times EF_{CO2}) + (EC \times EF_{el}) \quad (8)$$

Where $Emissions_{RDF}$ is greenhouse gas emissions from RDF production (tonne CO_{2eq}/tonne of MSW); FCis the fuel consumption apportioned to the activity type (mass or volume/tonne of MSW); NCV_{FF} is the net calorific value of the fossil fuel consumed (MJ/unit mass or volume); EF_{CO2} is the emission factor of CO_2 by combustion of fossil fuel (kg CO_2/MJ); EC is the electricity consumption for operation activities (MWh/tonne of MSW); EF_{el} is the emission factor of country grid electricity production (kg CO_2/MWh).

3.5 Composting

$$Emissions_{Composting} = E_{CH4} \times GWP_{CH4} + E_{N2O} \times GWP_{N2O} \quad (9)$$

Where $Emissions_{Composting}$ is the emission of greenhouse gases from the decomposition of organic waste (tonne CO_{2eq}/tonne of organic waste); E_{CH4} is the methane emission from the decomposition of organic waste (kg CH_4/tonne of organic waste); GWP_{CH4} is the global warming potential of methane; E_{N2O} is the emission of nitrous oxide from the decomposition of organic waste (kg N_2O/tonne of organic waste); GWP_{N2O} is the global warming potential.

Results and Discussion

1.Waste composition analysis

1.1 Scenario 1: Busines-as-Usual (BAU)

This study only studied the composition of municipal solid waste (MSW). According to the Pollution Control Department's definition of MSW, it means solid waste generated from activities in the community, such as houses, businesses, shops, establishments, bazaars, and institutions, including construction waste, excluding hazardous waste and infectious waste [11].The main composition of the MSW in scenario 1, which is the current waste management of Central Plaza Rattanathibet, is represented in Table 1. Food waste is the largest component of the shopping center waste, accounting for 39.28% by weight- followed by others at24.63%; plastic waste 15.52%; paper and board 10.48%; glass 5.45%; textile 2.70%; wood 1.02%; and metal and aluminum 0.92%. This study is consistent with Pluemchingchai's report in 2019, which surveyed waste composition in shopping centers in Nakhon Ratchasima Province. It found that food waste constituted the highest proportion at 40.93%, followed by other waste at 26.34%, and plastic at 19.04% [12]. The proportion of waste generated in the top three shopping centers in Nakhon Ratchasima Province was similar to Central Plaza Rattanathibet. The high proportion of food waste was due to the presence of fresh food sales departments and open spaces rented to restaurants in the two case study buildings.The amount and rate of MSW generation in Central Plaza Rattanathibet depend on the type of activity in the shopping center and the number of people in the shopping center, including employees, customers and vendors. The survey result in Central Plaza Rattanathibet showed that quantities of MSW generated were estimated to be 1967.44 tonne/year, and the density was 449 kg/m^3. Moreover, the detailed composition of the MSW from the shopping center is shown in Table 1.

The statistics show that more than 30% of scenario 1 waste sample from the shopping center is food waste which is biodegradable, as 772.85 tonne/year. Most food waste from food courts,restaurants and flea markets in shopping centres significantly influences food waste.

The most prevalent waste compositions identified were food waste, other waste, and plastic waste. To demenstrate, food waste mainly consisted of fruit peels, eggshells, vegetable scraps from cooking, and leftovers from meals. Other waste primarily comprised toilet tissue waste, resulting from numerous users in service facilities and shopping centres, leading to significant bathroom waste generation. Additionally, due to the absence of waste sorting, all types of waste were indiscriminately thrown together, resulting in a considerable amount of this particular waste category. Regarding plastic waste, it predominantly included plastic drinking bottles and cups obtained from coffee shops and water vendors in the food court.

