Evaluation of the greenhouse gas emissions resulting from waste management practices at the Central Plaza Rattanathibet shopping center: A case study

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การประเมินการปลดปล่อยก๊าซเรือนกระจกที่เกิดจากการจัดการของเสียภายในศูนย์การค้าเซ็นทรัล พลาซารัตนาธิเบศร์: กรณีศึกษา

น.ส.กนกพิชญ์ ศรีนอก

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Field of Study	Hazardous Substance and Environmental Management
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กนกพิชญ์ ศรีนอก : การประเมินการปลดปล่อยก๊าซเรือนกระจกที่เกิดจากการจัดการของเสียภายในศูนย์การค้าเซ็นทรัลพลาซารัตนาธิเบศร์: กรณีศึกษา. (Evaluation of the greenhouse gas emissions resulting from waste management practices at the Central Plaza Rattanathibet shopping center: A case study) อ.ที่ปรึกษาหลัก : รศ. ดร.นุตา ศุภคต, อ.ที่ปรึกษาร่วม : ดร.เสกสรร พาป้อง

การจัดการขยะในศูนย์การค้าเป็นกิจกรรมของมนุษย์ที่สามารถปล่อยก๊าซเรือนกระจกและมีส่วนสำคัญในการเปลี่ยนแปลงสภาพภูมิอากาศที่มีผลต่อโลก ปัญหานี้นับว่าเป็นปัญหาเร่งด่วนและท้าทายที่ทุกองค์กรทั่วโลกกำลังให้ความสนใจ งานวิจัยนี้จึงได้นำเสนอแนวทางบูรณาการที่รวมเอาประเด็นสำคัญ 3 ประการของการจัดการขยะที่ยั่งยืนในศูนย์การค้าได้แก่ การวิเคราะห์องค์ประกอบของขยะ การคำนวณการปล่อยก๊าซเรือนกระจก และการศึกษาทัศนคติของลูกค้าและพนักงานต่อการคัดแยกขยะในศูนย์การค้า การศึกษานี้ได้ทำการเปรียบเทียบระหว่างสถานการณ์การจัดการขยะ 2 สถานการณ์ โดยสถานการณ์ที่ 1 เป็นแนวทางการจัดการขยะในปัจจุบันของศูนย์การค้า โดยมีการจัดการด้วยวิธีการฝังกลบเป็นหลัก ในขณะที่สถานการณ์ที่ 2 เป็นการนำเสนอกลยุทธ์การจัดการขยะแบบบูรณาการซึ่งรวมถึงวิธีการกำจัดขยะ 4 วิธีเข้าด้วยกัน ได้แก่ การฝังกลบ การทำปุ๋ยหมัก เชื้อเพลิงจากขยะ (RDF 5) และการรีไซเคิล โดยผลการวิจัยพบว่าในปี 2565 ห้างสรรพสินค้ามีขยะเกิดขึ้นทั้งหมด 1,967.47 ตันต่อปี จากการศึกษาพบว่าองค์ประกอบขยะส่วนใหญ่ในห้างสรรพสินค้า ได้แก่ ขยะอาหาร (39.28%) รองลงมาคือขยะอื่น ๆ (24.63%) ขยะพลาสติก (15.52%) กระดาษและกระดาน (10.48%) และแก้ว (5.45%) นอกจากนี้ ในการศึกษายังได้มีการใช้แนวทาง IPCC ปี 2006 เพื่อประเมินการปลดปล่อยก๊าซเรือนกระจก โดยในสถานการณ์ที่ 1 ซึ่งมีการจัดการขยะแบบฝังกลบเพียงวิธีเดียวได้ส่งผลให้เกิดการปล่อยก๊าซเรือนกระจกเทียบเท่ากับ 124.94 ตันของคาร์บอนไดออกไซด์เทียบเท่าต่อปี ในทางตรงกันข้าม สถานการณ์ที่ 2 ซึ่งมีใช้การจัดการขยะแบบผสมผสานและแสดงให้เห็นการลดการปล่อยก๊าซเรือนกระจกอย่างมีนัยสำคัญสุทธิซึ่งคิดเป็น - 839.37 ตันของคาร์บอนไดออกไซด์เทียบเท่าต่อปี ผลลบนี้บ่งบอกได้ว่าวิธีการจัดการขยะในสถานการณ์ที่ 2 ส่งผลให้การปล่อยก๊าซเรือนกระจกสุทธิลดลงเมื่อเปรียบเทียบกับสถานการณ์ที่ 1 อีกทั้งการลดลงของปริมาณก๊าซเรือนกระจกในสถานการณ์ที่ 2 เกิดขึ้นได้จากการนำกลยุทธ์การจัดการขยะมาใช้ เช่น RDF 5 การทำปุ๋ยหมัก และการรีไซเคิล นอกจากนี้ ผลการวิจัยยังชี้ให้เห็นว่าทั้งความตั้งใจและความสามารถในการรับรู้ในการควบคุมพฤติกรรมมีอิทธิพลอย่างมากต่อการลดและการคัดแยกขยะในศูนย์การค้า เนื่องจากผู้ตอบแบบสอบถามแสดงความตั้งใจที่จะมีส่วนร่วมในการแยกขยะและมีความมั่นใจในความสามารถในการลดและคัดแยกขยะอย่างมีประสิทธิภาพ ดังนั้นการส่งเสริมการคัดแยกขยะกับลูกค้าและพนักงานภายในห้างสรรพสินค้าอาจมีส่วนช่วยเพิ่มประสิทธิภาพการจัดการขยะได้ อีกทั้งข้อมูลเชิงลึกที่ได้จากการศึกษาครั้งนี้จะสามารถเป็นแนวทางแก่ผู้กำหนดนโยบายของเทศบาลนครนนทบุรีในการแก้ไขปัญหาการเปลี่ยนแปลงสภาพภูมิอากาศและดำเนินมาตรการบรรเทาผลกระทบต่อไป

สาขาวิชา	การจัดการสารอันตรายและ	ลายมือชื่อนิสิต
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Kanokpish Srinok : Evaluation of the greenhouse gas emissions resulting from waste management practices at the Central Plaza Rattanathibet shopping center: A case study. Advisor: Assoc. Prof. NUTA SUPAKATA, Ph.D. Co-advisor: Seksan Papong, Ph.D.

Waste management in shopping center represents a human activity that has the potential to emit greenhouse gases, contributing to climate change. This issue is an urgent and challenging problem that every global organization is paying attention to. This research presents an integrated approach that combines three critical aspects of sustainable waste management in the shopping center: waste composition analysis, greenhouse gas emissions calculation, and an examination of customer and staff attitudes towards waste separation in shopping center. The study conducted a comparison between two waste management scenarios. Scenario 1 represents the current waste management approach in the shopping center, primarily relying on landfilling, while Scenario 2 presents an integrated waste management strategy that includes four waste disposal methods: landfilling, composting, refuse-derived fuel (RDF 5), and recycling.The results indicated that in the year 2022, the shopping center produced a total of 1,967.47 tonnes of waste annually. The investigation revealed the predominant waste compositions in the shopping center, with food waste (39.28%), followed by other waste (24.63%), plastic waste (15.52%), paper and board (10.48%), and glass (5.45%). To assess greenhouse gas emissions, the study adhered to the 2006 IPCC Guidelines for Greenhouse Gas National Inventories. Scenario 1, characterized by landfill-only waste management, resulted in greenhouse gas emissions equivalent to 124.94 tonnes of CO_2eq/year. In contrast, scenario 2, which embraced integrated waste management, demonstrated significantly reduced greenhouse gas emissions, equivalent to - 839.37 tonnes of CO_2eq/year. The presence of this negative value signifies that the waste management methods in scenario 2 led to a net decrease in greenhouse gas emissions when compared to scenario 1. This reduction was accomplished through the adoption of waste management strategies like RDF 5, composting, and recycling, all of which directly contributed to the decline in greenhouse gas emissions within scenario 2. Moreover, the research findings indicated that both the intention and the perceived ability to control behavior had a favorable influence on waste reduction and segregation. This result was due to

Field of Study:	Hazardous Substance and Environmental Management	Student's Signature ....
Academic Year:	2023	Advisor's Signature ....
		Co-advisor's Signature ....

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A special thank you to my co-advisor, Seksan Papong, Ph.D., who advised on greenhouse gas emissions knowledge and recommended research directions to be more comprehensive and complete. Moreover, I extend my gratitude to Oluseye Oludoye, Ph.D for reviewing the research and editing it to make it more complete.

I also want to express my very great appreciation to Nonthaburi municipality for facilitating the study of waste composition and Nonthaburi Provincial Administrative Organization for providing information to support the study of the Sai Noi landfill. Additionally, I am thankful to Central Plaza Rattanathibet for providing a place to collect waste samples and gather questionnaire data from customers and staff. I want to express my gratitude to all the participants and respondents who generously shared their time and insights, without whom this research would not have been possible.

I would like to gratefully acknowledge the financial support from the International Program in Hazardous Substances and Environmental Management, Graduate School, Chulalongkorn University, and the Graduate School Thesis Grant from the Graduate School, Chulalongkorn University. These resources played a crucial role in facilitating my research and ensuring its success.

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Kanokpish Srinok

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Chapter 1

Introduction

1.1 Background

The world is currently dealing with the problem of climate change, which is a major environmental issue. Climate change refers to significant shifts in variable climate values, such as temperature and rainfall patterns in a specific location, compared to past values (Ridhosari & Rahman, 2020). Furthermore, the effects of climate change include severe fires, water scarcity, acute droughts, increasing sea levels, flooding, melting polar ice, catastrophic storms, and a loss of biodiversity (United Nations, 2021). Global warming is one aspect of climate change. It is a gradual increase in the earth's temperature generally due to the greenhouse effect caused by increased levels of CO_2, N_2O and CH_4, which accumulate in the atmosphere that are out of balance. Usually, greenhouse gases (GHGs) are present in the earth's atmosphere, acting as a barrier to heat through the earth. At the same time, they retain some heat to keep the earth at a temperature suitable for living. However, the current increase in GHG prevents solar radiation from reflecting out of the atmosphere (United Nations, 2021).

GHGs from anthropogenic activities are a significant contributor to climate change. Following the UN IPCC's fifth assessment report, accounting for 25% of global GHG emission sources come from electricity and heat, followed by agriculture and land 20.4%, industry 17.9%, transportation 14%, other energy 9.6%, food waste 6.7%, and buildings 6.4%, respectively (IPCC, 2022). This has caused a rise in atmospheric GHG concentrations, impacting the energy balance and global climate patterns (Sununta et al., 2019). Many countries are working together to reduce GHG emissions, a major cause of global warming, to support achieving goals to prevent global average temperatures from rising above 1.5 degrees Celsius under the Paris Agreement (COP24) (Pluemchingchai, 2019).

According to Thailand's Fourth National Communication report, Thailand had a total GHG emission of 372,648.77 $GgCO_2eq$ in 2018. By way of illustration, the energy sector remains the most significant contributor to Thailand's GHG emissions, accounting for 257,340.89 $GgCO_2eq$ (69.06%), followed by agriculture forestry and other land use (AFOLU), industrial processes and product use (IPPU), and waste sector with 58,486.02 $GgCO_2eq$ (15.69%), 40,118.18 $GgCO_2eq$ (10.77%), and 16,703.68 $GgCO_2eq$ (4.48%), respectively (Ministry of natural resources and environment, 2022). Thailand has 70 landfill waste disposal sites and 1,707 dump sites (PCD, 2021). The management of solid waste by landfill creates an anaerobic organic waste composting process and gas formation in the landfill. For example, landfill gas contains methane, carbon dioxide, carbon monoxide, hydrogen sulfide, nitrogen, ammonia, and oxygen (Tun & Juchelková, 2018), which are the causes of global warming. In particular, methane is a major GHG produced by anaerobic digestion of organic matter in open dumping and landfill. Therefore, GHG emissions from the solid waste management sector are an important environmental problem and one of the causes of climate change. In addition, other GHGs are generated by the solid waste sector, such as carbon dioxide and nitrous oxide, produced using fossil fuels in machinery to collect, sort and transport solid waste (Markphan, 2019).

Nonthaburi Province is located in the central region of Thailand and is one of the metropolitan provinces adjacent to Bangkok. Therefore, it is an urbanized province with a large population. For this reason, Nonthaburi province has experienced tremendous economic and social growth as well as a rapidly growing population which causes problems affecting the environment, especially the garbage problem that tends to increase yearly. To illustrate, it has approximately 1,122.34 tons per day of solid waste, which the local government agency collects and transports the solid waste by itself. Some have hired private companies to collect and transport waste in the area (Nonthaburi Municipality, 2019). Nonthaburi municipality is one of the local government agencies facing problems in waste management in its area. The average amount of solid waste generated in Nonthaburi municipality is approximately 412.31 tons per day or 150,493.15 tons per year. There is a high cost for waste disposal because the Nonthaburi Provincial Administrative Organization area is used as a garbage disposal area (Sai Noi waste pit). In addition, the ability to support the waste of Sai Noi waste pits is declining, so it is necessary to solve the root cause of the problem. Nonthaburi municipality manages waste by collecting general solid waste with 45 garbage trucks per day and collecting an average of 412 tonnes of waste daily (National Statistical Office, 2021). After that, the waste was disposed of at the landfill under the responsibility of the Nonthaburi Provincial Administrative Organization. Moreover, organic waste generated within the municipality, such as vegetable scraps, fruit scraps, wood chips and twigs, is handled by biological treatment, which can be used to produce 5 tons of organic fertilizer per month. This process is supported by the European Union (EU). However, there are still many problems with solid waste management, such as no waste disposal sites, unhygienic disposal, and inefficient solid waste disposal system. In addition, people still lack consciousness of solid waste disposal and sorting (Nonthaburi Municipality, 2019) .

Shopping centers are gathering places for consumption as well as a place for relaxation and entertainment. Therefore, they are a source of much human activity that generates much waste. Central Plaza Rattanathibet is a large shopping center on Rattanathibet Road, Mueang Nonthaburi District, Nonthaburi Province. It has a total retail area of 105,000 sqm and a rental area of 77,008 sqm, which is considered a large area, and various activities occur here (Centralpattana, 2018). This shopping center produces much waste, from packaging materials used in stores to food waste from restaurants. Waste management in this shopping center is, therefore, a huge challenge. If not managed properly, these wastes could end up in landfills, where they would emit GHGs and contribute to climate change. In addition, Central Plaza Rattanathibet's waste management operations are under the responsibility of Nonthaburi municipality. Therefore, if the waste management in this shopping center is optimized, it would improve the next step of waste management, and all kinds of waste would reach their destination correctly.

Several studies indicate that waste management plays a vital role in GHG emissions, especially if there is no proper waste management in shopping center buildings. Pleumchingchai (2019) found that the most proportion of waste in shopping centers is food waste, followed by plastic and paper. From this study, the shopping mall buildings are still managed with solid waste, but some mismanagements can improve the efficiency of operations to help reduce the amount of waste going to landfills. Thus, applying the 3Rs principles to waste management may suit building management (Pluemchingchai, 2019). Similarly, Phupadpong (2019) investigated that the most significant proportion of solid waste from waste segregation in shopping center buildings was the proportion of food waste, on the average up to 60% of the total composition. The study also found that food waste can potentially emit GHG emissions from decomposition (Phupadtong et al., 2018). The Food and Agriculture Organization of the United Nations (FAO) has estimated that the amount of carbon dioxide produced by food waste in the world could be equivalent to 3.3 billion tons per year. It has been shown that the disposal of food waste by landfilling with other types of waste is a risky approach to emissions into the atmosphere due to decomposition causing methane, which causes the greenhouse effect if not managed properly (FAO, 2013).

Sustainable development is described as development that meets present needs without affecting the capacity of future generations to fulfill their own needs (United Nations, 2022). It is considered an important starting point for the current economic and social development. Achieving sustainable development involves three aspects, including economic growth, social inclusion, and environmental protection. Proper waste management will ensure that as much waste as possible is diverted from landfills and appropriately recycled or reused, thereby promoting sustainable development. Moreover, effective solid waste management will be able to achieve and fulfill Sustainable Development Goals 13 (SDGs 13: Climate action) (United States Environmental Protection Agency, 2020b).

This study aimed to analyze the waste composition and assess GHG emissions from waste management in Central Plaza Rattanathibet. Additionally, this study was conducted to know the attitude, subjective norm, perceived behavioral control, and intention of shopping center employees on the waste management system in this shopping center and recommends solutions to help reduce GHG emissions within the shopping center to lead to sustainable development.

1.2 Objectives

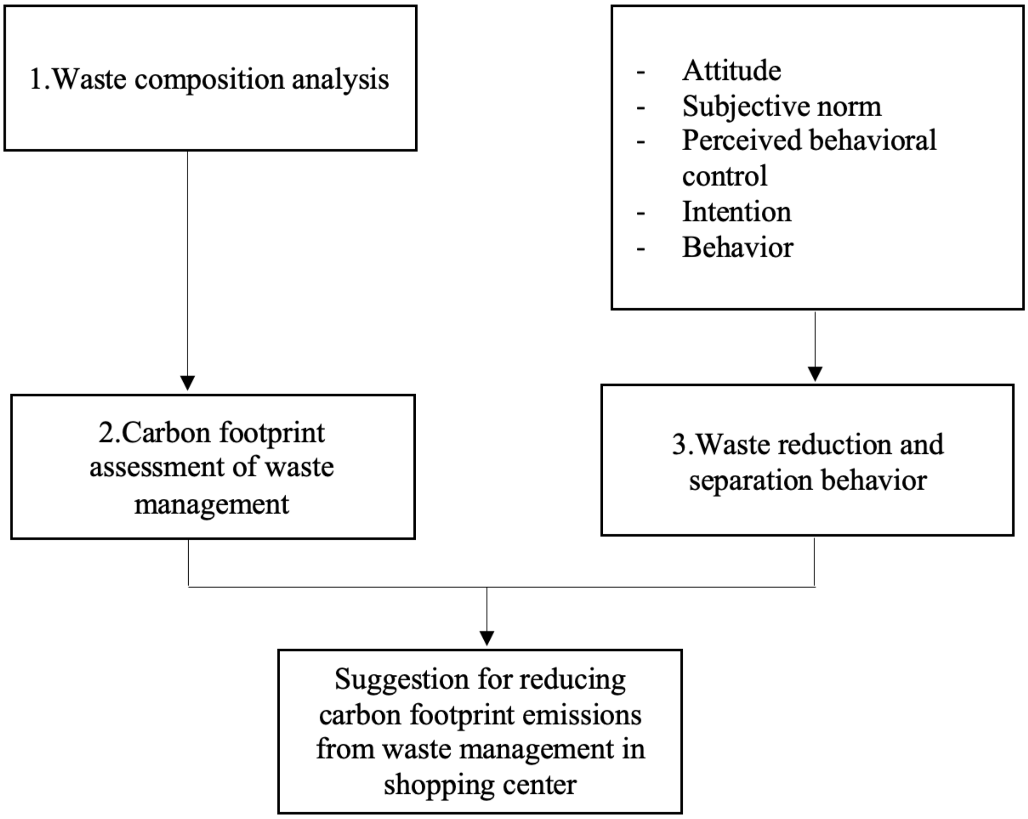
1. To analyze the composition of municipal solid waste generated inside the Central Plaza Rattanathibet by quartering method.
2. To assess the total amount of greenhouse gas emissions from waste management in Central Plaza Rattanathibet.

3. To study attitude, subjective norm, perceived behavioral control, and intention of customers and staffs about waste management system within Central Plaza Rattanathibet.

