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Greenhouse Gases Emission and Environmental Costs of Fast- Food Restaurants: A Case Study in Bangkok, Thailand

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Abstract

This study aimed to investigate and assess the restaurants' operational patterns and to identify the hotspot emitting the highest level of greenhouse gases (GHGs) and causing the highest environmental cost. The study was conducted in January 2022. The Life Cycle Assessment (LCA) method was applied to assess and analyze the amounts of GHG emissions and environmental costs associated with fast-food restaurants in terms of ingredients and food preparation, food delivery, and food waste transportation to the landfill. GHG emissions were divided into three categories according to the Carbon Footprint for Organization (CFO), namely: 1) direct GHG emissions from fast-food restaurants 2) indirect GHG emissions from energy consumption; and 3) indirect GHG emissions from other sources. The GHG emission hotspots in both western and Thai fast-food restaurants were identified based on two types of activities: those inside and outside the restaurants. The results from the data collected from the fast-food restaurants in the Sathorn District showed that the total GHG emission of the restaurants was 521,571.46 $kgCO_2e$/year. The first category of GHG emission was 20,558.63 $kgCO_2e$/year. The second category emitted the most GHG at 396,564.50 $kgCO_2e$/year. The third category of GHG emission was 111,456.48 $kgCO_2e$/year. The hotspots of both western and Thai restaurants originated from the same activity, which was electric energy consumption because all the restaurants used appliances and electronic devices to facilitate their business. The highest environmental cost was water treatment at 59,040.00 baht annually. This study can be utilized as a database for measurement, assessment, and management to reduce GHG emissions from fast-food restaurants, other food businesses, and other related activities.

Keywords: Greenhouse Gases; Carbon footprint; Life cycle assessment; Fast food restaurant; Food delivery

1. Introduction

Greenhouse gas emissions from human activities are a primary driver of global warming. Changes in climate patterns and seasons are directly linked to warmer global temperatures. As some areas suffer droughts, heavier downpours occur in other areas, which contributes to ecosystem imbalances. Ecological imbalances can provoke behavioral changes among animals, especially migration. Thailand has also been vulnerable to the effects of climate change. The 2011 flood, for example, was the worst flood in modern Thai history, affecting over 12.8 million people. The damage and losses in agricultural products cost were 50,183.00 million baht; the properties and assets of farmers cost were

14,810.60 million baht, and the public sector cost was 10,733.50 million baht. Overall, the total damage and loss amounted to 75,727.16 million baht (Lohsomboon, 2019).

The food sector is responsible for approximately 30% of the world's total energy consumption and approximately 22% of total GHG emissions (UN DESA, 2022). In 2015, the emissions from the food system reached a global annual total of 18 Gt CO_2 equivalent, which accounted for approximately 34% of the overall GHG emissions. Emissions were generated throughout the entire food system from agriculture and land use to supply chain activities such as industrial processing, transport, and waste management (Crippa *et al.,* 2021). Food service establishments, such as restaurants, cafes, and canteens, also contribute to various GHG emissions. Although much of the focus on restaurant sustainability revolves around food ingredients, GHG emissions often stem from the energy used for food preparation and HVAC (heating, ventilation, and air conditioning) systems (Messier, 2016). A case study conducted on a pizza restaurant in Turkey over a 5-year period revealed that its carbon footprint from only energy consumption amounted to 1,919.818 tCO_2e, which was equal to planting 3062 trees to achieve carbon neutrality (Özgen et al., 2021). Nowadays, apart from their traditional dine-in service, more and more restaurants offer online food delivery services to gain more revenue, leading to an increase in activities that generate carbon dioxide emissions (CO_2) (Wakeland *et al.,* 2012). In fact, GHG emissions of restaurants can arise from various sources, such as electricity and gas usage, fuel for food delivery, waste, and packaging. For example, packaging for one delivery order had GHG emissions between 0.15 and 0.29 kg CO_2e (Arunan & Crawford, 2021). During the COVID-19 pandemic in Thailand, the food delivery market experienced significant growth, leading to elevated energy consumption and GHG emissions, resulting in greater environmental costs (Pollution Control Department, 2021). Thus, to examine GHG emissions from restaurants comprehensively, it is necessary to investigate both dine-in and delivery operations.