Table 1 Waste composition (%mass/wet basis) of solid waste in scenario 1 from Central Plaza Rattanathibet

Fraction	Proportion (%w/w)	Amount of waste (tonne/year)
Food waste	39.28	772.85
Gardening waste	-	-
Paper and board	10.48	206.20
Wood	1.02	20.00
Textile	2.70	53.09
Rubber and leather	-	-
Diaper	-	-
Plastic	15.52	305.37
Metal and aluminum	0.92	18.11
Glass	5.45	107.18
Others	24.63	484.64
Total	100	1,967.44

1.2 Scenario 2: Zero Waste

The survey and analysis results in scenario 1 were re-categorized into 4 types of waste, classified as scenario 2, in which waste is categorized according to its handling characteristics. These categories are food, recyclable, single-use plastic/textile and wood, and general waste. The proportion and amount of wastein scenario 2 is shown in Table 2.

By grouping waste based on how it is managed, the study found that food waste accounted for 39.28% of the total waste and consisted of cooked food and raw materials used in cooking. Recyclable waste, including bottled plastic, aluminum, and glass, accounted for 19.16% of the total waste and can be sold to recyclers for further recycling. Single-use plastic/textile and wood accounted for 16.92% of the waste, which the Nonthaburi Municipality classified as orphan waste and would be managed by incineration as fuel or Refuel derived fuel 5 (RDF 5). Finally, 24.63% of toilet waste would be sent to landfill as general waste. In general, the analysis of the composition of samples taken from this shopping center indicates that the characteristics of the samples are similar to those found in MSW from urban areas [11].

Table 2 Waste composition (%mass/wet basis) of solid waste in scenario 2 from Central Plaza Rattanathibet

Type of waste	Proportion (%w/w)	Amount of waste (tonne/year)
Food waste	39.28	772.85
Recycle waste	19.16	376.99
Single-use plastic/textile and wood	16.92	332.96
General waste	24.63	484.64
Total	100	1,967.44

2.Greenhouse gas emissions

Waste management in shopping center can be a significant source of GHG emissions. At present, the waste management of Central Plaza Rattanathibet is operated by the Nonthaburi City Municipality, which is sent to the waste landfill at Sai Noi Subdistrict, Sai Noi District, Nonthaburi Province. Management in this way will release GHG into the environment, so to find a suitable way to manage the waste of the department store sustainably. Therefore, the waste management situation is simulated into 2 scenarios to estimate the GHG emissions from such scenarios.

2.1 Scenario 1: Business-as-Usual (BAU)

In most cities worldwide, landfilling is the prevailing approach to handling MSW. This method entails depositing the waste in designated lower-elevation areas, where it naturally decomposes without regulated control [13]. Consequently, this process leads to the emission of greenhouse gases, primarily methane (CH_4). The IPCC (2006) guideline promotes the adoption of the first-order decay (FOD) technique to obtain more precise estimations of emissions that reflect the natural degradation of waste within the landfill site [10].

From the study of GHG of Scenario 1, which is the current business as usual waste management of the shopping center that does not have waste sorting, all waste is managed by being sent to landfill at Sai Noi landfill, Nonthaburi province. The distance from the shopping center to the waste collection point and transportation to the landfill is 40 kilometers .The emissions of GHG from sanitary landfills include both the decomposition process and operational activities. Approximately 1,967.44 tonnes of mixed MSW from this shopping center are landfilled annually. The decomposition of the disposed MSW resulted in the production of approximately 35.68 tonnes CH_4/tonne of waste landfilled. By converting the estimated CH_4 emissions to GHG equivalent, the total emissions from the decomposition of landfilled MSW were approximately 999.04 tonnes CO_2eq/tonne of MSW. According to the report of Nonthaburi