1.3 Hypothesis

1. The most common waste composition that occurs in shopping center is food waste.
2. The amount of greenhouse gas emissions from scenario 2, which is an integrated waste management, has less greenhouse gas emissions than the shopping center's current waste management.
3. Attitude, subjective norm, perceived behavioral control, and intention positively impacted waste reduction and separation.

1.4 Scope of Study



Figures 1. Conceptual framework of the study.

1.4.1 Waste analysis

This study only studied waste composition separation and GHG emissions from municipal solid waste (MSW). According to the Pollution Control Department's principles, MSW is generated from various community activities such as residences, commercial establishments, business areas, shops, service places, fresh markets, and institutions. The composition of MSW consists of organic waste such as food scraps, leaves, and grass scraps; recyclable waste such as glass, paper, metal, plastic, aluminium, and rubber and general waste such as fabric scraps, wood scraps and other materials not including hazardous waste from the community (PCD, 2016).

1.4.2 Organizations

- Central Plaza Rattanathibet cooperates in using the site for study and collection of waste samples.
- Nonthaburi Muicipality facilitates the study of waste separation and provides useful information.
- International program in Hazardous Substances and Environmental Management (IP-HSM), Graduate school, Chulalongkorn University supports funding for the study.

1.4.2 Duration

November 2022 to April 2023

Chapter 2

Theoretical Background and Literature Reviews

2.1 Theoretical Background

2.1.1 Case study description

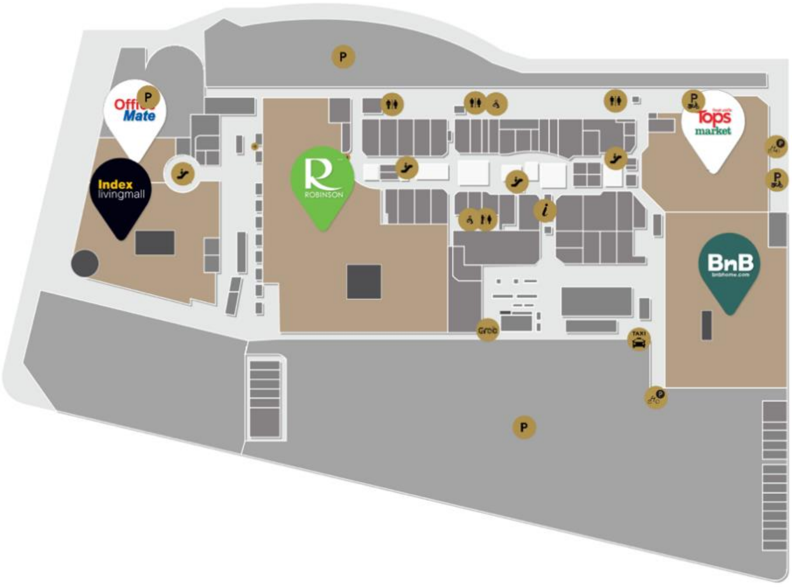
Nonthaburi province is one of Thailand's metropolitan provinces in the country's central region. It is a highly urbanized province with a sizable population. Currently, Nonthaburi province has experienced tremendous economic and social growth, as well as a rapidly growing population. These cause environmental problems in this province, especially waste management problems that worsen yearly. To illustrate, it has approximately 1,122.34 tons of solid waste per day, which the local government agency collects and transports, but private companies employ some areas to operate (National Statistical Office, 2021).

Central Plaza Rattanathibet is a large shopping center with a total retail area of 105,000 square meters and a rental area of 77,008 square meters, with waste management under the supervision of Nonthaburi Municipality. It 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 (Centralpattana, 2018). As for the shopping center, there are three floors as follows:

The 1st floor of the building contains various establishments, including restaurants, supermarkets, banks, coffee shops, and flea markets, as shown in Figure 4.

The 2nd floor consists of a fashion and beauty zone, coffee shop, IT and electronics zone, and fitness as shown in Figure 5.

The 3rd floor consists of a restaurant, food court, and movie theater, as shown in Figure 6.



Figures 2. The 1st floor of Central Plaza Rattanathibet.

Figures 3. The 2nd floor of Central Plaza Rattanathibet.

Figures 4. The 3rd floor of Central Plaza Rattanathibet.

MSW on every floor and shopping centre area is collected at the waste collection room and taken to the landfill by the Nonthaburi Municipality. Therefore, it is crucial to study the current waste management system and conduct alternative ways to improve the waste system to be better and environmentally friendly to be a future model shopping center.

2.1.2 Greenhouse gases (GHGs)

GHGs are gases that trap heat radiation or infrared radiation and are essential to maintaining a constant temperature in the Earth's atmosphere. These gases absorb heat waves during the day and gradually radiate heat at night. Therefore, the temperature in the global atmosphere does not change suddenly.

Many gases absorb thermal radiation and are classified as greenhouse gases, which include both natural greenhouse gases emission sources and anthropogenic greenhouse gases emission sources. There are many greenhouse gases but only seven are regulated by the Kyoto Protocol, which are anthropogenic gases: Carbon dioxide (CO_2), Methane (CH_4), Nitrous oxide (N_2O). Hydrofluorocarbon (HFC), Perfluorocarbon (PFC), Sulfur hexafluoride (SF_6), and Nitrogen trifluoride (NF_3) (IPCC, 2020) . In addition, there is another important greenhouse gas caused by human activities, CFCs or Chlorofluorocarbon, which is used as a refrigerant and used in the production of foam. However, it is limited to use in the Montreal Protocol (UNEP, 2019) and is therefore not defined in the Kyoto Protocol.

Carbon dioxide (CO_2): Carbon dioxide enters the atmosphere as a result of the combustion of fossil fuels (coal, natural gas, and oil), solid waste, trees, and other biological materials, as well as certain chemical reactions (e.g., manufacture of cement). It is removed from the atmosphere by plants as part of the biological carbon cycle.

Methane (CH_4): Methane is emitted during the production and transportation of coal, natural gas, and oil. Methane emissions are also caused by livestock and other agricultural practices, land use, and the decay of organic waste in municipal solid waste landfills.

Nitrous oxide (N_2O): Nitrous oxide is emitted during agricultural, land use, and industrial activities, as well as the combustion of fossil fuels and solid waste, and during wastewater treatment.

2.1.3 Municipal solid waste (MSW)

According to the Environment Protection Act 1993, waste is defined as any discarded, rejected, abandoned, unwanted or surplus matter, whether or not intended for sale or for recycling, reprocessing, recovery or purification by a separate operation from that which produced the matter (United States Environmental Protection Agency, 2020b).

The Pollution Control Department (PCD) has divided the types of solid waste according to the physical characteristics of the MSW into 12 types (PCD, 2016), as shown in Table 1:

Tables 1. Definition of each type of MSW.

Waste composition	Description
1. Food waste	Vegetable scraps, meat scraps, bones, fruit peels, raw materials discarded from cooking and food scraps discarded.
2. Garden waste	Organic waste that is not food waste, such as flowers, twigs, leaves, grass, fallen fruits, and other parts of plants from pruning or gardening
3. Paper	Office paper, computer paper, magazine paper, corrugated paper wax coated paper, newsprint paper, carton boxes, cushioning and products include mailboxes, paper bags, and milk cartons, but not including waste paper.
4. Wood	Wood planks, furniture, scrap wood, wood products used for cooking
5. Textile	Cloth, Rags, and other things related to textiles
6. Rubber and leather	Tires, rubber scraps, including scraps from automobile tires, motorcycles, bicycles and scrap leather from furniture. Jewelry, shoes and others.
7. Diaper	Disposable diapers for children and adults
8. Plastic	All types of plastics, including single-use plastics, such as plastic bags, food or beverage packaging bags, snack bags, snack bags, detergent or detergent packaging bags, fabric softener bags, plastic tubes, water bottles, crates, plastic food boxes packaging or packages from ordering food and others.
9. Foam	Styrofoam boxes or foam trays for packing food, Styrofoam for cushioning, Polyurethane foam, Styrofoam for insulation, etc.
10. Metal and aluminum	Iron, steel, tin-plated steel cans, metal cans or aluminum cans for food and beverages

Waste composition	Description
11. Glass	All types of glass containers containing beverages or containing food, medicine, cosmetics, broken glass and mirrors.
12. Others	Toilet paper and sanitary napkins from the toilet

2.1.4 GHGs from waste disposal

According to the European Union, greenhouse gas emissions from waste in the EU dropped by 42% between 1995 and 2017. The amount of waste emissions depends on how the waste is treated. For instance, when waste is disposed of in landfills, the organic components within the waste break down and generate gas as a result (European Union, 2020).

The main greenhouse gases generated during municipal solid waste management processes are carbon dioxide (CO_2), methane (CH_4), and nitrous oxide (N_2O). Landfills are the most important source of greenhouse gases because they are the most common waste management methods. It is also a management method that produces methane, a greenhouse gas,that has a global warming potential 28 times greater than carbon dioxide.

Organic waste in landfills will be degraded anaerobically, causing proteins, carbohydrates, and fats to be broken down by microorganisms into amino acids, sugars, and fatty acids. Finally, they are converted to hydrogen gas, ammonia, volatile acids and become biogas. To illustrate, biogas consists of about 60% methane, the rest is carbon dioxide and nitrous oxide. Landfills produce more methane gas if the solid waste has a high organic waste composition, high moisture content and high anaerobic conditions. The anaerobic state in a landfill depends on the thickness of the solid waste layer, pH, and soil filling/compaction will increase the anaerobic state. The use of operating machinery such as trucks, loaders, compactors, and granulators generate carbon dioxide emissions from the burning of fossil fuels. Furthermore, the use of electricity in this process also releases carbon dioxide because Thailand produces electricity by using fossil fuels as the main fuels, such as natural gas and coal. Burning waste also generates greenhouse gas emissions because burning converts the fossil carbon of plastic waste into carbon dioxide and releases small amounts of methane and nitrous oxide (TGO, 2013).

Municipal solid waste landfills were the third-largest source of human-related methane emissions in the United States in 2016, accounting for approximately 16% of these emissions (Chiemchaisri & Visvanathan, 2008). It is one of many non-CO_2 gases that contribute to global warming. Methane is released as wastes decompose, and emissions are affected by the total amount and composition of wastes, as well as the location, design, and practices of management facilities. The EPA is interested because recycling and changing product usage can have an impact on gas emissions. Recycling office paper or aluminum, for example, can have a positive impact on the environment, and it will also have a positive environmental impact, such as reduced energy consumption and greenhouse gas emissions (e.g., emissions associated with the production of products from virgin materials) (United States Environmental Protection Agency, 2020a).

2.1.5 Global Warming Potential (GWP)

The global warming potential depends on its radiative efficiency and lifetime in the atmosphere. It is a measure of how much a greenhouse gas, such as carbon dioxide (CO2), methane (CH4), or nitrous oxide (N2O), can trap heat in the Earth's atmosphere over a specific period, usually 100 years, compared to carbon dioxide. GWP is used to assess the relative contributions of different greenhouse gases to global warming and climate change. It provides a standardized way to compare the warming effects of various gases and helps policymakers prioritize efforts to mitigate climate change. By comparing it with the thermal radiation of carbon (IPCC, 2014) dioxide as shown in Table 2.

Tables 2. Global warming potential (GWP)

Greenhouse gases	Chemical formula	GWP
Carbon dioxide	CO_2	1
Methane	CH_4	28
Nitrous oxide	N_2O	265

Source: IPCC Fifth Assessment Report (2014)

2.1.6 GHG emissions from Thailand's waste management sector

The Thailand Greenhouse Gas Management Organization (TGO) studied greenhouse gas emissions from Thailand's waste management sector in 2013. It found that the waste management sector Waste has greenhouse gas emissions equal to 5.11 million tons of carbon dioxide equivalent ($MtCO_2e$), or 1.48% of the total sector's greenhouse gas emissions. For the quantity and proportion of greenhouse gas emissions in the management sector Waste of Thailand in 2013 is shown in Figure 2. The details of greenhouse gas emissions from the waste management sector are as follows (TGO, 2013):

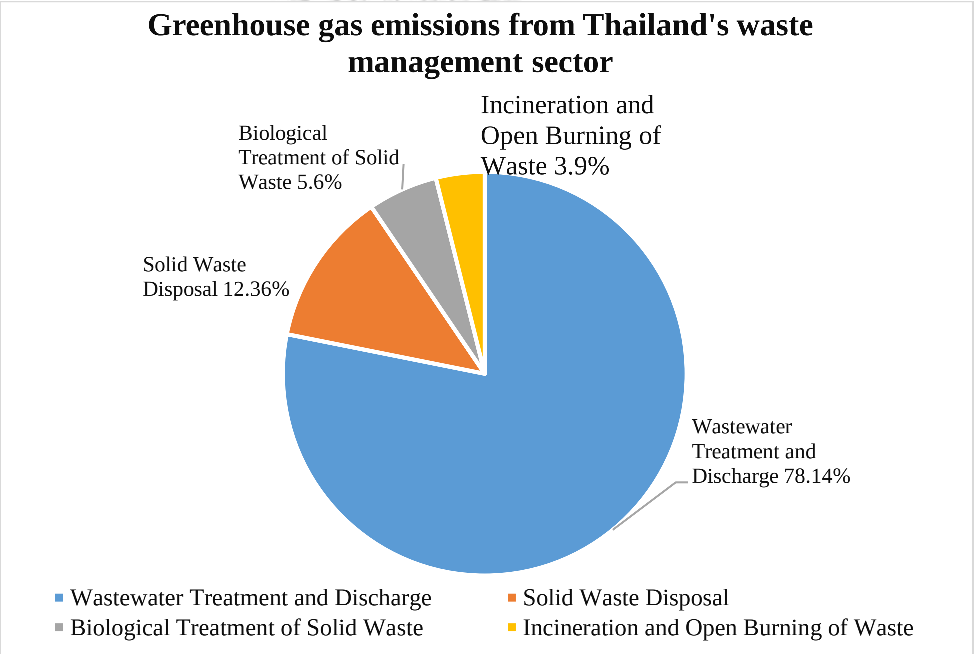
1. The disposal of solid waste considers the amount of greenhouse gas emissions from both sources. The first is controlled sources such as landfill disposal areas and the other is unregulated sources such as controlled dump and open dump sites. From the assessment results, it was found that waste management had GHG emissions equal to 0.63 MtCO2e per year, accounting for 12.36% of the total GHG emissions in the waste management sector. Landfills have GHG emissions of 0.34 $MtCO_2e$ per year and from unregulated sources 0.29 MtCO2e per year.

2. Biological waste treatment considers the amount of greenhouse gas emissions from fermentation and anaerobic fermentation. For Thailand, greenhouse gas emissions from integrated waste disposal and mechanical and biological waste

treatment (MBT) have not been taken into consideration because the relevant agencies do not report the amount of organic waste. GHG emissions from this treatment were 0.29 $MtCO_2e$ per year, representing 5.60% of the total GHG emissions in the waste management sector.

3. Waste incineration is burning waste in an incinerator that has a combustion control system, such as modern combustion systems with a large flue, a combustion chamber that can accommodate high-temperature combustion, and waste stirring and aeration to increase combustion efficiency. This method of waste disposal has greenhouse gas emissions equal to 0.20 $MtCO_2e$ per year, representing 3.90% of the total greenhouse gas emissions in the waste management sector.

4. Wastewater treatment and discharge are considered from the amount of municipal wastewater and industrial wastewater being treated. GHG emissions from anaerobic wastewater treatment equal to 3.99 $MtCO_2e$ per year, representing 78.14% of the total GHG emissions in the waste management sector.



Figures 5. Quantity and proportion of greenhouse gas emissions in the waste management sector in 2013.

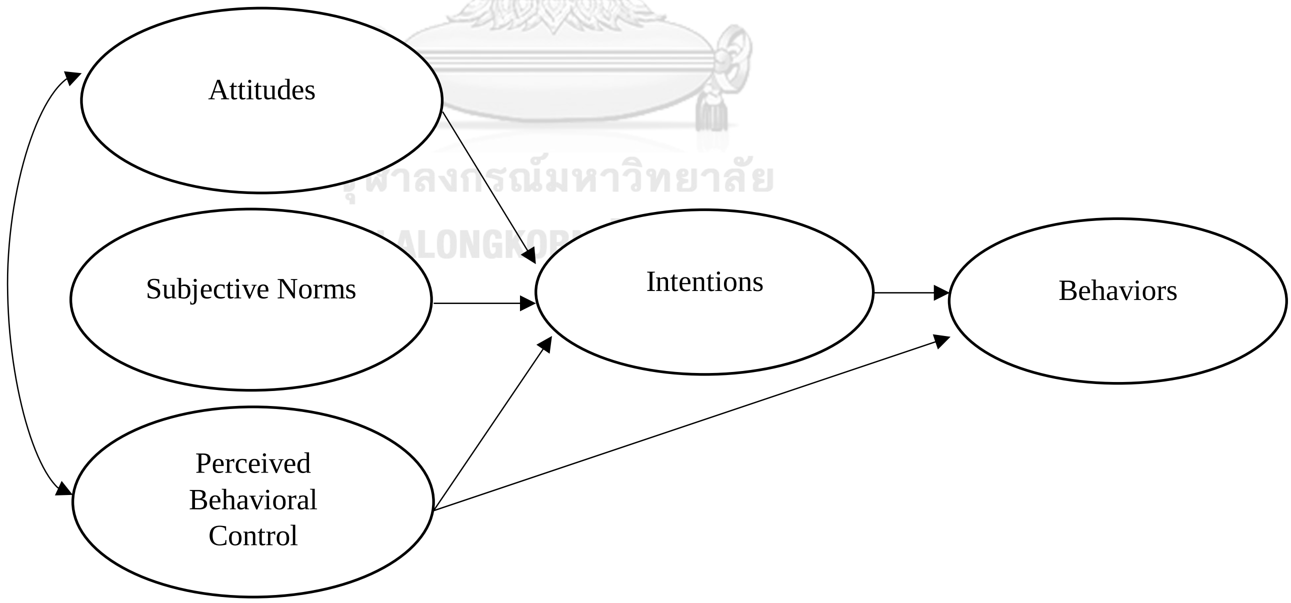
2.1.7 Carbon footprint

Carbon footprints are the result of calculating emissions, which include carbon dioxide, methane, nitrous oxide, etc. Moreover, it breaks down how much greenhouse gas emissions are released by an activity, process, or service. Carbon footprints can be specific, for example, for businesses, manufacturing processes or waste management. Products can also have a carbon footprint, which shows the total amount of emissions produced during the production, use, recycling, and disposal of the associated product. Many other activities and processes, such as hotel stays, business trips, events, or specific services, can also have their carbon footprints calculated.

The carbon footprint is typically calculated in what is known as carbon dioxide equivalent (CO_2e), which includes five other greenhouse gases alongside carbon dioxide listed in the Kyoto Protocol. These gases include methane (CH_4), nitrous oxide (N_2O), Sulphur hexafluoride (SF_6), Fluorocarbons, Perfluorocarbons and Nitrogen trifluoride (NF_3). The global warming potential of some of these is significantly higher than that of CO_2. For example, methane is 21 times greater than carbon dioxide and sulfur hexafluoride is 22,800 times greater than carbon (TGO, 2021) dioxide .

2.1.8 Theory of planned behavior (TPB)

The Theory of Planned Behavior (Ajzen, 2019) is a widely used theoretical framework in understanding waste separation behavior, which defines motivation and ability as predictors of behavior in a specific situation. Individuals' intentions to perform a specific behavior are formed by motivational factors (attitude toward the behavior and subjective norm). In situations where the person has control, the person's intention to perform the behavior predicts it. However, in most everyday life situations, factors beyond the individual's control may prevent the execution of intended behavior. In these cases, a person's ability becomes a significant factor in their behavior. Therefore, perceived behavioral control acts as a motivator of intention and, together with intention, has a direct impact on behavior (Figure. 3) (Ajzen, 2019). The more realistically a person perceives their level of control over the circumstance, the more predictive value perceived behavioral control has on subsequent behavior.