Life Cycle Assessment (LCA) is an analytical tool used to evaluate the environmental effects in every phase of a product's life cycle, starting from the acquisition of raw materials, continuing through production, utilization and consumption, end-of-life management, recycling, and terminal disposal, as well as transportation at each phase (Chancharoonpong, 2020). Currently, LCA is widely used as an educational tool for evaluating GHG emissions of specific processes. For example, Armstrong (2013) applied LCA to assess the life cycle of microalgae cultivation, including aspects such as food supply system, energy usage, waste management, and GHG reduction. Under the scope of study to examine only identifiable parameters, the data were collected from the organizations' parameter reports, focusing on hydropower and food for microalgae. Similarly, LCA was utilized to assess GHG emissions from the tofu industry in the Konawe Selatan district, Indonesia. The study encompassed the entire life cycle, from raw material acquisition and production processes to waste management and disposal (Herdhiansyah *et al.,* 2022). In terms of food service industry, Hu *et al.* (2023) studied CO_2 emissions of online food delivery in Japan using LCA by investigating the production, distribution, consumption, and disposal of the ingredients and found that food production was the main source of emissions.

Bangkok is Thailand's capital and most populous city, making it the country's developed center of economic management, politics, and culture, with access to public facilities and services. Food delivery services also gained popularity for their convenience and fast without waiting in line at restaurants. During the COVID-19 pandemic, Bangkok had the highest number of cases in Thailand. Every sector had to follow the order for the temporary closure of premises by the Bangkok Metropolitan Administration (BMA). Fast-food restaurants affected by the order must refrain from allowing customers to dine in without time limits and set limited opening hours and dine-in times. As a result, they had to adapt and rely more

on delivery services. The Sathorn District, a densely populated area in inner Bangkok, was no exception; hence, many restaurants in the district started their delivery services. According to the database of newly licensed restaurants from 2017 – 2019, the restaurants offering delivery services in the Sathorn District were 13 in 2017, 17 in 2018, and 91 in 2019 (Sathorn District Office, 2018). The number of restaurants is also likely to grow under the current circumstances, in which more people prefer food delivery.

Thus, the purpose of this research is to compare the GHG emissions and environmental costs of restaurant dining versus delivery services at the restaurants in the Sathorn District in Bangkok, Thailand. To determine the hotspot with the highest CO_2 emissions and environmental costs, the GHG emissions and environmental costs from activities inside and outside restaurants were assessed. There have been few studies on the environmental costs of the food delivery business. The results of this study will be useful to environmental management in terms of planning and providing guidelines for reducing GHG emissions, as well as environmental costs from fast-food restaurants, in order to lower the environmental and health effects of global warming, climate change, and pollution from restaurant businesses in a sustainable manner.

2. Materials and methods

2.1 Population and samples

The researcher selected fast-food restaurants located in the Sathorn District of Bangkok as the target population. Since the Sathorn District has three sub-districts, including Thung Wat Don, Yannawa, and Thung Mahamek, purposive sampling was used to select two fast-food restaurants, one Thai and one Western, from each sub-district. In total, there were six restaurants in this study. Thung Wat Don would be called Area 1, Yannawa would be Area 2, and Thung Mahamek would be Area 3. The Western restaurants would be referred to as EN, while the Thai restaurants would be referred to as TH. The abbreviations would be followed by Area numbers. Hence, for Area 1 (Thung Wat Don), EN1 represented Western fast-food restaurant and TH1 represented Thai fast-food restaurant. As for Area 2 (Yanawa), EN2 was Western fast-food restaurant, and TH2 was Thai fast-food restaurant. Lastly, for Area 3 (Thung Mahamek), EN3 was Western fast-food restaurant, and TH3 was Thai fast-food restaurant. The main criteria for the selection of the restaurants were the requirements that they possess an active food license, have an area of more than 200 m^2, with no more than 100 m^2 difference in size from other selected restaurants, and have a contract with the same food delivery company. Additionally, the restaurants must have a waste management system in place for both solid waste and wastewater. Apart from meeting all the criteria, the restaurants selected by the researcher also agreed to participate in data collection.

2.2 Scope and boundaries of LCA study

This study applied the concept and method of life cycle assessment (LCA) to analyze and assess GHG emissions and environmental costs. In the initial stage, the study examined the operational patterns of each selected restaurant within the sample group for this research, including location, customer demographics, restaurant size, duration of operation, type of service provided, food production methods, and waste management. The next step was the establishment of the boundaries for the LCA study. These boundaries are the criteria that determine specific unit processes, inputs, outputs, and impacts for consideration in the LCA. Each unit process represented a distinct stage in the life cycle of fast-food restaurants. Since the scope of this study included food production, food service, and waste management, specific processes within the entire production chain, known as 'gate to gate' were examined, from food preparation, food services both inside and outside the restaurants (food delivery), to waste generation, such as wastewater, food waste, general waste, and the transportation of solid waste to landfill disposal, as shown in Figure 1.