Municipality and Nonthaburi Provincial Administrative Organization in 2021 [14], a total of 16 vehicles were used, including 1 waste truck, 4 dozers, 1 landfill compactor, 4 backhoes, 1 motor grader, 1 water truck, and 4 dump trucks. Most of these trucks use diesel fuel and normally consume about 647,265.45 liters of diesel/year and transport 1,967.44 tonne of MSW landfilled/year. In this shopping center, using equation (1), the estimated greenhouse gas emissions from transported waste is 0.89 tonne CO_2eq/ tonne of MSW.Consequently, the estimated total GHG emissions contributedby this shopping center amounted to 999.93 tonne CO_2eq/tonne of MSW landfilled, as presented in Table 3.This section showed that the decomposition in the landfill produced more greenhouse gas emissions than operational activities, accounting for 1,965,551.26tonnes CO_2eq/year and 1,751.02tonnes CO_2eq/year. Therefore, the year's GHG emissions from landfills amounted to 1,967,302.28 tonnes CO_2eq/year.

2.2 Scenario 2: Zero Waste

This scenario represents a simulated waste management system implemented at Central Plaza Rattanathibet. The objective is to encourage individuals to segregate their waste and provide the shopping center with dedicated bins for various waste types. Each segregated waste category undergoes appropriate handling methods. For instance, food waste is converted into compost, while recyclable waste is processed for reuse as a substitute for new materials. Single-use plastic/textiles, and wood are transformed into briquettes called Refuse Derived Fuel (RDF-5). The remaining waste is disposed of in landfills. It's important to note that each waste management approach generates varying amounts of GHG emissions due to their distinct activities.

Table 3 Estimates of GHG emissions from landfill activities in Central Plaza Rattanathibet

At the Sanitary Landfill (Decomposition)		
Activities	Quantity	Unit
Total mix waste disposal at the landfill sites	1,967.44	tonnes/year
tonne of CH_4 /tonne	35.68	tonne of CH_4 /tonne
Global Warming Potential [15]	28.00	
GHG emission from landfilling	999.04	tonne CO_2eq /tonne of waste
At the Sanitary Landfill (Operational Activities)		
Diesel consumption for operating machinery at the landfill	647,265.45	Liters/year
A diesel requirement	328.99	Liters/tonne of waste
The total energy consumed by diesel	11,981.76	MJ/tonne of waste
Default CO_2 emission factor for combustion[16]	74,100	kg CO_2 /TJ
GHG emissions due to fossil fuel consumption	0.89	tonne CO_2eq/tonne of waste
Total GHG emissions from sanitary landfill sites	999.93	tonne CO_2eq/tonne of waste

2.2.1 GHG Emissions from Composting

Composting with a biodigester produces compost and biofertilizer, which is a soil improvement agent. The total amount of food waste used for the composting was 772.85 tonnes/year, and the amount of fossil fuel (i.e., diesel) used for the operation of the composition facility was 3,193.75 Liters/year. In addition, the amount of compost produced was 618.24 tonnes/year. The GHG emissions from the operational activities and the estimated value of 1.46 tonne CO_2eq/tonne of waste were calculated. Whereas GHG emitted during the degradation of organic waste was 148.00 tonnes CO_2eq/tonne of waste. Adding the estimated emissions of GHG from the operational activities and the degradation process, the total estimated GHG emissions from the composting system was 149.46 tonnes CO_2eq/tonne of waste. Therefore, greenhouse gas emissions from composting throughout the year accounted for 115,510.16tonnes CO_2eq/year.

Table 4 GHG emission estimates from composting activities

Activities	Quantity	Unit
The total amount of food waste used for composting	772.85	tonne/year
The total amount of fossil fuel used for operational activities	3,193.75	Liters/year
The total amount of compost production and biofertilizer	618.24	tonne/year
GHG emissions from operational activities	1.46	tonne CO_2eq/ tonne of waste
GHG emissions from waste degradation	148.00	tonne CO_2eq/ tonne of waste
Direct GHG emissions from composting	149.46	tonne CO_2eq/ tonne of waste
Avoided GHG emissions from food waste landfilling	- 528.72	tonne CO_2eq/ tonne of waste
Net GHG emissions from composting	- 379.26	tonne CO_2eq/ tonne of organic waste