Figures 6. Schematic representation of theory of planned behavior

The theory's first construct is behavioral intention, which refers to the motivational factors that influence behavior. The stronger the intention to engage in a given behavior, the more likely that behavior was performed. The second construct is attitude toward the behavior, which is the degree to which a person evaluates a given behavior favorably or unfavorably (Nickerson, 2023). Attitude is actually made up of behavioral beliefs and outcome assessments. The third construct is subjective norm, which is social pressure to perform or not perform a given behavior. Subjective norms are formed by the combination of normative beliefs and motivation to comply. Perceived behavioral control, which refers to people's perceptions of the ease or difficulty of performing the behavior of interest, is also important in the TPB (Asare, 2020).

2.2 Literature Review

Pluemchingchai (2019) assessed the waste composition of the sample buildings and analyzed the waste composition by using coning and quartering techniques. The analysis was repeated on weekdays and holidays and divided by type of waste into 11 categories: paper, food scraps, plastic, glass, metal, and rags. Rubber, Wood, Leather, Hazardous Waste, etc. In addition, the sources of solid waste in the building can be categorized into 7 sources: 1) Water park 2) Cineplex 3) Hall 4) Department 5) Supermarket 6) Food Park and 7) Rental store. There are carbon footprint emission measurements for 2 types of buildings. The results showed that in the category A buildings, the amount of solid waste generated is in the range of 237.17 to 2,742.77 tCO_2e per year, representing the amount of greenhouse gas emissions within the range 540.74 to 7,196.93 tCO_2e per year. As for the category B buildings, the amount of solid waste generated is in the range of 91.26 to 127.75 tCO_2e per year and the amount of greenhouse gas emissions is in the range of 248.76 to 328.83 tCO_2e per year (Pluemchingchai, 2019).

Aroonsrimorakot, S, et al. (2013) studied greenhouse gas emissions of the Faculty of Environment and Resource Studies, Mahidol University. By calculating the carbon footprint in terms of carbon dioxide equivalent (CO_2e) from the faculty's activities and collecting data from greenhouse gas emission sources such as electricity consumption, water consumption, wastewater, the amount of fuel and waste, etc. The results showed that the greenhouse gas emissions of the Faculty of Environment and Resource Studies Mahidol University is equal to 1.091.85 $tonCO_2e$ per year. The source that emits the most greenhouse gases is electricity consumption followed by waste management. Therefore, it should reduce energy consumption and the amount of waste generated, use energy-saving technologies, create energy-saving campaigns for students and staff, and classify waste to facilitate recycling (Aroonsrimorakot et al., 2013).

Nuntaya Keawsawang (2019) conducted a carbon footprint assessment and sustainability of GHG emission reduction of the Local Administration Organization in Bang Khae. Data were collected using a questionnaire representing all 10 agencies and interviews with 643 personnel of the Bang Khae District Officasaree. By calculating the carbon footprint is the value of carbon dioxide equivalent (CO2e) caused by various activities and causing greenhouse gas emissions, which uses the carbon footprint assessment methodology of the Thailand Greenhouse Gas

Management Organization (TGO). The results of the study showed that the amount of greenhouse gas emissions of the Bang Khae District Office was 4,224.91 tonCO_2e per year, and in the landfill waste management sector, the emission was 581.90, representing 13.77% (Sununta et al., 2019).

Strydom (2018) evaluated waste recycling behavior in South Africa by applying plan behavior theory in this research. The results explained 26.4% of the variance in recycling behavior and 46.4% of the variance in recycling intention. Only 3.3% of South Africans in large cities practice dedicated recycling of five materials: paper, plastic, glass, metal, and compostable organic waste. South Africans lack sufficient knowledge, positive attitude, social pressure, and awareness of controls that encourage recycling behavior. Furthermore, awareness campaigns that include moral values and information about available recycling schemes, along with the provision of a curbside collection service for recyclables, have the best chance of positively influencing recycling behavior among South African city dwellers (Strydom, 2018).

Kaewprayoon (2015) has studied the knowledge, attitudes, and household waste management behavior of the people in Khuan Lang Municipality, Hat Yai District, Songkhla Province. A total of 400 people were randomly sampled, and questionnaires were used as a tool to collect data which was divided into 5 sections. The results showed that the study population had a high level of knowledge, attitude, and behavior in waste management. In addition, people with different residences, ages, education levels, occupations and monthly incomes have different waste management knowledge. People's knowledge and attitudes in household waste management correlated with household waste management behavior at a statistically significant level of 0.5 with moderate positive correlation (Kaewprayoon, 2015).

Oehman et al. (2022) applied the theory of planned behavior to study food waste reduction and sorting behavior. Data collected through the New York State Resident Survey were used and analyzed using a structural equation model. The findings demonstrate that people have pro-environmental sentiments and a desire to separate their food waste, but they also encounter situational obstacles that limit their perceived practical ability to engage in this behavior (Oehman et al., 2022).

Chapter 3
Methodology

The study on carbon footprint of solid waste management in the shopping center consisted of three main stages: (1) estimate of the daily solid waste generation and characterization of samples (2) calculate the amount of greenhouse gas emissions from waste disposal by landfill for each type of waste, and (3) study the attitudes and behavior about waste management of employees and staffs in shopping center.

3.1 Goal and scope definition

The goal of this study is to evaluate the GHG emissions of the waste management system in the shopping center and analyzing the mitigation options is applied. This study has concentrated on accounting of the amount of three types of GHG emissions, namely, carbon dioxide (CO_2), methane (CH_4), and nitrogen oxide (N_2O).

The scope of this study is to calculate the amount of GHG emissions generated in Central Plaza Rattanathibet's waste management system and scale as carbon dioxide equivalent (CO_2eq), by surveying and collecting data on the amount of waste and waste management in the shopping center.

3.2 Waste composition analysis

Before this study, no data were collected on the amount of solid waste generation and solid waste composition within the shopping center. Therefore, it is necessary to assess the waste composition for further studies.

This study analysed the volume and makeup of waste produced within shopping center buildings. The quantity of MSW was categorized and studied at its source. The investigation focused on determining the amount of waste generated and its physical composition, utilizing a classification system based on the IPCC Guidelines for National Greenhouse Gas Inventories. The 12 types of waste included in the study were: food waste, garden waste, paper, wood, textile, rubber and leather, diapers, plastic, foam, metal and aluminum, glass, and other waste (PCD, 2016).

3.2.1 Quartering method

The quartering method is used in waste management to obtain representative samples of bulk waste materials. It involves dividing a large waste sample into smaller portions, called quarters, to create a representative subset for analysis or testing purposes. The proportion of each type of MSW is analyzed as follows (ASTM, 2008):

1) Collection of the Waste Sample: A representative sample of the waste material is collected from the source or designated area. The sample should be large enough to ensure accuracy and representativeness.

2) Initial Division: The collected waste sample is spread out on a clean, flat surface, such as a tarp or clean floor. It is then divided into four equal quarters by visually estimating or physically marking the divisions.
3) Selection of a Quarter: Two of the quarters opposite pile is randomly selected for further analysis or testing. This selection can be made through a random number generator, drawing lots, or any other randomization method to ensure unbiased representation.
4) Discarding of the Other Quarters: The remaining two quarters are set aside or discarded. They are no longer used for the analysis or testing process.
5) Separating: The two selected piles are sorted into 12 types: food waste, garden waste, paper, wood, cloth, rubber and leather, diapers, plastic, foam, metal and aluminum, glass, and other waste.
6) Repeat and Refine: If further subdivision or reduction of the waste sample is required, the selected quarter can be divided again into quarters, and the process is repeated. This helps obtain a smaller yet representative subset of the original waste sample.
7) Calculating: the percentage of the composition of each type of solid waste and bulk density of waste. The equation is shown in (1) and (2).

$$C_x = \frac{W_x \times 100}{W_T} \quad (1)$$

Where:

C_x is the percentage proportion of sample waste x (%)

W_x is the weight of sample waste x (kg)

W_T is the weight of the total sample (kg)

$$D = \frac{W_1 - W_0}{V} \quad (2)$$

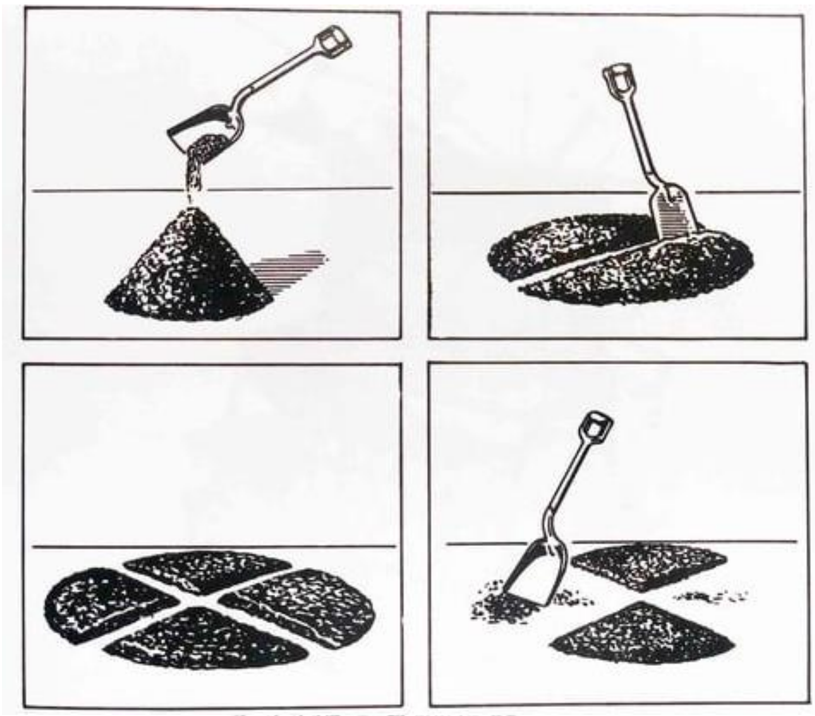
Where:

D is the bulk density of waste (kg/m^3)

W_1 is the total weight of solid waste and container (kg)

W_0 is the total weight of the container (kg)

V is container volume (m^3)



Figures 7. Quartering method

3.3 Greenhouse gas emissions calculation

This research examined the GHG emissions from managing MSW, including direct and indirect emissions associated with MSW disposal sites. The quartering method was employed for sampling, enabling the collection of information on the waste composition and quantities to gather primary data. Additionally, secondary data, such as fuel consumption and electricity usage, were obtained from reports, government entities, and private sector sources, following the Intergovernmental Panel on Climate Change (IPCC) Guidelines (IPCC, 2006), established methods estimated GHG emissions. Therefore, this research calculated according to the method of Thailand Greenhouse Gas Management Organization (TGO) and used the GHG calculator for solid waste ver.Thai II-2013 as well.

3.3.1 Estimation of GHG from Landfilling

The calculation of methane (CH_4) emissions from MSW management in landfill according to the IPCC Guidelines 2006 is based on the principle of the first order decay (FOD) model, which can be divided into 3 tiers of assessment:

1) Tier 1 is a calculation method based on the FOD principle that uses activity data and parameters as recommended by the IPCC.
2) Tier 2 calculation method based on the FOD principle uses some parameters as recommended values. Information on current activities and information from at least the last 10 years must be country specific.
3) Tier 3 is a calculation method based on the FOD principle that requires the same activity-specific data as Tier 2 and uses country-developed parameters or

measured values such as Half-Life, Methane Generation Potential (Lo), the fraction of degradable organic carbon (DOC) in the waste, and the fraction of the degradable organic carbon that decomposes (DOCf).

CH_4 constitutes the primary GHG discharged from landfill. The magnitude of this emission is contingent upon various factors, encompassing pH levels, moisture content, the quantity and composition of waste, and the waste management processes employed. Generally, CH_4 emissions tend to rise in correlation with higher levels of organic material and moisture. Consequently, it is imperative to include the landfill's composition as an input into the model, which may comprise items like food waste, garden waste, plastic waste, paper, textiles, leather, rubber, glass, metal, hazardous waste, and other materials. Additionally, the model necessitates inputs for the total volume of mixed waste (measured in tonnes per month). Lastly, the specific method of MSW management at the landfill must be chosen to calculate GHG emissions (Outapa & Na Roi-et, 2018).

GHG emissions from MSW landfills can be 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, GHG emissions from MSW landfills are calculated only for CH_4 emissions 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 3 (TGO, 2020) .

$$BE_{CH4,SWDS,y} = \varphi_y x\ (1 - f_y)\ x\ GWP_{CH4}\ x\ (1\text{-}OX)\ x\ 16/12\ x\ F\ x\ DOC_{f,y}\ x\ MCF_y\ x\ \sum_{x=1}^{y} \cdot \sum_{j} W_x\ x\ p_j\ x\ DOC_j\ x\ e^{-kj(y-x)}\ x(1-e^{-kj}) \quad (3)$$

Where:

$BE_{CH4,SWDS,y}$ is quantity of CH_4 released from landfills for MSW in year y (tCO_2e)

y is the year for calculating greenhouse gas emissions.

x is the year of calculation is from the first year of landfilling of MSW (x=1) to the year of calculation (x = y).

j is types of compositions of MSW.

φ_y is model correction factor in year y (Default = 0.85).

f_y is proportion of CH_4 that is forcibly collected from landfills and used for incineration, power generation, or other uses in year y (with no collection, the value is equal to 0).

GWP_{CH4} is global warming potential of CH_4.

OX is oxidation factor value (Default = 0.1).

F is proportion of CH_4 in the total gases generated from MSW landfills (quantitative proportion) (Default = 0.5).

$DOC_{f,y}$ is proportion of organic carbon that can be decomposed in year y (Default = 0.5).

MCF_y is methane correction factor in year y (Default = 0.4 - 1.0).

W_x is the amount of MSW generated in year x.

p_j is proportion by weight of MSW type.

DOC_j is proportion of biodegradable organic carbon (by wet weight) of organic waste type j (Default = 0.15-0.43).

k_j is decomposition rate of organic waste type j (Default = 0.035 - 0.40).

3.3.2 Estimation of GHG from Waste Recycling

Waste recycling is widely regarded as the optimal and sustainable approach to waste management. It offers multiple benefits, including recovering valuable materials and avoiding substantial GHG emissions and harmful pollutants. The recycling process not only contributes to a cleaner environment but also creates diverse employment opportunities, leading to significant socio-economic advantages for society. Incorporating recycling into integrated waste management is considered a pivotal step toward achieving overall sustainability within the system. This is because recycling is not a one-step process. Collecting specific data is difficult and may affect the calculation of GHG emissions. Therefore, the recycling calculation in this research uses the GHG calculator for solid waste ver.Thai II-2013 to help. This software has a database from Nonthaburi Province, which is the same source as the case study of this research (MENIKPURA Nirmala, 2013). The recycling process releases GHGs in the form of CO_2 from the use of electricity and fossil fuels.

Tables 3. Quantity of emissions and greenhouse gas reductions from recycling (Thailand).

Material	**(A) GHG emission from recycle process**	**(B) Avoided GHG emission in reduction raw material production**	**(C) Avoided GHG emission from landfill**	**(D) Net GHG emissions (D) = (A)-(B)-(C)**
Paper	1,266	971	2,383	-2,088

Material	(A) GHG emission from recycle process	(B) Avoided GHG emission in reduction raw material production	(C) Avoided GHG emission from landfill	(D) Net GHG emissions (D) = (A)-(B)-(C)
Plastic	2,148	1,899	0	249
Aluminum	393	12,486	0	-12,093
Glass	569	1,024	0	-454

3.3.3 Estimation of GHG from Refuse Derived Fuel (RDF 5)

Refuse Derived Fuel (RDF) is a fuel derived from non-recyclable MSW. It is produced by processing and treating MSW to remove recyclable materials such as metals, plastics, and paper, leaving behind a fuel with higher energy content. RDF is typically used as a substitute for fossil fuels in industrial boilers, power plants, and cement kilns (Aluri et al., 2018). By extracting energy from non-recyclable waste, RDF production helps conserve natural resources that would otherwise be used for fuel production. The RDF process releases CO_2 from the use of fossil fuels for transporting waste and the use of electricity in machinery.

In the RDF process, fossil fuels are used in the waste separation process. After that, electricity is used for machines in the Size Reduction, Screening Air, Magnetic Separation, and Briquetting processes. Therefore, the estimation of GHG emissions from RDF, considering the use of fossil fuel and electricity, was calculated using the following equation (TGO, 2023b):

<u>GHG emissions from the use of fossil fuels</u>

$$PE_{FF,y} = \sum(FC_{PJ,i,y} \times (NCV_{i,y} \times 10^{-6}) \times EF_{CO_2,i}) \times 10^{-3} \quad (4)$$

Where:

$PE_{FF,y}$ is the amount of GHG emissions from the use of fossil fuels in project operations in year y (tonne of CO_2/year)

$FC_{PJ,i,y}$ is the amount of fossil fuel use type i for project operation in year y (unit/year)

$NCV_{i,y}$ is the net calorific value of the fossil fuel consumed (MJ/unit)

$EF_{CO_2,i}$ is the emission factor of CO_2 by combustion of fossil fuel (kg CO_2/TJ)

<u>GHG emissions from the use of electricity.</u>

$$PE_{EL,y} = (EC_{PJ,y} \times 10^{-3}) \times EF_{EC,PJ,y} \quad (5)$$

Where:

$PE_{EL,y}$ is the amount of greenhouse gas emissions from electricity consumption for project operation in year y (tCO_2e/year).

$EC_{PJ,y}$ is the amount of electricity used in project operations in year y (kWh/year).

$EF_{EC,PJ,y}$ is GHG emissions for electricity use in year y (tCO_2/MWh).

3.3.4 Estimation of GHG from composting

Composting waste refers to the process of decomposing organic materials, such as food scraps, yard trimmings, and agricultural residues, in a controlled manner to produce compost. Composting is a natural biological process that mimics the decomposition of organic matter in nature. It involves creating an environment that encourages the activity of microorganisms, such as bacteria, fungi, and other decomposers, to break down organic waste into a nutrient-rich soil amendment called compost. Moreover, composting reduces the generation of GHG emissions, particularly methane, which is produced when organic waste decomposes in anaerobic conditions (such as in landfills). Furthurmore, composting organic waste has several benefits: it reduces methane emissions from landfills, reduces the need for chemical fertilizers, improves crop yields, aids in environmental restoration, remediates contaminated soils, offers cost savings, retains water in soils, and helps capture carbon (EPA, 2023). Utilizing a biodigester machine for composting organic waste presents an effective alternative for enhancing waste management quality because it converts biomass waste into biological substances to improve soil within 24 hours. There is also a production process in every step continuously in a single automatic machine environmentally friendly. As for the use of fossil fuels and electricity in the process, calculations according to equations (4) and (5) are used. The composting process releases GHG in the form of CO_2 from transportation by fossil fuels and the use of electricity from biodigesters. Including the release of CH_4 and N_2O from the fermentation process.

In the case of the shopping center, GHG emissions from the composting activities were estimated using the following equation (TGO, 2023a):

$$PE_{COMP,y} = W_y \text{ x } (EF_{CH_4} \text{x } GWP_{CH_4} + EF_{N_2O} \text{ x } GWP_{N_2O}) \qquad (6)$$

Where:

$PE_{COMP,y}$ is the emission of GHGs from the decomposition of organic waste (tonne of CO_2/year)

W_y is the amount of organic waste in year y (tonne of organic waste)

EF_{CH_4} is the CH_4 emission from the decomposition of organic waste (tonne of CH_4/tonne of organic waste).