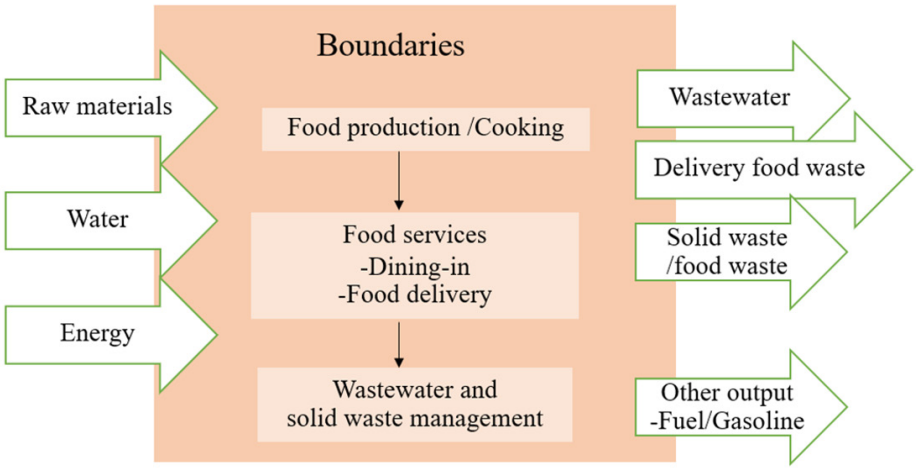

Figure 1. Boundaries of the LCA study for the fast-food restaurants

2.3 Data collection and analysis

The data collection was performed from January 1 – 31, 2022, in three time slots per day: 9:00 – 12:00, 12:01 – 15:00, and 15:01 – 18:00. The LCA methods were applied to examine the amounts of GHG emissions and environmental costs from the restaurants' activities.

2.3.1 GHG emission

To assess the impacts of fast-food restaurant operations, calculations were made to determine GHG emissions from various activities of the restaurants. These emissions are categorized into three types. Type 1 is direct GHG emissions, including the use of LPG gas for food preparation, the use of fuel for food transportation to consumers, and the use of fuel for transporting solid waste to landfills. Type 2 is indirect GHG emissions, which include electricity consumption. Type 3 involves other indirect GHG emissions, such as the disposal of general and organic food waste from food preparation activities, the consumption of food at the restaurant and at consumers' homes, and the packaging used for food delivery. Additionally, the use of water for cleaning utensils and kitchen equipment is also considered. As depicted in Figure 2, the data would be used to calculate the GHG emission produced by each activity. The method employed was derived from the guidelines for estimation and GHG emission coefficients, as outlined in both the IPCC Guidelines for National Greenhouse Gas Inventories (2006) and the Thailand Greenhouse Gas Management Organization (TGO). In terms of environmental costs, Figure 2 shows the restaurants' activities involving solid waste, which would be transported to the landfill for disposal, as well as the wastewater and treatment fees.

As mentioned earlier, GHG emissions were separated into three categories: 1) direct GHG emissions; 2) indirect emissions from energy consumption; and 3) other indirect emissions. The GHG emission hotspots in the Western and Thai fast-food restaurants were identified based on two groups of activities: those inside the restaurants and those outside. As displayed in Figure 2, the fast-food restaurants' direct GHG emissions included LPG and fuel, while the indirect GHG emissions from energy consumption were attributed to electricity. The other indirect GHG emissions were related to organic waste, solid waste, and food delivery packaging.

The quantitative data, which included general information and the amounts of GHG emissions from restaurant activities, were analyzed using statistics, percentages, and mean values in the SPSS program. The GHG emissions were calculated using the IPCC Guidelines for National Greenhouse Gas Inventories (2006) to explain the relationship between each fast-food restaurant activity and its GHG emissions. The equation used for the calculation was as follows:

$$\text{GHG emission } (kgCO_2e/year) = (\text{activity data} \times \text{emission factor}) \quad (1)$$