If the 772.85 tonnes of organic waste is subjected to sanitary landfill disposal instead of being composted annually, a substantial quantity of greenhouse gas (GHG) emissions arises from the decomposition of the organic waste within the landfills. The estimated GHG emissions were calculated to be 528.13 tonne CO_2eq/tonne of waste. In addition, GHG emissions from chemical fertilizers amounted to 0.59tonne CO_2eq/tonne of waste. However, by composting the 772.85 tonnes of food waste, the emissions of GHGs equivalent to 528.72 tonne CO_2eq /tonne of waste were avoidedfrom landfill and chemical fertilizer. Moreover, if compost is used instead of chemical fertilizers and can reduce landfill, the compost plant will prevent net GHG emissions (-) 379.26 tons CO_2eq/ton of waste, as shown in Table 4. Therefore, composting food waste can reduce greenhouse gases for the whole year, net (-) 293,111.09 tonne CO_2eq/year.

2.2.2 GHG Emissions from Recycling

Recycling presents numerous advantages and represents an environmentally responsible method of waste management. Recycling can recover valuable materials while mitigating the emission of significant amounts of greenhouse gases and harmful pollutants [17]. Therefore, incorporating recycling practices into a comprehensive waste management system is essential in our pursuit of sustainability and enhancing the system's overall efficiency.

Table 5 Quantity and proportion of each type of recyclable waste

Types of waste	Amount of waste (tonne/year)	Fraction (%)
Paper	206.20	54.70
Plastic	45.50	12.07
Aluminum	18.11	4.80
Glass	107.18	28.43
Total	376.99	100.00

Four categories of waste can be recycled at Central Plaza Rattanathibet: paper, plastic, metal and glass bottles. Each type is separated by type and quantity, as shown in Table 5. GHG emission estimates are based on the Menikpura (2011) GHG emission coefficient [18]. For paper, plastic, metal and glass bottles, GHG emissions were 692.50, 259.26, 18.86 and 161.77 kg CO_2eq/tonne of recycled waste. The recycling process is complex and involves energy consumption for sorting and transporting recyclable waste from its source to sorting facilities and recycling plants. As a result, these activities contribute significantly to releasing GHG. However, the materials recovered through recycling have the potential to substitute an equivalent amount of new materials, effectively mitigating substantial GHG emissions. At this shopping center, recycling 376.99 tonnes of MSW annually has avoided 1.82 tonnes CO_2eq/ton of recycled waste. By deducting the direct GHG emissions from the indirect savings achieved through emission avoidance, the net GHG emissions are estimated at (-) 686.84 tonne CO2eq/ton of waste. To illustrate, paper waste reduced greenhouse gas emissions the most by (-) 1.14 tonne CO_2eq/tonne of recycled waste, followed by aluminum (-) 0.58 tonne CO2eq/ tonne of recycled waste, Glass (-) 0.13 tonne CO_2eq/tonne of recycled waste and the least amount of plastic, 0.03 tonne CO_2eq/tonne of recycled waste. The negative values signify a reduction in GHG emissions as a direct outcome of the MSW recycling process.

2.2.3 GHG Emissions from Refuse Derived Fuel (RDF 5)

In this scenario, single-use plastic/textile and wood are sorted into the RDF-5 process, which many alternative agencies have recommended as a suitable waste management method. During the Refuse Derived Fuel (RDF) process, various activities such as waste transportation, shredding, hot air drying, and briquetting are conducted using fuel and electricity [19]. These steps aim to convert waste into a fuel source that can replace coal. In this particular study, the focus was on waste sorting, specifically single-use plastic/textile and wood, up until the point of waste briquetting. The findings reveal that the RDF-5 process produces a total greenhouse gas

(GHG) emission of 12.77 tonnes CO_2eq/tonne of waste and an annual emission of 4,254.90 tonnes CO_2eq/year.