GWP_{CH4} is the global warming potential of CH_4.

EF_{N_2O} is the N_2O emission from the decomposition of organic waste (tonne of N_2O /tonne of organic waste).

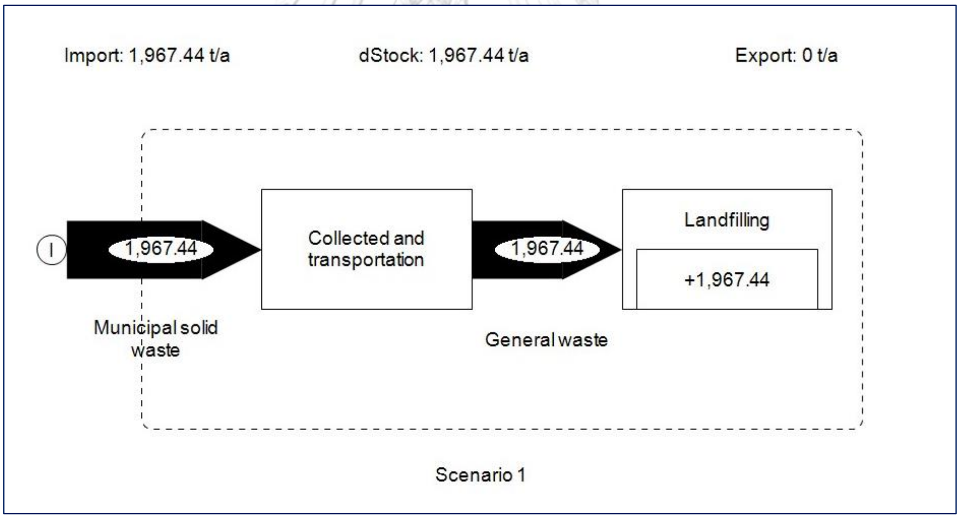
GWP_{N_2O} is the global warming potential of N_2O.

3.3.5 Estimation of GHG from Transportation

The GHG emissions assessment of waste management involves factoring in waste transportation to landfill sites. In the case of transportation, only CO_2 emissions from the use of fuel to transport waste are calculated. The total distance of transportation was calculated, which is calculated using equation (4).

3.4 Description of scenario

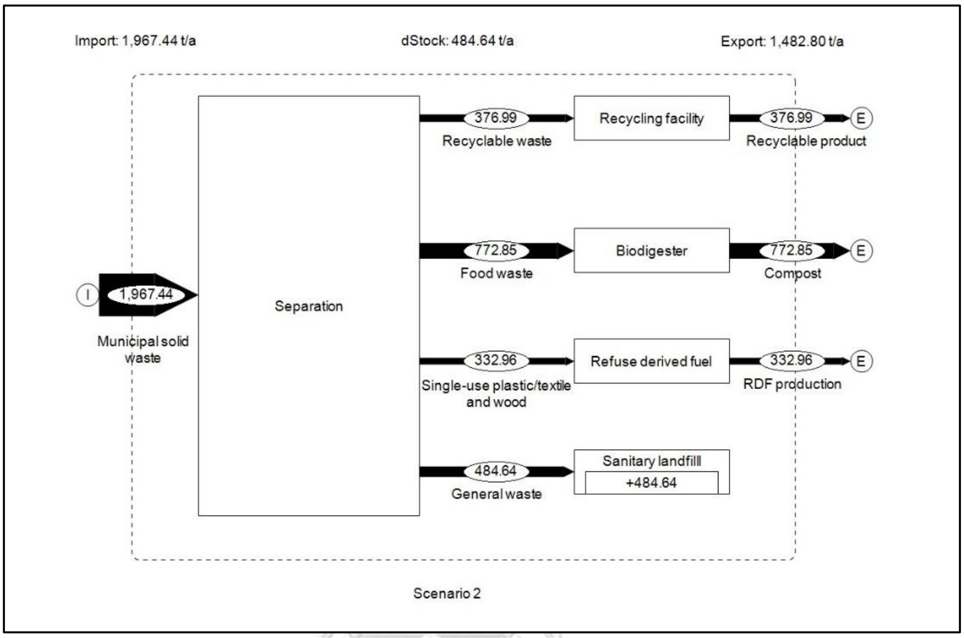
3.4.1 Scenario 1 (S1)



Figures 8. MSW flow of Scenario 1: Current scenario.

Scenario 1 represents the current waste management of this shopping center. All generated waste is classified as general waste, so there is only one way to manage it: landfill and no sorting.

3.4.2 Scenario 2 (S2)



Figures 9. MSW flow of Scenario 2: Alternative scenario.

Scenario 2 represents alternative waste management that supports waste separation at source by sorting four types: recycled waste, food waste, single-use plastic/paper waste, and general waste. Each type of waste has more appropriate management than Scenario 1. To illustrate, recyclable waste such as plastic, aluminum, glass, and paper also enters the recycling plant to convert the waste into products that can be reused again. Moreover, food waste is processed in a biodigester to be fermented into compost and bio-fermentation liquid. Nonthaburi municipality uses orphan waste, which cannot be recycled but can be disposed of by making alternative fuels for coal, known as Refuel Derived Fuel (RDF 5). Finally, all toilet waste is classified as general waste and was only disposed of in a sanitary landfill. This scenario was inspired by Chula Zero Waste (CZW) of Chulalongkorn University, which pushed for proper and sustainable waste management. In adopting Chula Zero Waste's waste management approach for integrated waste management, the research considers it due to its suitable waste disposal practices. This alternative scenario promises a more effective waste management system for the shopping center compared to the current approach represented in Scenario 1. Currently, waste is managed in a single way, with all waste disposed of in landfills without any sorting. Notably, each disposal station in our shopping center provides only one bin for general waste disposal, which prompted our selection of the CZW model. Moreover, Siam Square and Samyan Mitrtown, two other shopping malls, have successfully implemented waste management strategies inspired by CZW. In these malls, waste bins are clearly separated, each with designated destinations, rather than indiscriminately sending everything to landfills. If more shopping centers adopt this approach, featuring separate waste disposal and clear waste destinations, it would undoubtedly contribute to better waste management practices. Moreover, the ratio of each type of waste that is taken to each destination comes from grouping according to the waste detected from the waste composition study.

In terms of the waste management destinations, the various types of waste follow distinct disposal routes:

1) Recyclable Waste: Housewives collect recyclable waste and then sell it to Wongpanich shop in Nonthaburi province, which conveniently resides near the shopping center.
2) Food Waste: Food waste is gathered and transported to a biodigester facility located in Nonthaburi Municipality, near the shopping center.
3) Single-Use Plastic, Textile, and Wood Waste: This category of waste is collected and sold to N15 Technology Company, which operates from Saraburi Province. There, it is transformed into a fuel source that can replace coal.
4) General Waste: The disposal of general waste is typically managed by Nonthaburi Municipality. It involves collecting waste and transporting it to a central holding point before onward transportation to the Sai Noi landfill in Nonthaburi Province.

3.5 Uncertainty analysis

Evaluating the uncertainty analysis in the greenhouse gas inventory for waste management in shopping center is a crucial step indicating the quality of the information employed in the assessment. The method chosen for uncertainty assessment is suitable for addressing uncertainties arising from the data and emissions (Sikiwat Warisara, 2020). These selected factors can be used to assess the quality of the data by assigning scores, as detailed in Tables 4 and 5.

Tables 4. Matrix of mapping data quality indicator.

Scoping of emission factor (E)	**Scoring of data quality (Q)**		
	Q = 6 Data from continuous monitoring	**Q = 3 Data from bills and receipts**	**Q = 1 Data from assumptions**
E = 4 (from direct measurement)	6 x 4 (24)	3 x 4 (12)	1 x 4 (4)
E = 3 (from Thai LCI Database)	6 x 3 (18)	3 x 3 (9)	1 x 3 (3)

Scoping of emission factor (E)	Scoring of data quality (Q)		
	Q = 6 Data from continuous monitoring	**Q = 3 Data from bills and receipts**	**Q = 1 Data from assumptions**
E = 2 (from regional level)	6 x 2 (12)	3 x 2 (6)	1 x 2 (2)
E = 1 (EF from international level)	6 x 1 (6)	3 x 1 (3)	1 x 1 (1)

Tables 5. Uncertainty and data quality levels.

Levels	Total scores	Descriptions
1	1 – 6	High uncertainty, low quality of data
2	7 – 12	Low uncertainty, moderate quality of data
3	13 – 18	Low uncertainty, high quality of data
4	19 - 24	Low uncertainty, very high quality of data

3.6 Waste Reduction and Separation Behavior

3.6.1 Population and Sample

Central Plaza Rattanathibet, located in the center of Rattanathibet Road, Mueang Nonthaburi District, Nonthaburi Province, is the site selected for research. This shopping center complies with the Nonthaburi Municipality's waste management system, which landfills manage all waste. The study was conducted between March 2023 to April 2023. The target groups consist of customers and employees in the shopping center because they are a sample group who know the shopping center's waste management system and are a group of people who regularly produce waste in the shopping center.

Cochran's formula determines the sample size needed for estimating a population proportion when the true population proportion is unknown. The formula is given as follows (Cochran, 1977):

$$n = \left(\frac{Z}{2E}\right)^2 \quad (7)$$

Where:

n = size of sample to be used in research

p = proportion of traits of interest in the population (set at p = 0.5),

Z = value at the confidence level (set at 95%) or the significance level (set at 0.05), where Z has the value is 1.96.

E = The level of sampling error allowed to occur. (set the size of tolerance of 5% or 0.05)

Substitute the values in the formula as follows:

$$n = \left(\frac{1.96}{2 \times 0.05}\right)^2$$

$$n = 384.16$$

By using Cochran's formula, the calculation yields approximately 384 as the minimum required sample size when aiming for a 95% confidence level with a maximum margin of error of 5%. This means that at least 384 individuals from the population should be included in the study. However, for the sake of convenience in data analysis and evaluation, the researchers decided to collect a slightly larger sample of 400 people.

3.6.2 Data collection

The data was collected in three stages.

Stage I: Ask for permission.

The researcher sent a request letter to the manager of Central Plaza Rattanathibet to gain collaboration and access to conduct the research in advance before doing the pre-test and the actual study.

Stage II: Pre-test

The researcher did the pre-test to find the reliability of questionnaires by examining Cronbach Alpha. The questionnaire was tested with 30 employees and food vendors, not in the sample group.

Stage III: Questionnaire Distribution

After the validity and credibility of the questionnaire had been thoroughly checked, the researcher distributed questionnaires to employees and food vendors. The researcher then collected, analyzed and interpreted those data.

3.6.3 Validity

There are 3 steps of validity checking:

1) The questionnaire was presented to the thesis committee for any improvement suggestions.

2) The questionnaire was revised according to the comments and recommendations of the advisory committee.
3) After receiving feedback and recommendations from the advisory committee, the Index of Item-Objective Congruence (IOC) was used to determine content validity.

The Item-Objective Congruence (IOC) was used to evaluate the items of the questionnaire based on the score range from -1 to +1:

Congruent = + 1
Questionable = 0
Incongruent = -1

The items that have scores lower than 0.5 were revised. In contrast, the items with scores higher than or equal to 0.5 were reserved (APPENDIX C).

3.6.4 Reliability

The reliability of the questionnaire was assessed to guarantee the accuracy and consistency of the data acquired using the tool. The questionnaire was tested with 30 customers and staff, not in the sample group.

The reliability value was calculated using Cronbach's alpha to ensure internal consistency within the items. George and Mallery (2010) explained the value of the Coefficient Cronbach's Alpha as the following: ≥ 0.9 = Excellent, ≥ 0.8 = Good, ≥ 0.7 = Acceptable, ≥ 0.6 = Questionable, ≥ 0.5 = Poor, and ≤ 0.5 =Unacceptable. For the research questionnaire to be reliable, its value of Coefficient Cronbach’s Alpha must be at least 0.7 (George & Mallery, 2010).

3.6.5 Research instrument

All questionnaires were distributed and collected through field visits. The questionnaire was distributed face-to-face to the customers and staffs in the shopping center after being revised based on comments from questionnaire pretesting. Moreover, the questionnaire was designed based on the guidelines for constructing a Theory of Planned Behaviour (TPB) questionnaire (Ajzen, 2019) and divided into 3 main parts:

(1) demographic information

(2) TPB constructs measurements

(3) suggestions

In the second part, most of the questions were asked using a five-point Likert-type scale, ranging from (e.g., 1 = strongly disagree and 5 = strongly agree, etc.). In addition, there are 5 sections in part 2, which are based on theory of planned behavior. All the five sections were arranged accordingly shown as in table 2. To avoid inductivity and increase the diversity of the answers, all of the question items will present in a random order (APPENDIX D).

Hence, according to the five levels of frequency, the interpretation of these responses will be calculated by using the following formula:

$$\text{Interval} = \frac{\text{the highest score} - \text{the lowest score}}{\text{the number of interval}} \tag{8}$$

For this reason, the interval scale in this study is:

$$\text{Interval} = \frac{5-1}{5} = 0.8$$

Therefore, range of five levels of frequency as detailed below:

Mean range	**Meaning**	**Interpretation**
4.21 - 5.00	Very good	Highest level of separating waste
3.41 - 4.20	Good	High level of separating waste
2.61 - 3.40	Neutral	Moderate level of separating waste
1.81 - 2.60	Bad	Low level of separating waste
1.00 - 1.80	Very bad	Lowest level of separating waste

3.6.6 Data analysis

The quantitative data is analyzed using Statistical Program for Social Sciences (SPSS). Descriptive statistics, including frequencies, percentages and measures of dispersion (range and standard deviation), are the most appropriate for analyzing the quantitative data. In addition, correlation and multiple regression analyses were employed to examine the association between each factor.

Chapter 4
Results and discussions

4.1 Waste composition analysis

4.1.1 Scenario 1

This study specifically focused on analyzing the composition of MSW. According to the definition provided by the Pollution Control Department, MSW refers to solid waste generated from various community activities, including residential households, businesses, shops, establishments, bazaars, and institutions. It encompasses construction waste but excludes hazardous and infectious waste (PCD, 2021).

The study identified 12 classifications for MSW. Table 3 and Figure 10 depict the primary composition of MSW in scenario 1, which represents the current waste management practices at Central Plaza Rattanathibet. Food waste accounted for the largest proportion of the waste components, weighing in at 39.28%. This was followed by other waste at 24.63%, plastic at 15.52%, paper and board at 10.48%, glass at 5.45%, textile at 2.70%, wood at 1.02%, and metal and aluminum at 0.92%. Notably, no gardening waste, rubber and leather, diapers, and foam were detected during the survey. All 12 types of waste mentioned in the study were entirely managed through landfill disposal.

The quantity and rate of MSW produced at Central Plaza Rattanathibet vary depending on the type of activities in the shopping center and the number of individuals present, including employees, customers, and vendors. Based on the survey conducted at Central Plaza Rattanathibet, the estimated amount of MSW generated annually was 1967.44 tonnes, with a density of 220 kg/m^3 (APPENDIX B). Table 6 and Figure 10 provide the specific composition of MSW originating from the shopping center. The waste quantity and composition assessment at Central Plaza Rattanathibet was conducted in the shopping center's waste collection room by conducting surveys and analyzing the waste composition using the quartering method.

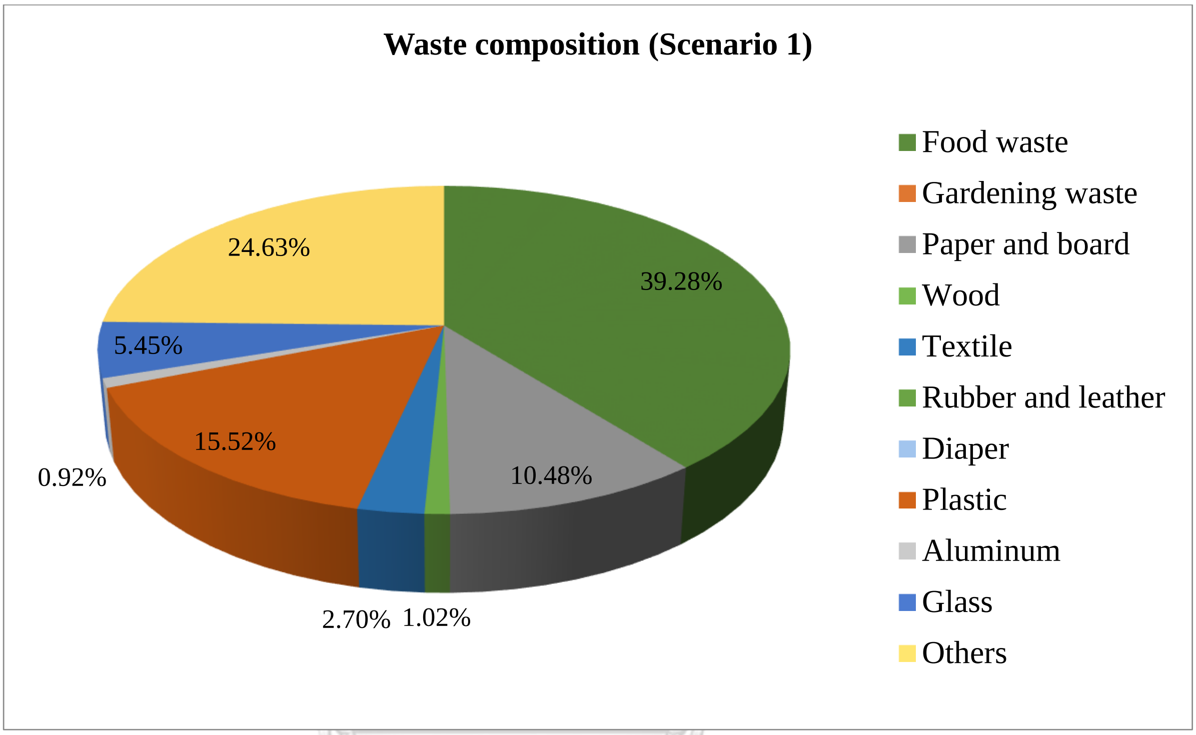
Tables 6. Waste composition (% mass per wet basis) analysis MSW in scenario 1.

Material classification	Proportion (%w/w)	Quantity of waste (tonnes/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

Material classification	Proportion (%w/w)	Quantity of waste (tonnes/year)
Rubber and leather	-	-
Diaper	-	-
Plastic	15.52	305.37
Foam	-	-
Metal and aluminum	0.92	18.11
Glass	5.45	107.18
Others	24.63	484.64
Total	100	1,967.44

The data reveals that more than 30% of the waste sample collected in Scenario 1 from the shopping center is biodegradable, totaling 772.85 tonnes/year. The main contributor to this category is the kitchen waste generated by food courts, restaurants, and flea markets within the shopping center. The results of this study are consistent with the study of Sinaga (2016), which stated that the research findings revealed that Depok Town Square produced a higher amount of organic waste compared to other types of waste. The organic waste primarily originated from non-consumable food items, vegetables, meat, and fruit waste from the hypermart located within the shopping. Sinaga's research emphasized the significance of effective waste management, particularly focusing on waste generated in the mall's food court area, where Depok Town Square predominantly offers fast food options (Adiandri & Kristanto, 2019). According to Pleumchingchai's investigation in 2019, which centered on waste composition within shopping center structures in Nakhon Ratchasima, the primary waste constituent was food waste, comprising the largest portion at 40.93%. Following this, other waste components constituted 26.34%, plastic accounted for 19.04%, paper comprised 8.83%, glass constituted 1.98%, while metal and wood had proportions of 1.33% and 0.86%, respectively. Additionally, fabric and rubber had even smaller proportions of 0.45% and 0.24%, respectively. The study's findings highlight the significant prevalence of food waste, which can be attributed to the presence of a food department and restaurant spaces within the examined shopping center. This observation aligns with similar studies that have consistently identified food waste as a prominent waste type in shopping center contexts (Pluemchingchai, 2019).

The most prominent waste compositions identified in the study were food waste, other waste, plastic, paper and board, and glass (APPENDIX A). Food waste primarily consists of fruit peels, eggshells, vegetable scraps from cooking, and leftovers from meals. The presence of numerous users in service facilities and shopping centers leads to a significant amount of toilet tissue waste, which contributes to the category of other waste. Additionally, the lack of waste sorting practices results in the indiscriminate mixing of all types of waste, contributing to a substantial portion of this particular waste category. Plastic waste mainly comprises plastic drinking bottles and cups from coffee shops and water vendors in the food court. Paper and board waste mainly originate from coffee shops, including milk cartons, whipped cream cartons, and paper cups. Lastly, glass waste primarily consists of glass beverage bottles. Overall, these waste compositions dominate the scenario 1 sample from the shopping center, reflecting the specific sources and types of waste generated in that environment.



Figures 10. Percentage of MSW (% wet mass) in different waste types (scenario 1).

4.1.2 Scenario 2

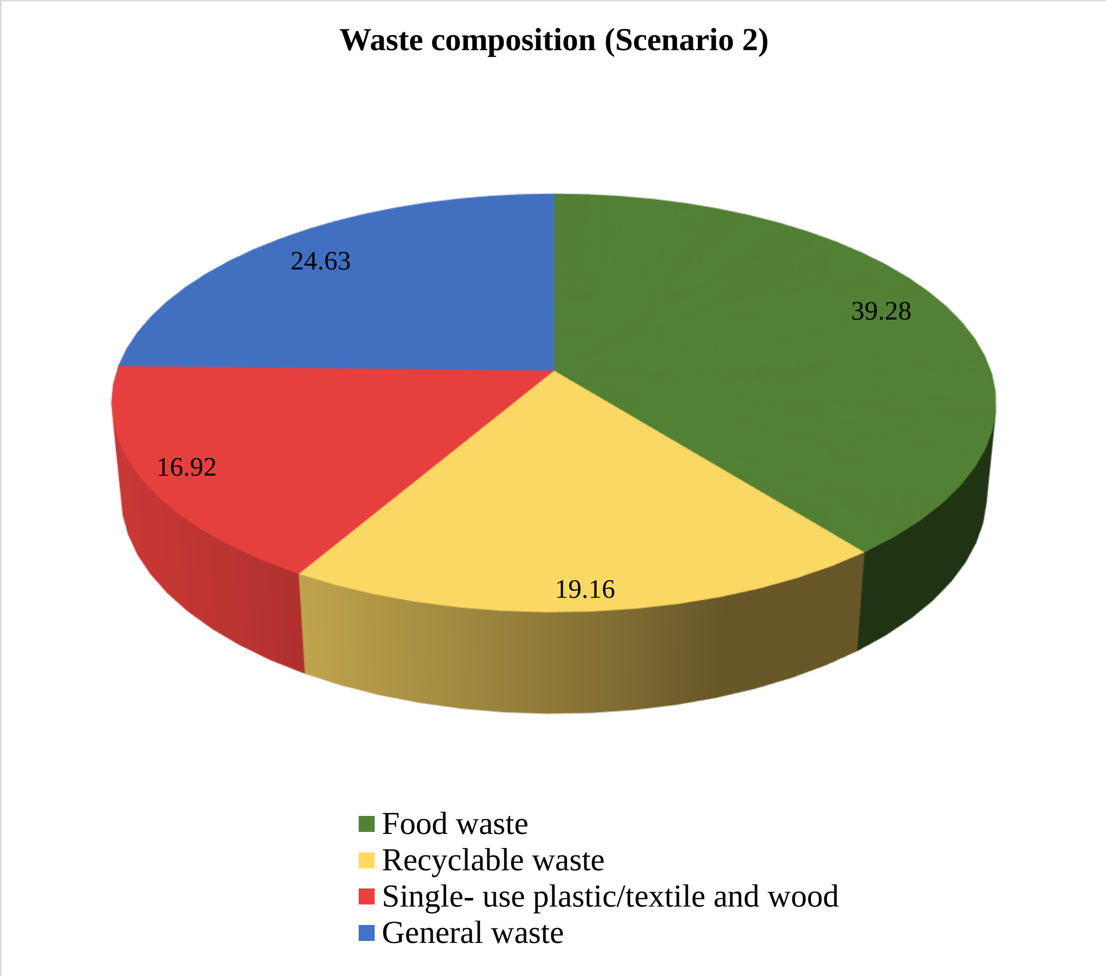
The survey and analysis results obtained in scenario 1 were further categorized into four waste types, referred to as scenario 2, based on their handling characteristics. These categories include food, recyclable, single-use plastic/textile and wood, and general waste. The distribution and quantities of waste in scenario 2 are presented in Table 7 and Figure 11.

The study revealed that food waste constituted 39.28% of the total waste and encompassed cooked food and raw materials used in cooking. Recyclable waste, comprising plastic bottles, aluminum, and glass, accounted for 19.16% of the total waste and was sold to recycling facilities for further processing. Single-use plastic, textile, and wood waste made up 16.92% of the waste, which was categorized as Refuse Derived Fuel (RDF) or ขยะกำพร้า by the Nonthaburi Municipality and would be managed through incineration as fuel or Refuel derived fuel 5 (RDF 5). Lastly, 24.63% of the waste, mainly toilet waste, would be sent to a landfill as general waste.

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 because the waste generated in shopping centers is typically a representative subset of the broader waste generated in urban settings. Shopping centers serve a large number of people from various backgrounds, and the waste generated reflects the consumption patterns and habits of urban populations. In urban areas, MSW is a mixture of different types of waste, including food waste, packaging materials (plastics, paper, and cardboard), glass, metals, textiles, and other miscellaneous items. Similarly, in shopping centers, there is a significant presence of food waste from food courts and restaurants, packaging waste from retail products, and other types of waste commonly found in urban areas. Moreover, shopping centers are commercial establishments where various goods and products are sold, leading to a higher concentration of waste compared to residential areas. The waste composition is influenced by consumer behavior, the types of businesses operating in the shopping center, and the availability of waste management facilities. Overall, the similarity in waste composition between the samples taken from this shopping center and MSW from urban areas reinforces the notion that shopping centers play a substantial role in generating waste that reflects the consumption patterns of urban communities (PCD, 2016).

Tables 7. Waste composition (% mass per wet basis) of MSW in scenario 2.

Material classification	Proportion (%w/w)	Quantity of waste (tonnes/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



Figures 11. Percentage of MSW (% wet mass) in different waste types (scenario 2).

4.2 Greenhouse gas emissions

Waste management activities, such as landfilling, composting, and recycling, affect GHG emissions due to energy consumption and the chemical reactions involved in these processes. In the case of Central Plaza Rattanathibet, the waste management operations are currently handled by the Nonthaburi City Municipality, and the waste is directed to a landfill located in Sai Noi Subdistrict, Sai Noi District, Nonthaburi Province, employing landfill management techniques. However, this approach releases pollutants into the environment. Two scenarios were simulated to estimate GHG emissions from each scenario to identify a sustainable waste management approach for the shopping center. GHG emissions from waste management are both direct and indirect emissions.

Direct emissions in this study refer to greenhouse gas emissions that result from all waste management processes, including decomposition in landfills, composting, fossil fuel consumption in transportation and operations, and electricity consumption. Indirect emissions savings, on the other hand, involve reducing greenhouse gas emissions resulting from avoiding landfill by treating waste through other methods, such as composting, recycling, and RDF 5. The calculation uses tools from T-VER, the calculation method is shown in APPENDIX B.

4.2.1 Scenario 1

Landfilling is the prevailing waste management method adopted in numerous cities globally for handling MSW. This approach entails waste disposal in designated areas at lower elevations, where it naturally decomposes without strict regulation. Regrettably, this decomposition process releases GHGs, with methane (CH_4) being the primary gas emitted. The Intergovernmental Panel on Climate Change (IPCC) guidelines recommend utilizing the first-order decay (FOD) technique to obtain accurate emissions estimations that align with the natural waste degradation in landfills.

The GHG emissions from scenario 1, which represents shopping center' current waste management practices without waste sorting, involve sending all waste to the Sai Noi landfill in Nonthaburi province. The distance between the shopping center and the waste collection point, and the transportation to the landfill is 40 kilometers. The emissions from sanitary landfills encompass both the decomposition process and operational activities.

Approximately 1,967.44 tonnes of mixed MSW are landfilled annually at this shopping center. The decomposition of the disposed MSW leads to the production of around 35.68 tonnes of CH_4/tonne of waste landfilled. Converting the estimated CH_4 emissions into their GHG equivalent (CO_2eq.), the total emissions from the decomposition of landfilled MSW amount to approximately 115.10 tonnes of CO_2eq/year. Additionally, the transportation to landfill contributes an estimated 9.84 tonnes CO_2eq/year. Consequently, the total estimated GHG emissions from the entire landfill system in this shopping center reached 124.94 tonnes of CO_2eq/year, as presented in Table 8. It is also calculated as 0.06 tonnes CO_2eq/tonne of waste.

The analysis reveals that decomposition in the landfill generates more GHG emissions than transportation. There may also be GHG emissions from landfill operations, which were not taken into account in this research because it is within the scope of the Nonthaburi Provincial Administrative Organization.

Tables 8. Estimations of GHG emissions resulting from landfill activities at Central Plaza Rattanathibet.

In the context of the sanitary landfill (Decomposition)		
Categories	**Quantity**	**Unit**
Total mix waste disposal at the landfill sites	1,967.44	tonnes/year
tonne of CH_4 /year	4.11	tonne of CH_4 /year
Global Warming Potential	28.00	
GHG emission from landfilling	115.10	tonne CO_2eq/year

In the context of the transportation to landfill		
Diesel consumption for operating machinery at the landfill	3,650	litre/year
A diesel requirement	1.86	litre/tonne of waste
The total energy consumed by diesel	67.57	MJ/tonne of waste
Default CO_2 emission factor for combustion	0.074	kg CO_2 /MJ
GHG emissions due to fossil fuel consumption	9.84	tonne CO_2eq/year
Total GHG emissions from sanitary landfill sites	124.94	tonne CO_2eq/year

An example calculation in landfill of scenario 1 is shown below.

$$BE_{CH4,SWDS,y} = \varphi_y x (1 - f_y) x GWP_{CH4} x (1\text{-}OX) x 16/12 x F x DOC_{f,y} x MCF_y x \sum_{x=1}^{y} \cdot \sum_{j} W_x x p_j x DOC_j x e^{-kj(y-x)} x(1-e^{-kj})$$

$$BE_{CH4,SWDS,y} = 0.85 x (1 – 0) x 28 x (1 – 0.1) x 16/12 x 0.5 x 0.5 x 1.00 x \{[772.85 x 0.39 x 0.15 x e^{-0.4} x (1 – e^{-0.4})] + [20.00 x 0.01 x 0.43 x e^{-0.035} x (1 – e^{-0.035})] + 690.84 x 0.35 x 0.4 x e^{-0.07} x (1 – e^{-0.07})] + [53.09 x 0.03 x 0.24 x e^{-0.07} x (1 – e^{-0.07})]\}$$

$BE_{CH4,SWDS,y}$ = 115.10 tonne CO_2eq

Transportation

$$PE_{FF,y} = \sum(FC_{PJ,i,y} x (NCV_{i,y} x 10^{-6}) x EF_{CO_2,i}) x 10^{-3}$$

$$PE_{FF,y} = (3,650 x (36.42 x10^{-6}) x 74,100) x 10^{-3}$$

$PE_{FF,y}$ = 9.84 tonne CO_2eq /year

Total GHG emissions from landfill = 115.10 + 9.84 = 124.94 tonnes CO_2eq /year

4.2.2 Scenario 2

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 specific activities. When calculating the emissions for each waste management process in Scenario 2, Scenario 1 serves as the baseline for emissions. Subsequently, the project emissions are calculated, and the emissions reduction is determined by subtracting the baseline emissions from the project emissions, resulting in the net emissions associated with each process. Comprehensive calculations for each step can be found in APPENDIX B.

4.2.2.1 GHG Emissions from Composting

The composting process utilized a total of 772.85 tonnes/year of food waste, while the transportation of the composting facility required 3,193.75 liters/year of fossil fuel (specifically diesel) and uses electricity from the biodigester machine 3,240 kWh/year. Furthermore, the composting system generated 618.24 tonnes/year of compost. The GHG emissions from the operational activities, including transportation and electricity use, were estimated at 10.19 tonnes CO_2eq/year, while the degradation of organic waste produced 84.24 tonnes CO_2eq/year. The total GHG emissions from the composting system were calculated to be 94.43 tonnes CO_2eq/year, combining these estimated emissions from operational activities and organic waste degradation.

The decision to use a biodigester machine for managing food waste at Central Plaza Rattanathibet was made due to the predominantly vegetable, fruit waste, and coffee ground resulting from food court and coffee shop. This type of waste is well-suited for processing with a biodigester machine, making it the best choice for composting and waste management purposes. Biodigester machine is specifically engineered to address issues related to organic waste. It is particularly effective in handling foul-smelling organic waste or biomass. The machine has the capability to transform organic waste into beneficial bio-nutrients within a span of 24 hours, starting from the moment the waste is introduced into the machine. This is achieved through a combination of mechanical and microbial decomposition processes that efficiently break down the waste without causing any harm to the environment. The biodigester functions as a continuous system, allowing waste to be added at any time. Moreover, an automated electrical system is incorporated to regulate the entire process automatically. The biodigester produces compost and bioextract that can be used as nutrients for plants. Furthermore, composting is a process that relies on oxygen and is well-suited for organic materials with lower moisture content (Kristanto & Koven, 2019).

Tables 9. GHG emission estimates from composting activities.

Categories	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	litre/year
The total amount of compost production	618.24	tonnes/year
GHG emissions from operational	10.19	tonne CO_2eq/ year

activities (transportation and electricity use)		
GHG emissions from waste degradation	84.24	tonne CO_2eq/ year
Direct GHG emissions from composting	94.43	tonne CO_2eq/ year
Avoided GHG emissions from organic waste landfilling	- 215.19	tonne CO_2eq/ year
Net GHG emissions from composting	- 120.76	tonne CO_2eq/year

If the 772.85 tonnes of organic waste is subjected to sanitary landfill disposal instead of being composted annually, a substantial quantity of GHG emissions arises from the decomposition of the organic waste within the landfills. The estimated GHG emissions were calculated to be 215.19 tonnes CO_2eq/year. However, by composting the 772.85 tonnes of food waste, the emissions of GHGs equivalent to 215.19 tonnes CO_2eq/year were avoided from landfill because if food waste is managed with compost instead,, it will release just 94.43 tonnes CO2eq /year of GHG. Therefore, composting food waste can reduce GHGs for the whole year, net (-) 120.76 tonnes CO_2eq/year, as shown in Table 9. It is also calculated as - 0.15 tonnes CO_2eq/tonne of waste.

4.2.2.2 GHG Emissions from Recycling

Recycling offers various benefits and serves as an environmentally conscious approach to waste management. It allows for the recovery of valuable materials while reducing the release of substantial quantities of GHGs and harmful pollutants (Verma & Borongan, 2022). As a result, integrating recycling practices into a comprehensive waste management system is crucial for achieving sustainability goals and improving the system's overall efficiency. The calculation of the recycling process is performed using the GHG calculator for solid waste ver.Thai II-2013, the program page of which is shown in APPENDIX B.

Tables 10. Quantity and proportion of each type of recyclable waste.

Types of waste	Quantity of waste (tonnes/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

Central Plaza Rattanathibet has four categories of waste that can be recycled: paper, plastic, metal, and glass bottles. Each category was separated based on its type, as indicated in Table 10. The GHG emissions estimates are derived from the

Menikpura (2011) GHG emission coefficient. The GHG emissions of recycle process accounting to 426.92 tonnes CO_2eq/year. The recycling process is intricate and entails energy consumption for sorting and transporting recyclable waste from its source to sorting facilities and recycling plants. Consequently, these activities significantly contribute to the release of GHGs (MENIKPURA Nirmala, 2013). However, the materials obtained through recycling can potentially replace an equivalent amount of new materials, thereby effectively reducing substantial GHG emissions. At this shopping center, recycling 376.99 tonnes of MSW annually has reduced GHG emissions by 1,113.76 tonnes CO_2eq/year. Therefore, the amount of emissions net GHG throughout the year is calculated as (-) 686.84 tonnes CO_2eq/year. It is also calculated as – 1.82 tonnes CO_2eq/tonne of waste. The negative values signify decreased GHG emissions from the MSW recycling process. In a study by Liu et al. (2020), recycling presents the chance to prevent the breakdown of waste materials that lead to greenhouse gas emissions (Liu et al., 2022). Moreover, it has the potential to promote resource sustainability by substituting recycled materials for raw materials, while also diminishing greenhouse gas emissions stemming from organic waste through the prevention of emissions from landfills (Yaro et al., 2023).

Recycling non-organic compositions of MSW, such as glass, paper, aluminum cans, and mixed plastics, can lead to significant reductions in GHG emissions, as demonstrated by Turner et al. (2015). Specifically, this research found that recycling these materials can result in GHG emissions reductions of up to 314 kg CO_2eq/tonne for glass, 459 kg CO_2eq/tonne for paper, 8,143 kg CO_2eq/tonne for aluminum cans, and 1,024 kg CO_2eq/tonne for mixed plastics (Turner et al., 2015).

Similarly, Ayodele et al. (2018) estimated that recycling MSW in Nigeria could lead to the avoidance of 307,364 tonnes of CO_2eq GHG emissions (Ayodele et al., 2018). Friedrich and Trois (2013) also demonstrated GHG savings through recycling, with reductions of 19,110.7 kg CO_2eq/tonne for aluminum, 568.6 kg CO_2eq/tonne for paper, 290.1 kg CO_2eq/tonne for glass, 980 kg CO_2eq/tonne for plastic, and other savings in a South African context (Friedrich & Trois, 2013). These studies confirm that separating waste for recycling can help reduce GHG emissions.

4.2.2.3 GHG Emissions from Refuse Derived Fuel (RDF 5)

The RDF-5 process is implemented to sort single-use plastic/textile and wood waste, which various alternative agencies have recommended as an appropriate waste management method. The RDF process involves multiple activities, such as waste transportation, shredding, hot air drying, and briquetting, which rely on fuel and electricity (G A Kristanto, 2020). These steps aim to convert waste into a fuel source capable of replacing coal. This specific study focuses on waste sorting, specifically single-use plastic/textile and wood, up until the stage of waste briquetting. The findings demonstrate that the RDF-5 process generates a total GHG emission of 13.30 tonnes of CO_2eq /year, which is the result of transportation and electricity use.