If 332.96 tonne/year of single-use plastic/textile and wood waste were not sorted and managed in a sanitary landfill, it would emit 232.12 tonne CO_2eq/tonne of waste. However, when bringing these wastes into the process RDF-5, greenhouse gas emissions can be reduced by (-) 232.12 tonne CO_2eq/tonne of waste. Therefore, total net greenhouse gas emissions are (-) 219.35 tonne CO_2eq/tonne of waste and for the whole year, the reduction in greenhouse gas emissions is 73,034.78 tonnes CO_2eq/year.

2.2.4 GHG Emissions from Landfilling

By segregating food waste, recyclable materials, and waste suitable for processing into Refuse-Derived Fuel (RDF), no compostable organic waste ends up in landfills. As a result, no GHG emissions originate from landfills, totaling 0 tonne CO_2eq/year. Nonetheless, other waste can only be deposited in landfills, but they do not decompose in such environments. Therefore, the transportation of other wastes still needs to happen. This leads to emissions from transportation and landfill operations of 650,915.45 Liters/year, equivalent to GHG emissions of 0.89 tonne CO_2eq/tonne of MSW. As a result of proper waste segregation, it has been shown that if waste is correctly sorted for all its endpoints, there is very little or no waste to be disposed of in landfills. This would benefit the agency responsible for waste management to be able to work more efficiently.

Table 6 Summary of estimates of GHG emissions MSW management in scenario 2

Activity	GHG Emissions (tonne CO_2eq/ tonne of MSW)			Total MSW (tonne/year)	GHG Emissions (tonne CO_2eq/year)
	Direct Emission	Indirect Emission Saving	Net Emission		
Landfilling	0.89	-	0.89	484.67	431.36
Composting	149.46	- 528.72	- 379.26	772.85	- 293,111.09
Refuse Derived Fuel (RDF 5)	12.77	- 232.12	- 219.35	332.96	- 73,034.78
Recycling	1.13	-2.95	-1.82	376.99	- 686.12
Total	164.25	- 763.79	-599.54	1,967.47	- 366,400.63

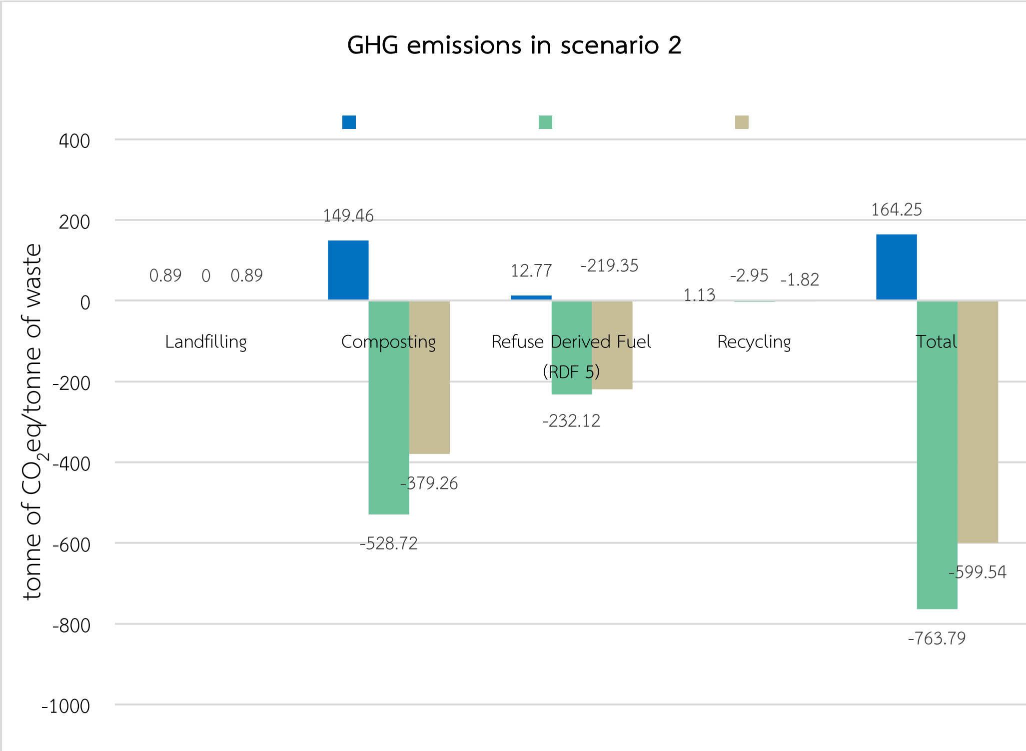

Figure 1 Estimates of GHG emissions from the MSW management of Central Plaza Rattanathibet in scenario 2

Table 6 and Figure 1 present the GHG emissions from the entire waste management system in scenario 2. According to the study results, landfills exhibit minimal GHG emissions due to proper waste sorting. The majority of GHG emissions in this scenario arise from transportation and operational activities associated with landfills. Waste management practices such as composting, RDF 5, and recycling in scenario 2 also generate direct GHG emissions. However, these practices effectively reduce a significant amount of GHG emissions. Consequently, the net GHG emissions from these three processes were negative. The study estimated that in this scenario, the direct and indirect GHG emissions savings from the overall MSW management system were 164.25 and -763.79 tonneCO_2eq/tonne of waste, respectively. The net GHG emissions from the MSW management system amounted to -599.54 tonne CO_2eq/tonne of waste. When summing up the contributions from each MSW management process (landfilling, composting, RDF 5, and recycling), the net GHG emission from the MSW management system in the shopping center was -366,400.63 tonne of CO_2eq/year.

Figure 2 Comparison of greenhouse gas emissions between scenario 1 and scenario 2

Comparing the GHG emissions assessment between scenario 1 and scenario 2 reveals a significant reduction in GHG emissions in scenario 2, as shown in Figure 2. In scenario 1, direct emissions amount to 999.93 tonne CO_2eq/tonne of MSW, whereas scenario 2 demonstrates a much lower direct emission of only 164.25 tonnes CO_2eq/tonne of MSW. Scenario 1 does not achieve complete avoidance when considering indirect emission savings since all waste is managed in landfills. On the other hand, scenario 2, with improved management practices, shows substantial GHG emission savings of -763.79 tonne CO_2eq/tonne of MSW. Consequently, the net GHG emissions from the MSW management system in the shopping center were 999.93 tonne CO_2eq/tonne of MSW for scenario 1 and -599.54 tonne CO_2eq/tonne of MSW for scenario 2.

Conclusions

This study estimated GHG emissions from the MSW management system of Central Plaza Rattanathibet, considering the current waste management practices (Scenario 1: BAU) and a simulated waste management system (Scenario 2: ZW). In this shopping center, about 1,967.47 tonnes of MSW was generated per year in 2022, which contains the five most common waste compositions: food waste, other waste, plastic waste, paper and board, and glass. In scenario 1, all waste is managed by landfill with GHG emissions of 1,967,302.28 tonnes CO_2eq/year. Scenario 2, a simulated waste management scenario, divides waste management into four categories: Landfilling, Composting, Refuse Derived Fuel (RDF 5), and Recycling. The emissions of GHGs in scenario 2 from the whole MSW management system, including direct and indirect savings, were 164.25 and –769.79 (tonne CO_2eq/tonne of MSW), respectively, while the net GHG emissions were -599.54 tonne CO_2eq/tonne of MSW, which is equal to - 374,129.13 tonnes CO_2eq/year. For example, composting reduces greenhouse gas emissions the most, followed by RDF 5 and Recycling, respectively. The GHG emission data obtained from this study could provide valuable insights for policymakers in Nonthaburi municipality when formulating climate change mitigation policies.

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