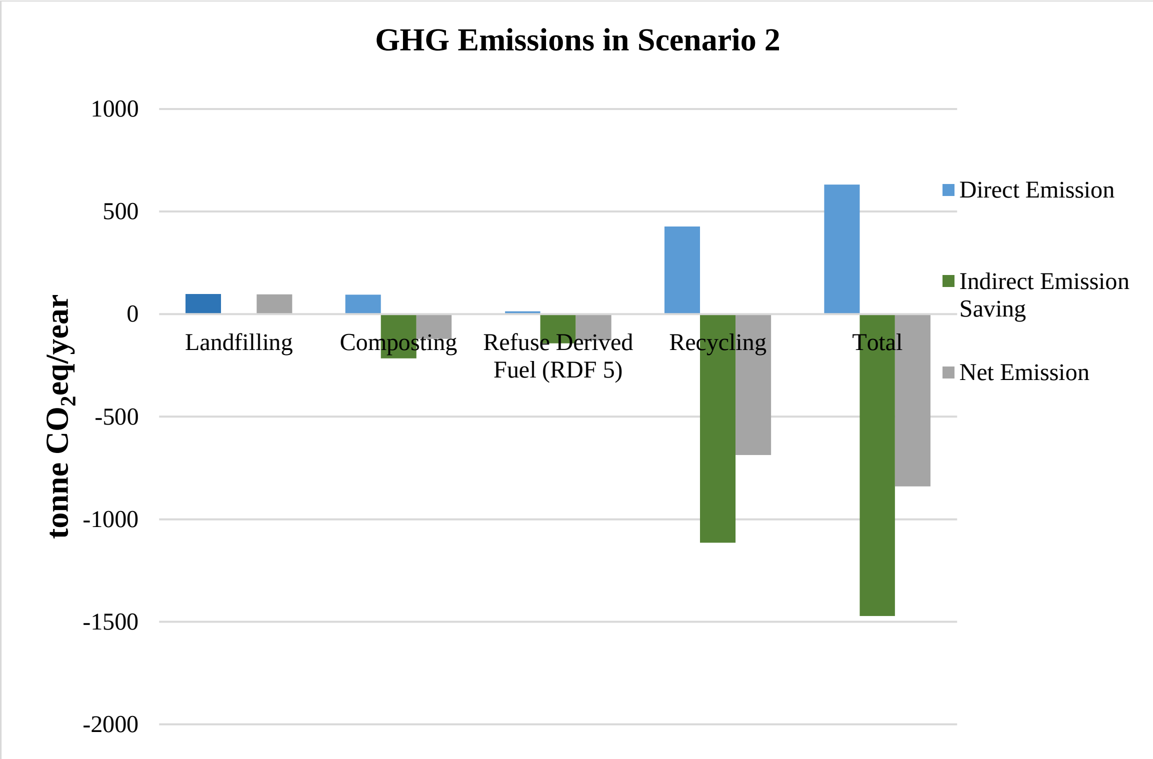
If the annual amount of 332.96 tonnes of single-use plastic/textile and wood waste were not sorted and disposed of in a sanitary landfill, it would result in GHG emissions of 142.16 tonnes of CO_2eq/year. Nevertheless, subjecting these wastes to the RDF-5 process can reduce GHG emissions by (-) 142.16 tonnes of CO_2eq/ year. As a result, the total net GHG emissions would be (-) 128.86 tonnes CO_2eq/year. It is also calculated as – 0.38 tonnes CO_2eq/tonne of waste.

4.2.2.4 GHG Emissions from Landfilling

Through the seperation of food waste, recyclable materials, and waste suitable for RDF processing, the resulting waste sent to landfill is left with general waste, which is waste from toilets. To illustrate, waste from bathrooms is mostly toilet paper, which when GHG emissions are estimated is 87.25 tonnes CO_2eq/year and from transportation it is 9.84 tonnes CO_2eq /year. Therefore, GHG emissions from landfills in scenario 2 are only 97.09 tonnes CO2eq per year, representing a reduction from scenario 1 where all waste is sent to landfills. It is also calculated as 0.2 tonnes CO_2eq/tonne of waste. This demonstrates that proper waste separation has proven that when waste is appropriately sorted for its intended destinations, the amount of waste remaining for landfill disposal is minimal or non-existent. This significantly benefits waste management agencies, allowing them to operate more efficiently.

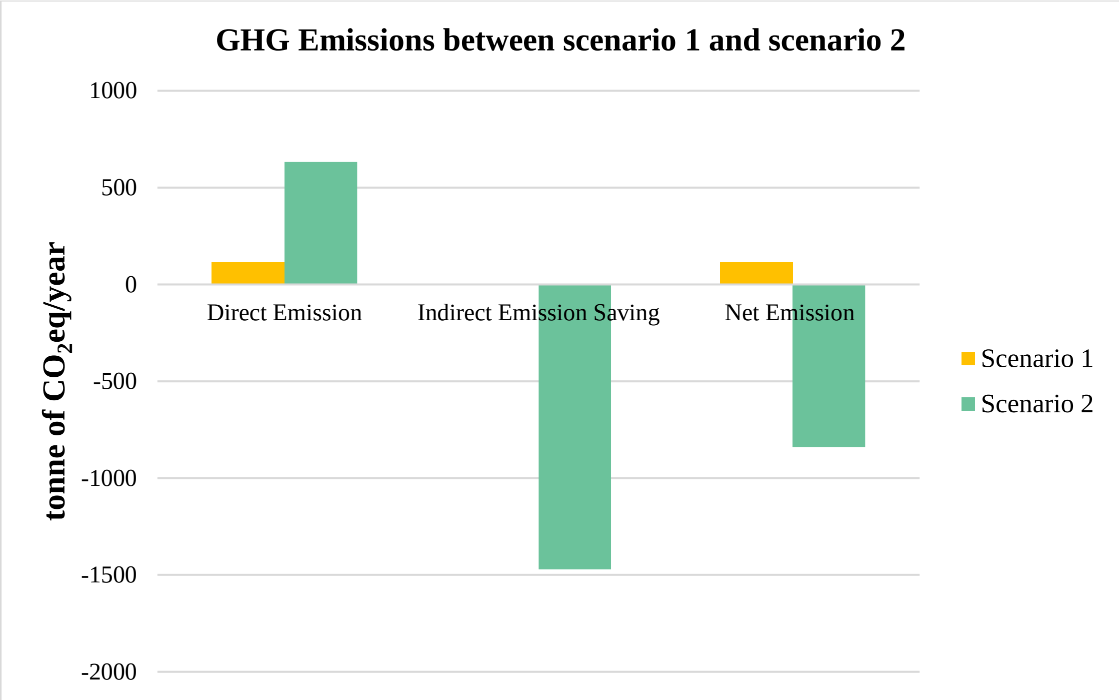
Tables 11. Summary of estimates of GHG emissions from MSW management activities in Central Plaza Rattanathibet of scenario 2.

Activity	**GHG Emissions (tonnes CO_2eq/year)**			**GHG Emissions (tonnes CO_2eq/tonne of waste)**
	Direct Emission	**Indirect Emission Saving**	**Net Emission**	**Net Emission**
Landfilling	97.09	-	97.09	0.20
Composting	94.43	- 215.19	- 120.76	- 0.15
Refuse Derived Fuel (RDF 5)	13.30	- 142.16	- 128.86	- 0.38
Recycling	426.92	- 1,113.76	- 686.84	- 1.82
Total	631.74	- 1,471.11	- 839.37	- 2.15



Figures 12. The GHG estimates encompass direct emissions, indirect emission savings (or avoidance), and net emissions

Table 11 and Figure 12 provide an overview of the GHG emissions stemming from the waste management system in scenario 2. The study findings indicate that proper waste sorting significantly reduces GHG emissions from landfills, resulting in minimal emissions in this scenario. The main greenhouse gas emissions in this scenario come from recycling, which can result from the process of using coal and diesel to produce thermal energy. At the same time, the recycling process has the most indirect emission savings because it helps reduce greenhouse gas emissions from the production of materials from raw materials and landfill. Moreover, other practices, namely composting and RDF 5, can also effectively reduce most greenhouse gas emissions. Regarding landfills, direct greenhouse gas emissions have reduced due to a decrease in the quantity of organic waste being disposed of there, with only toilet waste remaining. As a result, the net GHG emissions from these three processes were negative, indicating emission reductions. The study estimated that in this scenario, the overall MSW management system achieved direct GHG emissions of 631.74 tonnes CO_2eq/year and indirect GHG emissions savings of -1,471.11 tonnes CO_2eq/year. Considering the contributions of each MSW management process (landfilling, composting, RDF 5, and recycling), the net GHG emission from the MSW management system at the shopping center was - 839.37 tonnes CO_2eq/year.



Figures 13. Contrasting the GHG emissions between scenario 1 and scenario 2.

Figure 13 illustrates the comparison of GHG emissions assessment between scenario 1 and scenario 2, highlighting a significant reduction in GHG emissions in scenario 2. In scenario 1, the direct emissions amount to 124.94 tonnes CO_2eq/year, while scenario 2 exhibits a direct emission of 631.74 tonnes CO_2eq/year. By the way, scenario 1 does not achieve complete avoidance of indirect emissions, as all waste is managed in landfills. Conversely, scenario 2, with alternative management practices, demonstrates substantial GHG emission savings of - 1,471.11 tonnes CO_2eq/year. As a result, the net GHG emissions from the MSW management system in the shopping center are calculated as 124.94 tonnes CO_2eq/year for scenario 1 and – 839.37 tonnes CO_2eq for scenario 2. Moreover, it also represents 0.06 tonnes CO_2eq/tonne of waste in scenario 1 and -2.15 tonnes CO_2eq/tonne of waste in scenario 2.

The research on greenhouse gas emissions from waste management in department stores in Nakhon Ratchasima Province revealed interesting findings. Building A exhibited a wide emissions range, spanning from 7.41 to 65.72 tonnes CO_2eq/tonne of waste. In contrast, Building B's emissions were more consistent, falling within the range of 2.25 to 2.27 tonnes CO_2eq/tonne of waste (Pluemchingchai, 2019).

Furthermore, a study by Atitinon Phuphatthong (2017) emphasized the diverse activities within department store buildings, attracting a substantial number of visitors. This study unveiled that shopping center buildings generate a significant amount of waste, ranging from 990 to 7,600 tonnes/year. This, in turn, results in greenhouse gas emissions ranging from 2,600 to 20,000 tonnes CO_2eq/year, equivalent to approximately 2.63 tonnes CO_2eq/tonne of waste. Notably, the predominant types of solid waste include food waste, paper, and plastics (Phupadtong Athitinon, 2018).

These findings indicate that the greenhouse gas emissions from Central Plaza Rattanathibet's shopping center are comparatively lower than those in other referenced studies. The composition of waste aligns with patterns observed in similar studies. The composition of waste and the amount of greenhouse gas emissions depend on the activities of the shopping center and the number of customers who visit the shopping center.

Michel Devadoss, P.S. (2021) concludes that the best strategy to reduce GHG emissions is an integrated approach toward MSW management (Michel Devadoss et al., 2021). Additionally, the work of Chuenwong, Kannaphat, et al. (2022) states that on-site waste sorting plays a potential role in achieving net-zero emissions in waste management. The sorting of organic waste holds significant potential for reducing greenhouse gas emissions by preventing methane release from landfills. Various scenarios presented in this study assist decision-makers in identifying the most suitable waste management approach based on specific circumstances (Chuenwong et al., 2022). The research concludes that attaining net-zero emission targets is a challenging yet feasible endeavor, contingent upon different constraints and contexts. The study offers alternative strategies for municipal solid waste management to attain net-zero emissions, serving as guidance for policymakers and local authorities. Furthermore, emphasizing the importance of public awareness in municipal solid waste management is crucial for its effectiveness. These studies therefore confirm that the integrated waste management can help reduce GHG emissions from waste management and allow waste to be managed in a more appropriate destination. In addition, waste sorting at the source is an important aspect of shopping center’s waste management. If a good and quality system is put in place, it will make waste management more convenient.

4.2.3 Uncertainty analysis

Based on the uncertainty analysis, it was determined that the quality level of most assessments was at level 1 and 2 (the lowest level). This is primarily because the data collection relied heavily on secondary data, which tends to be somewhat inaccurate. Furthermore, Thailand has not yet established emission factors that are sufficiently precise, necessitating the use of international-level emission factors. Consequently, data concerning fuel and electricity usage received lower ratings due to the potential inaccuracies, as shown in Table 8. To improve scores in this aspect of the assessment, Nonthaburi Municipality and shopping center should implement a continuous data collection system.

Table 8. Uncertainty analysis

Scenarios		Resources and energy used	Data sources	Sources of Emission factors	Data quality (Q)	Scoring of EF (E)	Q x E	Quality levels
1	Landfill	Fuel consumption	Receipt	TGO	3	3	9	2
2	Composting	Fuel consumption	Estimation	TGO	1	3	3	1
		Electricity consumption	Receipt	TGO	3	3	9	2
	Recycling	Fuel consumption	Estimation	TGO	1	3	3	1
		Recycling process	Estimation	GHG calculator for solid waste ver.Thai II-2013	1	3	3	1
	RDF 5	Fuel consumption	Estimation	TGO	1	3	3	1
		Electricity consumption	Estimation	TGO	1	3	3	1
	Landfill	Fuel consumption	Receipt	TGO	3	3	9	2

The initial investigation focused on the waste composition and quantifying the greenhouse gas emissions associated with waste management practices within the shopping center. This included an assessment of emissions from waste transportation, landfill disposal, and varios disposal waste management methods. The findings highlighted the significant environmental impact of conventional waste management methods, prompting a deeper exploration of sustainable alternatives. The study also found that integrated waste management, which is the proper management of waste by type, has lower net emissions than landfill management alone. Recognizing the importance of consumer engagement in sustainable waste management, the study conducted a subsequent study to understand customer attitudes towards waste separation in the shopping center. Surveys and interviews were administered to assess their awareness and willingness to participate in waste separation initiatives. The study also explored the factors influencing customer and staff behaviors in regard to waste disposal.

4.3 Attitude and behavior of waste reduction and sorting

The reliability of this questionnaire was assessed using Cronbach's alpha with a score of 0.86, which means that the questionnaire has a good level of reliability. The inter-item reliability of the specific elements or scales was assessed, resulting in reliability coefficients of 0.70 for the attitude scale, 0.64 for the subjective norm scale, 0.77 for the perceived behavioral control scale, 0.76 for the intention scale, and 0.64 for the behavior scale (APPENDIX C). The relationships among the elements in the model were examined to determine their significance. Table 12 displays the correlations, which were statistically significant at a level below 0.01.

Tables 12. Simple correlations among the scales.

Scale	Attitude	Subjective Norm	Perceived behavioral control	Intention
Subjective Norm	0.464	-	-	-
Perceived behavioral control	0.422	0.565	-	0.658
Intention	0.464	0.573	0.658	-
Behavior	0.388	0.498	0.661	0.691

4.3.1 Characteristics of the study participants

The general information analysis about customers and employees at Central Plaza Rattanathibet, located in Muang Nonthaburi District, Nonthaburi Province, yielded several results. A total of 406 respondents participated in the survey, and the questionnaire was categorized based on the gender, age, education level, occupation, income, and frequency of visiting shopping center. The data were analyzed using frequency and percentage statistics, as presented in Table 9 with details as follows:

Table 13 presents the gender distribution of the respondents, indicating a higher proportion of female participants at 60.1%, followed by male participants at 37.7%. Additionally, the other (LGBTQ+) accounted for 2.2% of the respondents.

Tables 13. Gender of the study participants.

Variables		Frequency (n = 406)	Percentage (%)
Gender			
	Male	153	37.7
	Female	244	60.1
	Other	9	2.2

Table 14 displays the age distribution of the respondents. Most participants, accounting for 52.2%, fell within the age range of 21 to 35. Participants under 20 years old and those between the ages of 36 to 55 accounted for 20.2% and 20.0%, respectively. Lastly, respondents over 55 constituted 7.6% of the sample.

Tables 14. Age of the study participants.

Variables		Frequency (n = 406)	Percentage (%)
Age (years)			
	Under 20 years old	82	20.2
	21 – 35	212	52.2
	36 – 55	81	20.0
	Over 55 years old	31	7.6

Table 15 shows the respondents' status; most are single, representing 76.4%, followed by married 23.4% and other 0.2%.

Tables 15. Status of the study participants.

Variables		Frequency (n = 406)	Percentage (%)
Status			
	Single	310	76.4
	Married	95	23.4

Variables		Frequency (n = 406)	Percentage (%)
	Other	1	0.2

Table 16 displays the educational status of the participants, with a significant proportion holding a bachelor's degree, constituting 67.5% of the sample. The next largest group comprises high school graduates, accounting for 19.7%, followed by individuals with a master's degree at 11.3%. A small percentage of respondents, approximately 1.5%, reported having other educational backgrounds.

Tables 16. Education status of the study participants.

Variables		Frequency (n = 406)	Percentage (%)
Education status			
	High school	80	19.7
	Bachelor’s degree	274	67.5
	Master’s degree	46	11.3
	Other	6	1.5

Table 17 illustrates the income distribution of the participants, with a considerable portion having an income below 15,000 baht, accounting for 43.3% of the sample. The following largest groups consist of individuals with incomes of 15,000 to 30,000 baht and 30,001 to 45,000 baht, representing 36.0% and 12.6%, respectively.

Tables 17. Income of the study participants.

Variables		Frequency (n = 406)	Percentage (%)
Income			
	Less than 15,000	176	43.3
	15,000 – 30,000	146	36.0
	30,001 – 45,000	51	12.6
	45,000 or more	33	8.1

Table 18 presents the occupational distribution of the participants, with the largest proportion being students, representing 41.9% of the sample. Then, private employees and government officers accounted for 23.2% and 20.4%, respectively.

Tables 18. Occupation of the study participants.

Variables		Frequency (n = 406)	Percentage (%)
Occupation			
	Student	170	41.9
	Government officer	83	20.4
	Private employee	94	23.2
	Business owner	36	8.9
	Other	23	5.7

Table 19 shows the frequency of visiting shopping centers, with most respondents visiting the shopping center 1 - 2 times per week, representing 64.3%, followed by 3 - 4 times per week and 5 - 6 times per week, representing 25.4% and 6.2%, respectively.

Tables 19. Frequency of visiting shopping center of the study participants.

Variables		Frequency (n = 406)	Percentage (%)
Frequency of visiting shopping center			
	1 - 2 times a week	261	64.3
	3 - 4 times a week	103	25.4
	5 - 6 times a week	25	6.2
	Everyday	17	4.2

4.3.2 Factor Analysis of the Theory of Planned Behavior

A factor analysis conducted on the attitude of customers and employees in Central Plaza Rattanathibet revealed a highly positive attitude towards waste sorting. They strongly believed that waste sorting significantly contributes to recycling efficiency. Additionally, they recognized that proper waste management plays a crucial role in reducing GHG emissions, as indicated in Table 20.

Tables 20. Analysis of attitudes toward waste reduction and sorting.

Items	$\overline{X}$	S. D	Results
Attitudes			
I believe that sorting waste reduces greenhouse gas emissions.	4.58	0.615	Highest level
I believe generating more waste leads to greater greenhouse gas emissions.	4.50	0.705	Highest level
I believe correctly waste management reduces the amount of greenhouse gas emissions.	4.51	0.726	Highest level
I think waste sorting is beneficial for recycling efficiency.	4.61	0.648	Highest level
Total	4.55	0.520	Highest level

The analysis of subjective norms indicates that respondents perceive subjective norms positively. They believe observing others around them engaging in waste sorting is more likely to influence their behavior. Thus, this analysis highlights the influence of individuals in their social circle on the respondents' waste reduction and sorting practices, as depicted in Table 21.

Tables 21. Analysis of subjective norms of waste reduction and sorting.

Items	$\overline{X}$	S. D	Results
Subjective norms			
My family plays an important role in making me want to sort waste.	4.00	0.812	High level
If I see people around me sorting waste, I'll separate	4.21	0.841	Highest level

Items	$\overline{X}$	S. D	Results
the waste too.			
My friend would approve of me sorting waste before throwing it.	4.15	0.786	High level
Most people around me believe that waste segregation is a good thing and can make waste management more appropriate.	4.03	0.877	High level
Total	4.09	0.633	High level

The perceived behavioral control analysis indicated that the respondents had a high level of perceived behavioral control. They express confidence in their ability to utilize cloth bags instead of plastic bags while shopping to a great extent. Additionally, they perceive waste sorting as a relatively simple task that they can easily accomplish. However, they find it challenging to bring their water bottles when purchasing beverages and feel that hurried waste sorting poses difficulties, as illustrated in Table 22.

Tables 22. Analysis of perceived behavioral control of waste reduction and sorting.

Items	$\overline{X}$	S. D	Results
Perceived behavioral control			
Waste separation is easy for me to do.	4.19	0.791	High level
I can correctly sort waste even when I am in a hurry.	3.91	0.882	High level
It's easy for me to carry my own bottle to buy drinks.	3.95	0.983	High level
Using cloth bag instead of accepting plastic bags when shopping at the shopping center is something that I can do.	4.27	0.795	Highest level

Items	$\overline{X}$	S. D	Results
Total	4.08	0.646	High level

An analysis of the respondents' intent of this department store was found to be at a high level. Respondents had the highest level of willingness to sort waste to make it easier for agencies to manage waste further. Secondly, they intend to separate waste because they think it helps reduce GHG emissions and is their duty at a high level, as shown in Table 23.

Tables 23. Analysis of intentions of waste reduction and sorting.

Items	$\overline{X}$	S. D	Results
Intentions			
I deliberately sort waste to help reduce greenhouse gas emissions.	4.19	0.783	High level
I deliberately sort waste every time before throwing it away.	4.07	0.830	High level
I sort the waste because I consider it my duty.	4.14	0.806	High level
I am willing to sort waste because I feel it is easier for the authorities to continue to properly manage waste.	4.26	0.764	Highest level
Total	4.16	0.662	High level

From the analysis of the behaviors of the respondents, it was found that the respondents' behavior was at a high level. They attempted to sort waste even though their peers did not sort it at the highest level. Secondly, they sort food waste from other waste before throwing it away and refuse to accept plastic bags when shopping. Their behavior is a good practice which tends to encourage the development of waste management systems better, as shown in Table 24.

Tables 24. Analysis of behaviors of waste reduction and sorting.

Items	$\overline{X}$	**S. D**	**Results**
Behaviors			
I refuse to accept plastic bags when I shop in shopping centers.	4.01	0.821	High level
I sort my recyclables to sell to recycling shops.	3.93	0.971	High level
I separate food waste from other waste before throwing it away.	4.05	0.885.	High level
I try to sort the waste, even if the people around me don't sort it at all.	4.15	0.787	High level
Total	4.03	0.629	High level

The investigation findings into waste management behavior among customers and employees in department stores indicated that the sample group displayed the highest inclination towards waste reduction and sorting ($\bar{x}$ = 4.55, *S. D* = 0.520). It was observed that respondents perceived waste sorting as highly beneficial for recycling ($\bar{x}$ = 4.61, *S. D* = 0.648). The next highest variable is having intentions that were followed at the highest level, with respondents thinking they tried to sort waste because it was easier for agencies to deal with it at the highest level. The subjective norms were also high ($\bar{x}$ = 4.09, S. D = 0.633), in which the respondents thought that if people around them sorted waste, they tended to sort waste as well ($\bar{x}$ = 4.21, S. D = 0.841).

Tables 25. Coefficient of multiple regression equation of factors affecting waste reduction and sorting behavior.

Model	**Variable**	**B**	**Std. Error**	**Beta**	**t**	**P-value**
1	Constant	0.657	0.198		3.324	0.00*
	Attitude	0.027	0.048	0.023	0.576	0.565
	Subjective norm	0.050	0.044	0.050	1.146	0.253
	Perceived behavioral control	0.334	0.045	0.343	7.335	0.00*
	Intention	0.405	0.045	0.426	8.922	0.00*

R^2 = 0.554, Std. Error = 0.422 * There was a statistical significance at 0.05.

The waste reduction and sorting behavior of customers and employees at Central Plaza Rattnathibet were primarily influenced by intention and perceived behavioral control, with intention having a stronger impact (β = 0.426) than perceived behavioral control (β = 0.343). In contrast, attitude and subjective norms were insignificant in influencing waste reduction and sorting behavior in this context.

According to the theory of planned behavior, multiple factors influence waste reduction and segregation. The study revealed that intention and perceived behavioral control positively impacted waste reduction and separation. This is because the respondents expressed a willingness to engage in waste sorting and believed they could effectively reduce and segregate waste. These beliefs likely translated into actual behavioral practices. On the other hand, attitude and subjective norms were not found to be significant factors. This could be because the respondents may not perceive waste reduction and segregation as effective methods for reducing GHG emissions. Additionally, other important individuals' influence on the respondents did not play a significant role in their waste reduction and segregation behavior. It appears that the respondents considered their behavior to be independent of the opinions or actions of others.

In a study carried out by Razali et al. (2020), an investigation aimed to pinpoint factors that could have a positive impact on waste separation behavior among high-rise residents in Kuala Lumpur. The findings of the study indicated that perceived behavior control (PBC) emerged as the second most prominent determinant shaping waste separation behavior. The study also highlighted that the direct influence of PBC significantly contributes to the actual waste separation behavior practiced within households (Razali et al., 2020) . In addition, Yuan et al. (2016) conducted research that also investigates the correlation between PBC and waste separation behavior (Yuan et al., 2016). Furthermore, Nguyen et al. (2015) established the importance of this correlation through their study on waste separation intentions. Their research centered on residential households in Hanoi, Vietnam (Nguyen et al., 2015). The study's findings demonstrated a correlation between households' intentions to separate their waste and perceived challenges (PBC), which will ultimately result in conduct.

In Ayob et al. (2017) investigated students' intentions regarding waste separation in universities and found that PBC is strengthened by the discovery that students' willingness to engage in waste separation is determined by their ability to do so. PBC was discovered to have a positive and significant correlation with students' intentions to practice waste separation on campus. The students expressed certainty in their ability to separate waste when they chose to do so. This observation illustrates that greater confidence among students in executing waste separation is linked to a heightened intention to engage in this behavior (Ayob et al., 2017). The research also indicates that individuals' intentions to engage in waste sorting are contingent on their personal motivation and self-assurance in their ability to do so, rather than being influenced by the views of significant individuals in their lives.

In addition, promoting waste reduction and proper waste separation in shopping centers is essential for sustainability efforts. Several activities can be implemented to increase people's attitudes and behaviors in this regard (US EPA, 2004):

Educational Signage: Place clear and informative signage throughout the shopping center, providing guidance on waste separation and recycling. Visual cues can remind shoppers to properly dispose of their waste.

- Waste Separation Stations: Set up dedicated waste separation stations with clearly labeled bins for recyclables, organics, and non-recyclables. Make these stations easily accessible throughout the shopping center.

- Green Rewards Programs: Implement a rewards program that offers discounts or incentives to shoppers who bring their reusable bags or containers. Such programs encourage waste reduction and sustainable shopping practices.

- Recycling Awareness Campaigns: Launch recycling awareness campaigns within the shopping center, using posters, pamphlets, and social media to inform shoppers about the benefits of recycling.

- Composting Initiatives: If feasible, introduce composting bins for food waste in food courts or areas with restaurants. Educate shoppers about the environmental benefits of composting.

- Recycling Competitions: Organize friendly recycling competitions or challenges among shops or customers. Offer prizes or recognition to incentivize proper waste separation.

- Sustainable Packaging Policies: Encourage shops within the shopping center to adopt sustainable packaging practices, such as reducing single-use plastics or using eco-friendly materials.

- Reusable Item Giveaways: Provide reusable shopping bags, water bottles, or coffee cups with the shopping center's branding as giveaways to promote sustainable shopping habits.

- Waste Audits: Conduct waste audits to assess the composition of waste generated within the shopping center. Use the results to identify areas for improvement and set waste reduction goals.

- Collaboration with Retailers: Collaborate with retailers to implement in-store recycling programs. Encourage shops to collect and recycle specific items, such as electronics or clothing.

- Environmental Events: Host special environmental events or fairs within the shopping center, featuring eco-friendly products, green vendors, and educational activities for families.

- Waste Reduction Challenges: Challenge retailers to reduce their waste generation and adopt more sustainable practices. Recognize and reward shops that achieve waste reduction milestones.

- Feedback Mechanisms: Establish a feedback mechanism for shoppers to report any issues or suggestions related to waste separation and recycling within the shopping center.

- By implementing these activities, shopping centers can create a culture of waste reduction and recycling, ultimately leading to more responsible waste management practices among customers and staffs.

Upon studying the waste compositions, it was determined that food waste constituted the majority, followed by other waste and plastic waste, respectively. Scenario 1 involved no waste separation, leading to all waste being sent to landfills. In contrast, Scenario 2, with integrated waste management, resulted in a reduction in net greenhouse gas emissions compared to Scenario 1. This research has demonstrated that food waste, which is the most prevalent type in the shopping center, originates mainly from restaurants and food courts and is typically disposed of in landfills. This practice contributes to greenhouse gas emissions primarily due to the anaerobic decomposition process that occurs in the landfill environment. When organic materials like food waste are buried in landfills, they undergo anaerobic (oxygen-deprived) decomposition. In this condition, microorganisms break down the organic matter without the presence of oxygen, leading to the production of CH4, a potent greenhouse gas. Methane is approximately 25 times more effective at trapping heat in the Earth's atmosphere than CO_2 over a 100-year period. Composting offers an alternative method for managing food waste and can significantly reduce greenhouse gas emissions. This is because composting promotes aerobic decomposition, which produces CO_2 instead of CH_4 and CO_2 has a lower global warming potential, making it a less harmful greenhouse gas. Furthermore, compost is rich in organic matter and carbon. When food waste is composted, the resulting compost can enhance soil quality. The carbon in the composted organic matter is effectively sequestered in the soil, preventing its release into the atmosphere as CO_2 or methane. This process helps offset greenhouse gas emissions by capturing and storing carbon in the soil.

Regarding plastic waste, although plastic waste cannot decompose in landfills within 100 years, the landfill method also increases the landfill area. Therefore, using plastic waste, especially single-use waste, to produce fuel waste can help reduce the reliance on coal-based fuels. For example, RDF 5 is commonly used as a substitute for fossil fuels in various industrial processes, such as cement kilns and power plants. Utilizing RDF 5 as an energy source reduces the need to burn fossil fuels like coal or natural gas, thereby decreasing CO_2 emissions and other greenhouse gases associated with fossil fuel combustion (G A Kristanto, 2020). Additionally, textile and wood waste can also be utilized as fuel waste. Regarding plastic, paper, aluminum, and glass waste that can be recycled, they should be managed by sorting for recycling into substitute virgin material products. In conclusion, all types of waste should be separated and disposed of properly. Reducing and separating waste from customers and employees in shopping center is essential. A study of customer and staff attitudes indicates their willingness and ability to separate waste, demonstrating their readiness to engage in waste separation within the shopping center. However, improving the waste management system, such as adding various types of bins, clearly labeling bins for easy understanding, providing media explanations on waste separation, and organizing training sessions on waste reduction and sorting for shopping center employees, may help reduce waste generation and ensure clear source-based waste separation. Adjusting these waste management systems may help reduce the amount of waste and ensure that waste components are clearly separated from the source, which will be easier to manage in the middle and at the destination.

Together, these findings suggest that a holistic approach to waste management, encompassing waste composition analysis, GHG emission assessment, and behavioral change, is crucial for promoting environmental sustainability in shopping center. This research provides a comprehensive framework for businesses and policymakers to enhance waste management practices and contribute to a greener future.

4.4 Feasibility Economics

Waste management is a critical aspect of sustainability for department stores, encompassing both environmental and economic considerations. Typically, department stores incur a monthly waste management fee payable to the Nonthaburi Municipality, amounting to 20,000 Baht (Nonthaburi Municipality, 2023). However, this study examines the feasibility of implementing an integrated waste management system within shopping center, emphasizing its potential to not only improve environmental sustainability but also contribute to significant cost reductions associated with landfill disposal. The economic feasibility of integrated waste management hinges on its potential to reduce costs incurred by shopping center. In the current scenario, a substantial portion of the waste generated within shopping center is ultimately destined for landfill disposal. As previously mentioned, a monthly fee of 20,000 Baht is applied to shopping center for this purpose. By shifting to integrated waste management, shopping center can realize cost savings primarily by diverting waste from landfills. Integrated waste management includes measures such as source separation, recycling, and effective disposal of different waste streams (e.g., recyclables, food waste, single-use plastics/textile and wood, general waste). These practices reduce the volume of waste destined for landfill disposal, directly translating into reduced disposal costs.

Chapter 5
Conclusions

This study aimed to examine the waste composition produced at Central Plaza Rattanathibet and evaluate the GHG emissions associated with the solid waste management system in Nonthaburi Municipality, Nonthaburi Province. Additionally, the study investigated the attitudes and practices of waste reduction and segregation among both customers and employees of Central Plaza Rattanathibet. The findings of the study can be summarized as follows:

1) The investigation of waste composition was conducted through two scenarios: scenario 1 and scenario 2. Scenario 1 involved examining the current waste management system at Central Plaza Rattanathibet. The study revealed that the total amount of waste generated annually in Central Plaza Rattanathibet was 1,967.44 tonnes. The waste composition analysis indicated that food waste was predominant, accounting for 39.28% of the total waste generated using the quartering method. Other waste types and plastic waste followed, comprising 24.63% and 15.52%, respectively. In scenario 1, all waste was indiscriminately disposed of in landfills without any sorting or proper management. On the other hand, scenario 2 was a simulated approach aimed at categorizing and managing each waste type appropriately. According to the study results, waste management in Scenario 2 was divided into four categories: food waste, general waste, recyclable waste, and single-use plastic, textile, and wood. Their respective proportions were 39.28%, 24.63%, 19.16%, and 16.92%.
2) Regarding the investigation of GHG emissions, the findings revealed that scenario 1 had 124.94 tonnes of CO_2eq/year, which has a greater release than scenario 2, which has a release of – 839.37 tonnes of CO_2eq/year. In scenario 1, where only a landfill was employed as the waste management system, the emissions were high due to GHG emissions from various operational processes and methane emissions resulting from waste decomposition within the landfills. On the other hand, Scenario 2, which implemented more suitable waste management practices for each waste type, exhibited a reduced volume of GHG emissions.
3) The theory of planned behavior was assessed using a questionnaire administered to customers and employees at Central Plaza Rattanathibet. The questionnaire data were analyzed using the SPSS statistical program. The findings reveal that the respondents displayed high levels of attitude, subjective norm, perceived behavioral control, intention, and behavior. Furthermore, when examining the factors influencing behavior individually, it was observed that intention ($\beta = 0.426$) and perceived behavioral control ($\beta = 0.343$) were significant. This suggests that these two factors notably influenced waste reduction and sorting behavior.

5.1 Recommendations

1. The study indicates that the most effective approach for reducing greenhouse gas emissions is recycling. Therefore, it is highly advised to establish an extensive recycling and waste separation program within shopping centers, involving both customers and staffs in sustainable waste management practices. The least practical practice is to manage garbage bins according to the type of waste management and label the bins clearly so that there is no confusion in disposal. In addition, public relations media should be made to provide knowledge about waste management in an interesting way, attracting customers and staff to create awareness in reducing and separating waste. These recycling and waste separation efforts not only promote an eco-friendlier and more conscientious environment but also align seamlessly with the organization's dedication to social responsibility.
2. The primary waste component commonly encountered in shopping center is food waste, originating from restaurants, food courts, and coffee shops. Consequently, it is highly advisable to acquire and install biodigester machine within shopping center as an eco-conscious approach to food waste management. Biodigester machine not only offers sustainability but also lead to reduced expenses associated with waste transportation and landfill management. These biodigesters are cutting-edge, environmentally friendly systems that can substantially enhance the food waste management process. In addition, the products obtained from composting food waste in the biodigester can be further used as a soil quality improver for trees around the shopping center.

5.2 Future work

In future studies, the goal is to implement the integrated waste management system in department stores and subsequently analyze the composition of waste in each bin to determine whether waste separation is being done correctly. Additionally, the effectiveness of waste separation campaign activities will be evaluated. Furthermore, a study of greenhouse gas emissions will be conducted after the implementation of changes to the waste management system. This study includes an examination of the attitudes and behaviors of customers and staff following the alteration of the mall's waste management system. The aim is to assess the effectiveness of the integrated waste management system and identify the specific changes that have occurred.

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APPENDIX A

Figure A. The waste composition from the study using the quartering method in 7 days.

Day 1

Day 2

Day 3

Day 4

Day 5

Day 6

Day 7

APPENDIX B

B.1 Calculating the density and quantity in shopping center.

Density

D = m/V

D = 14.82 kg / 66 L = 0.22 kg/L = 220 kg/m^3

Quantity of waste

m = D x V

m = 0.22 kg/L x 24000 L = 5,389.01 kg/day = 1,968.44 tonnes/year

B.2 Calculating GHG assessments from waste management in Scenario 1 and Scenario 2.

Scenario 1

<u>Landfill</u>

Coefficient data		
Fraction	**Proportion (%)**	**DOC_f (%Wet)**
- Food waste	39.28	15
- Gardening waste	0.00	20
- Paper and board	10.48	40
- Wood	1.02	43
- Textile	2.70	24
- Rubber and	0.00	0
leather	0.00	0
- Diaper	15.52	0
- Plastic	0.92	0
- Metal and		
aluminum	5.45	0
- Glass	24.63	0
- Others		
DOC	0.15 – 0.43	$tonne_C/tonne_{waste}$
DOC_f	0.50	%
Type of landfill	Sanitary landfill (MCF=1)	
MCF	1.00	%
F	0.50	%Volume

Coefficient data		
Fraction	**Proportion (%)**	**DOC_f (%Wet)**
Recovery	0.00	m^3CH_4
OX	0.10	%
Ratio CH_4/C	1.33	%
k	0.035 – 0.40	y-1
Quantity of waste	1967.44	tonness/year

$BE_{CH4,SWDS,y}$= φ_yx (1 - f_y) x GWP_{CH4} x (1-OX) x 16/12 x F x $DOC_{f,y}$ x MCF_y x $\sum_{x=1}^{y}.\ \sum_j W_x$ x p_j x DOC_j x $e^{-kj(y-x)}$ x$(1-e^{-kj})$

$BE_{CH4,SWDS,y}$= 0.85 x (1 – 0) x 28 x (1 – 0.1) x 16/12 x 0.5 x 0.5 x 1.00 x {[772.85 x 0.39 x 0.15 x $e^{-0.4}$ x (1 – $e^{-0.4}$)] + [20.00 x 0.01 x 0.43 x $e^{-0.035}$ x (1 – $e^{-0.035}$)] + 690.84 x 0.35 x 0.4 x $e^{-0.07}$ x (1 – $e^{-0.07}$)] + [53.09 x 0.03 x 0.24 x $e^{-0.07}$ x (1 – $e^{-0.07}$)]}

$BE_{CH4,SWDS,y}$ = 115.10 tonnes CO_2eq/year

<u>Transportation</u>

$PE_{FF,y}$ = $\sum(FC_{PJ,i,y}$ x ($NCV_{i,y}$ x 10^{-6}) x $EF_{CO_2,i}$)x 10^{-3}

$PE_{FF,y}$ = (3,650 x (36.42 x10^{-6}) x 74,100) x 10^{-3}

$PE_{FF,y}$ = 9.84 tonnes CO_2eq/year

Total GHG emission from landfill = 115.10 + 9.84 = 124.94 tonnes CO_2eq/year

Scenario 2

Landfill

$BE_{CH4,SWDS,y}$= φ_yx (1 - f_y) x GWP_{CH4} x (1-OX) x 16/12 x F x $DOC_{f,y}$ x MCF_y x $\sum_{x=1}^{y}.\ \sum_j W_x$ x p_j x DOC_j x $e^{-kj(y-x)}$ x$(1-e^{-kj})$

$BE_{CH4,SWDS,y}$= 0.85 x (1 – 0) x 28 x (1 – 0.1) x 16/12 x 0.5 x 0.5 x 1.00 x 484.64 x 1.00 x 0.4 x $e^{-0.07}$ x (1 – $e^{-0.07}$)

$BE_{CH4,SWDS,y}$ = 87.25 tonnes CO_2eq/year

<u>Transportation</u>

$PE_{FF,y} = \sum(FC_{PJ,i,y} \times (NCV_{i,y} \times 10^{-6}) \times EF_{CO_2,i}) \times 10^{-3}$

$PE_{FF,y} = (3{,}650 \times (36.42 \times 10^{-6}) \times 74{,}100) \times 10^{-3}$

$PE_{FF,y} = 9.84$ tonnes CO_2eq/year

Total GHG emission from landfill = 87.25 + 9.84 = 97.09 tonnes CO_2eq/year

Composting

$PE_{COMP,y} = W_y \times (EF_{CH4} \times GWP_{CH4} + EF_{N2O} \times GWP_{N2O})$

$PE_{COMP,y} = 772.8 \times (0.002 \times 28 + 0.0002 \times 265)$

$PE_{COMP,y} = 84.24$ tonnes CO_2eq/year

<u>Fuel consumption</u>

$PE_{FF,y} = \sum(FC_{PJ,i,y} \times (NCV_{i,y} \times 10^{-6}) \times EF_{CO_2,i}) \times 10^{-3}$

$PE_{FF,y} = (3{,}193.75 \times (36.42 \times 10^{-6}) \times 74{,}100) \times 10^{-3}$

$PE_{FF,y} = 8.62$ tonnes CO_2eq/year

<u>Electricity</u>

$PE_{EL,y} = (EC_{PJ,y} \times 10^{-3}) \times EF_{EC,PJ,y}$

$PE_{EL,y} = (3{,}240$ kWh/year $\times 10^{-3}) \times 0.4857 = 1.57$ tonnes CO_2eq/year

<u>Project Emission</u>

$PE_y = PE_{FF,y} + PE_{EL,y} + PE_{COMP,y}$

$PE_y = 8.62 + 84.24 + 1.57 = 94.43$ tonnes CO_2eq/year

<u>Emission Reduction</u>

$BE_{CH4,SWDS,y} = W_y \times (p_{food\ waste,y} \times 1.00) \times CF \times 0.1$

$BE_{CH4,SWDS,y} = 772.8 \times (0.39 \times 1.00) \times 7.14 \times 0.1 = 215.19$ tonnes CO_2eq/year

$ER_{composting} = BE_y - PE_y$

$ER_{composting} = 215.19 – 94.43 = 120.76$ tonnes CO_2eq/year

RDF – 5

Fuel consumption

$PE_{FF,y} = \sum(FC_{PJ,i,y} \text{ x } (NCV_{i,y} \text{ x } 10^{-6}) \text{ x } EF_{CO2,i}) \text{x } 10^{-3}$

$PE_{FF,y} = (3,967.55 \text{ x } (36.42 \text{ x} 10^{-6}) \text{ x } 74,100) \text{ x } 10^{-3}$

$PE_{FF,y} = 10.71$ tonnes CO_2eq/year

Electricity

$PE_{EL,y} = (EC_{PJ,y} \text{ x } 10^{-3}) \text{ x } EF_{EC,PJ,y}$

$PE_{EL,y} = (5,340.68 \text{ kWh/year x } 10^{-3}) \text{ x } 0.4857 = 2.59$ tonnes CO_2eq/year

Project Emission

$PE_{RDF} = PE_{FF,y} + PE_{EL,y} + PE_{COMP,y}$

$PE_{RDF} = 10.71 + 2.59 = 13.30$ tonnes CO_2eq/year

Emission Reduction

$BE_{CH_4,RDF} = W_y \text{ x } (p_{wood,y} \times 4.02 + p_{textile,y} \times 2.23) \text{ x } CF \text{ x } 0.1$

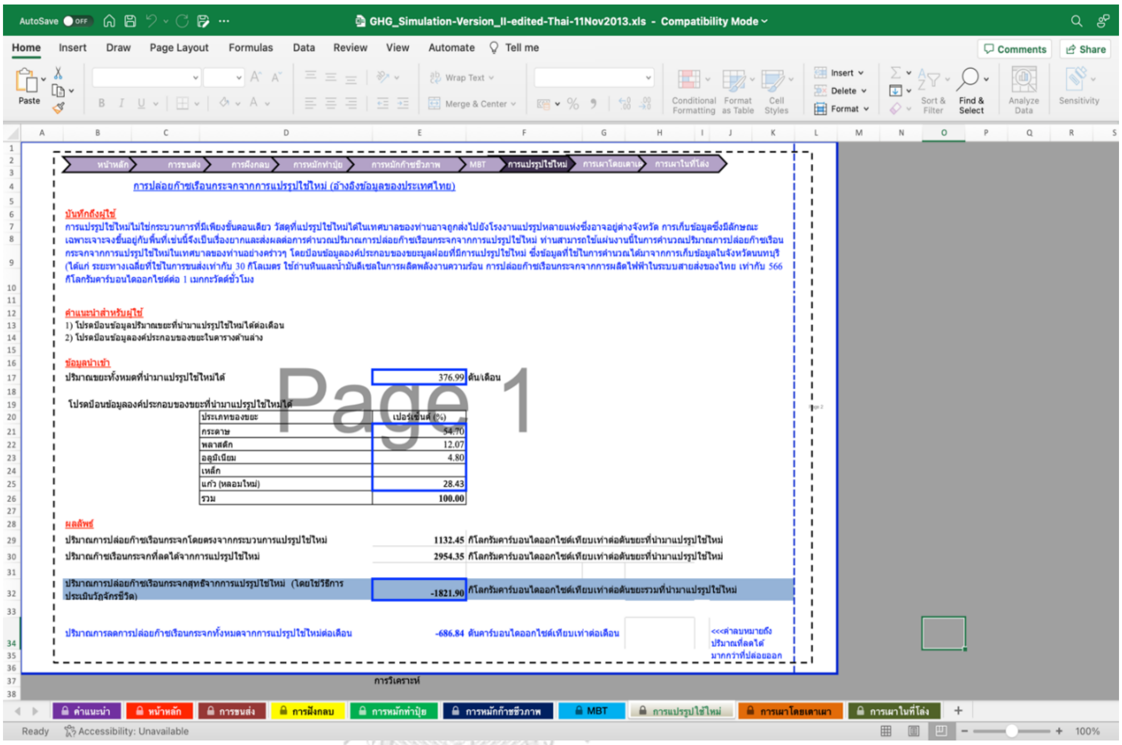
$BE_{CH_4, RDF} = 332.95 \text{ x } ((0.16 \text{ x } 2.23) + (0.06 \text{ x } 4.02)) \text{ x } 7.14 \text{ x } 0.1$

$BE_{CH_4, RDF} = 142.16$ tonnes CO_2eq/year

$ER_y = BE_y - PE_y$

$ER_y = 142.16 – 13.30 = 128.86$ tonnes CO_2eq/year

Recycling


AutoSave
GHG_Simulation-Version_II-edited-Thai-11Nov2013.xls - Compatibility Mode
Home Insert Draw Page Layout Formulas Data Review View Automate Tell me
Comments Share
Page 1
Ready
Accessibility: Unavailable
100%

APPENDIX C

C.1 Sample letter requesting expert assistance in evaluating Item-Objective Congruence (IOC) of questionnaire

No.

Hazardous Substance Management Interdisciplinary Program and environment (International Program)
Chula Research Building, 9th floor
Chulalongkorn University
Phaya Thai Road, Bangkok 10330

29 March 2023

Dear Dr. Oluseye Olalekan Oludoye

Subject: Asking for courtesy to be an expert in checking the quality of research tools

I have the honor to request your kind assistance to be an expert in verifying the validity of the objectives of the questionnaire along with other suggestions of Ms. Kanokpish Srinok, student number 6488049720, in order to further improve the research tools. Therefore, I would like to send a questionnaire and information for specialists to examine the questionnaire of the thesis title "Evaluation of the greenhouse gas emissions resulting from waste management practices at the Central Plaza Rattanathibet shopping center: A case study", details of which are attached.

Yours sincerely,

(Associate Professor Dr. Ekawan Luepromchai)
Director of the Hazardous Substance Management Interdisciplinary Program and environment

Hazardous Substance Management Interdisciplinary
Program and environment (International Program)
Tel. 0-2218-4162
Fax 0-2219-1761

C.2 Item-Objective Congruence (IOC) Assessment Expert Form

Title: Evaluation of the greenhouse gas emissions resulting from waste management practices at the Central Plaza Rattanathibet shopping center: A case study

Instruction Ask experts to verify the validity of the questionnaire or the Index of item objective congruence (IOC) by using the following criteria for reviewing the questionnaire:

The score = 1, if the expert is sure that this item really measured the attribute.
The score = 0, if the expert is not sure that the item does measure or does not measure
the expected attribute.
The score = –1, if the expert is sure that this item does not measure the attribute.

Item	Question	Relevant			Comment
		Relevant +1	Not sure 0	Nonrelevant -1	
Part 1 Personal information					
1.	Age				
2.	Gender				
3.	Status				
4.	Education				
5.	Salary				
6.	Occupation				
Part 2 Behavior of waste reduction and separation					
Attitudes					
1.	I believe that sorting waste reduces greenhouse gas emissions.				
2.	I believe generating more waste leads to greater greenhouse gas emissions.				
3.	I believe appropriate waste management reduces the amount of greenhouse gas emissions.				
4.	I think waste sorting is				

Item	Question	Relevant			Comment
		Relevant +1	Not sure 0	Nonrelevant -1	
	not difficult or complicated.				
Subjective norms					
5.	My family plays an important role in making me want to sort waste.				
6.	If I see people around me sorting waste, I'll separate the waste too.				
7.	Most people I know would approve of me sorting waste before throwing it.				
8.	Most people around me believe that waste segregation is a good thing and can make waste management more appropriate.				
Perceived behavioral control					
9.	Waste separation is easy for me to do.				
10.	Even in rush hour, I can sort the waste correctly.				
11.	It is easy for me to dispose of the waste correctly according to each type of bin.				
12.	Whether I separate waste completely depends on me.				
Intention					
13.	I deliberately sort waste to make waste management as efficient as possible.				
14.	I sort the waste every time I create it.				
15.	I regularly sort the waste because I consider it my duty.				

Item	Question	Relevant			Comment
		Relevant +1	Not sure 0	Nonrelevant -1	
16.	I deliberately sort the waste because I feel it's useful.				
Behaviors					
17.	I refuse to accept plastic bags when I shop in shopping centers.				
18.	I always sort my recyclables to sell to recycling shops.				
19.	I always separate food waste from other waste before throwing it away.				
20.	I always try to sort the waste, even if the people around me don't sort it at all.				

Table C.1 Results of Item-Objective Congruence (IOC) of questionnaire on assessment of greenhouse gas emissions from waste management in shopping center: case study of Central Plaza Rattanathibet.

Item	Question	Item-Objective Congruence (IOC) score							Result	Developed question after validation
		Expert 1	Expert 2	Expert 3	Expert 4	Expert 5	Total score	Average score		
Attitudes										
1.	I believe that sorting waste reduces greenhouse gas emissions.	+1	+1	+1	+1	+1	5	1	Accepted	
2.	I believe generating more waste leads to greater greenhouse gas emissions.	+1	+1	+1	+1	+1	5	1	Accepted	
3.	I believe appropriate waste management reduces the amount of greenhouse gas emissions.	+1	0	+1	0	+1	3	0.6	Accepted	I believe correctly waste management reduces the amount of greenhouse gas emissions.
4.	I think waste sorting is not	-1	+1	+1	+1	+1	4	0.8	Accepted	I think waste

Item	Question	Item-Objective Congruence (IOC) score							Result	Developed question after validation
		Expert 1	Expert 2	Expert 3	Expert 4	Expert 5	Total score	Average score		
	difficult or complicated.									sorting is beneficial for recycling efficiency.
Subjective norms										
5.	My family plays an important role in making me want to sort waste.	+1	+1	+1	+1	+1	5	1	Accepted	
6.	If I see people around me sorting waste, I'll separate the waste too.	+1	0	+1	+1	+1	4	0.8	Accepted	
7.	Most people I know would approve of me sorting waste before throwing it.	+1	0	+1	0	+1	3	0.6	Accepted	My friend would approve of me sorting waste before throwing it.
8.	Most people around me believe that waste segregation is a good thing	+1	+1	+1	+1	+1	5	1	Accepted	

Item	Question	Item-Objective Congruence (IOC) score							Result	Developed question after validation
		Expert 1	Expert 2	Expert 3	Expert 4	Expert 5	Total score	Average score		
	and can make waste management more appropriate.									
Perceived behavioral control										
9.	Waste separation is easy for me to do.	+1	+1	+1	+1	+1	5	1	Accepted	
10.	Even in rush hour, I can sort the waste correctly.	+1	0	+1	-1	+1	3	0.6	Accepted	I can correctly sort waste even when I am in a hurry.
11.	It is easy for me to dispose of the waste correctly according to each type of bin.	+1	0	+1	0	+1	3	0.6	Accepted	It's easy for me to carry my own bottle to buy drinks.

Item	Question	Item-Objective Congruence (IOC) score							Result	Developed question after validation
		Expert 1	Expert 2	Expert 3	Expert 4	Expert 5	Total score	Average score		
12.	Whether I separate waste completely depends on me.	+1	0	0	-1	+1	2	0.4	Unaccepted	Using cloth bag instead of accepting plastic bags when shopping at the shopping center is something that I can do.
Intentions										
13.	I deliberately sort waste to make waste management as efficient as possible.	+1	+1	+1	0	+1	4	0.8	Accepted	I deliberately sort waste to help reduce greenhouse gas emissions.
14.	I sort the waste every time I create it.	+1	+1	+1	0	+1	4	0.8	Accepted	I deliberately sort waste every time before throwing it away.

Item	Question	Item-Objective Congruence (IOC) score							Result	Developed question after validation
		Expert 1	Expert 2	Expert 3	Expert 4	Expert 5	Total score	Average score		
15.	I sort the waste because I consider it my duty.	+1	+1	+1	+1	+1	5	1	Accepted	
16.	I deliberately sort the waste because I feel it's useful.	+1	0	+1	+1	+1	4	0.8	Accepted	I am willing to sort waste because I feel it is easier for the authorities to continue to properly manage waste.
Behaviors										
17.	I refuse to accept plastic bags when I shop in shopping centers.	+1	+1	+1	+1	+1	5	1	Accepted	
18.	I sort my recyclables to sell to recycling shops.	+1	+1	+1	+1	+1	5	1	Accepted	
19.	I separate food waste from other waste before throwing it away.	+1	+1	+1	+1	+1	5	1	Accepted	

Item	Question	Item-Objective Congruence (IOC) score							Result	Developed question after validation
		Expert 1	Expert 2	Expert 3	Expert 4	Expert 5	Total score	Average score		
20.	I try to sort the waste, even if the people around me don't sort it at all.	+1	+1	+1	+1	+1	5	1	Accepted	

Figure C.1 Reliability of the questionaire

Case Processing Summary

		N	%
Cases	Valid	30	100.0
	Excluded[a]	0	.0
	Total	30	100.0

a. Listwise deletion based on all variables in the procedure.

Reliability Statistics

Cronbach's Alpha	N of Items
.860	20

Item-Total Statistics

	Scale Mean if Item Deleted	Scale Variance if Item Deleted	Corrected Item-Total Correlation	Cronbach's Alpha if Item Deleted
AT1	81.50	54.466	.472	.854
AT2	81.67	53.057	.276	.864
AT3	81.50	56.328	.153	.863
AT4	81.23	56.806	.190	.861
SN1	81.93	51.237	.677	.845
SN2	81.67	53.540	.413	.855
SN3	81.90	54.852	.233	.862
SN4	81.90	54.369	.329	.858
PBC1	81.67	52.575	.565	.850
PBC2	81.93	49.444	.709	.842
PBC3	82.60	48.455	.616	.846
PBC4	81.57	53.978	.408	.855
IT1	81.70	50.769	.712	.844
IT2	81.80	51.959	.601	.848
IT3	81.90	51.817	.656	.847
IT4	81.70	54.148	.436	.854
BV1	81.97	53.895	.310	.859
BV2	82.60	50.869	.382	.860
BV3	82.00	52.345	.496	.852
BV4	81.80	51.890	.608	.848

APPENDIX D

D.1 Questionnaire form

Title: Evaluation of the greenhouse gas emissions resulting from waste management practices at the Central Plaza Rattanathibet shopping center: A case study

A. Participants' details

1. Age? _____________

2. Gender? ❑1 Female ❑2 Male ❑3 Others ___________

3. Marital status? ❑1 Single ❑2 Married ❑3 Others ___________

4. Level of education? ❑1 Secondary school ❑2 Bachelor's degree ❑3 Master's degree ❑4 Others ___________

5. Salary? ❑1 < 15,000 ❑2 20,000 – 30,000 ❑3 30,000 – 40,000. ❑4 > 40,000

6. Job position? _____________

B. It assesses waste management behavior in Central Plaza Rattanathibet

Instructions Please mark (√) in the box that corresponds to your opinion the most. By specifying the answer as the 5-level score is

5 means strongly agree

4 means agree

3 means neutral

2 means disagree

1 means strongly disagree

Questions	Levels				
	5	4	3	2	1
Attitudes 1. I believe separating solid waste makes waste management more efficient.					
2. I believe that waste is what I produce, so I should separate it properly.					
3. I believe that it is possible to reuse usable waste.					

Questions	Levels				
	5	**4**	**3**	**2**	**1**
4. I feel ashamed when I don't separate the waste.					
Subjective norm 5. My family believes that waste sorting is possible.					
6. My family always separates the waste regularly.					
7. Most people I know would approve of me separating waste.					
8. Most people around me believe that waste separation is a good thing, making waste management easier.					
Perceived behavioral control 9. Separating food waste is easy for me.					
10. Public relations media that educate solid waste segregation can motivate me to separate waste.					
11. It is convenient for me to throw all the waste together.					
12. Whether I separate solid waste is up to me.					
Intention 13. I intend to separate solid waste to manage waste as efficiently as possible.					
14. I separate solid waste every time I generate waste.					
15. I deliberately do not separate waste because I felt that it was not my duty.					
16. I deliberately didn't sort the waste because I felt it was useless.					
Behaviors 17. I only sort waste if there are containers or bins for sorting.					
18. I have a sorting bin for myself.					
19. I always throw everything together.					
20. I try to separate solid waste. Even if the people around me don't separate the waste.					

VITA

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DATE OF BIRTH	17 July 1998
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INSTITUTIONS ATTENDED	Bachelor of Science
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AWARD RECEIVED	3rd place in “Innovation Solving PM2.5 Problem Hackathon” 2023 in Bangkok, hosted by YouTHful Issue organization.