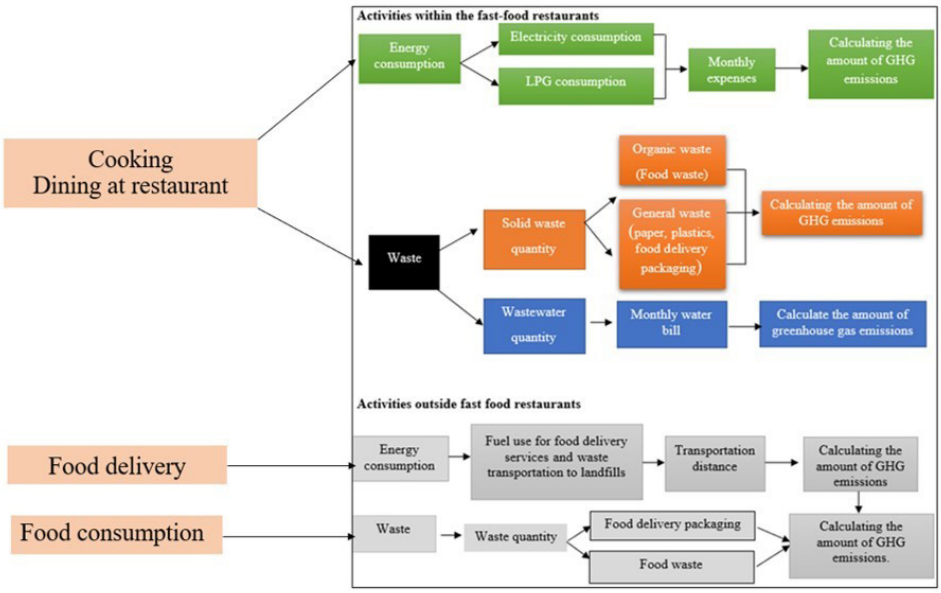

Figure 2. The study framework for GHG emissions of the fast-food restaurants

Activity data includes both primary and secondary data such as vehicle fuel consumption in liters (L), electricity consumption in kilowatt hours (kWh), and solid waste mass in kilograms (kg) or tons (ton) while the emission factors are constants that translate activity data into GHG emissions. The descriptive analysis was carried out by comparing each activity data of the fast-food restaurants for their GHG emissions before categorizing them. The calculated GHG emissions in this study would be reported in annual amounts.

The data in Table 1 would be used to calculate the GHG emission from each activity with the method adapted from the guidelines for estimation and GHG emission coefficients, outlined in the IPCC Guidelines for National Greenhouse Gas Inventories (2006). Table 1 shows the CO_2 emission factors used to convert energy consumption in fast-food restaurant activities to carbon dioxide emission equivalents.

The calculation of GHG emissions from transportation includes GHGs emitted from vehicle journeys for food delivery as well as from waste trucks transporting solid waste to the landfill. The GHG calculations followed the method outlined in the TGO guidelines (TGO, 2019), using Equation (1) and fuel consumption data for each vehicle type, which can be categorized as shown in Table 2.

$$\text{Emission } (kgCO_2e/year) = (\text{Activities} \times EF)/\text{Fuel consumption} \quad (2)$$

The calculation of GHG emissions from wastewater generated by the fast-food restaurants is estimated to be 80% of the water used in each fast-food restaurant (Tchobanoglous & Burton, 1991). Then, this value would be multiplied by the EF value of collecting and improving the quality of wastewater in a large urban community, using the method provided by TGO, as shown in Equation (2).

$$\text{Emission } (kgCO_2e/year) = (\text{Water consumption} \times 0.8) \times EF \quad (3)$$

2.3.2 Environmental costs

Environmental costs refer to the expenses incurred to prevent the environmental impacts of business operations or to demonstrate responsibility for managing environmental impacts. This can include environmental impact reduction or compensation for damage caused to the environment and affected parties (Rakos & Antohe, 2014). Regarding the environmental costs, the researcher calculated the environmental costs resulting from the activities of transporting solid waste to the landfill and managing wastewater in

monetary terms (averaged per restaurant). The environmental costs included employee expenses for collecting and transporting solid waste to transfer stations, fuel costs from the Sathorn district to the transfer stations, outsourcing costs for waste transportation to the landfill, maintenance expenses for equipment and machinery, and fees for wastewater treatment. The data for these costs were compiled from the restaurants' annual expenditure plans and relevant receipts for expense claims.

3. Results and discussion

3.1 General data of the fast-food restaurants

Table 3 shows the details of the selected fast-food restaurants in the study. The size of the restaurants was more than 200 m^2 (215 – 290 m^2) in compliance with the criteria and requirements for obtaining a restaurant license set forth in the Public Health Act, B.E. 2535 (1992), to control restaurant hygiene and waste management. In terms of location, every restaurant was in the commercial zone of the Sathorn District, Bangkok.

Area 1 (EN1 and TH1) restaurants were in an area with many department stores, communities, condominiums, and government offices, with most of the people living in the area being Thai. There were both convenient and less convenient routes to the restaurants because some were on the main street with all-day heavy traffic and others were on the subsidiary streets with office workers as target customers. For Area 2, restaurants EN2 and TH2 were situated among small and large office buildings, hotels, and condominiums, and were linked to the main street and the

Table 1. CO_2 emission factors

Activities		Unit	Emission factor ($kgCO_2e/kg$)	References
Waste management	Solid waste	kg	0.8421	IPCC (2006)
	Organic waste (food waste)	kg	2.5300	IPCC (2006)
LPG consumption	LPG	kg	1.1839	TGO (2019)
Transportation	Gasohol 91/95	L	2.1896	IPCC (2006)
	Gas/Diesel Oi1		2.7080	IPCC (2006)
Electricity consumption	Electricity	kWh	0.5986	TGO (2019)
Water Supply (Metropolitan Waterworks Authority)	Water supply	m^3	0.7948	TGO (2019)
Wastewater	Wastewater collection and treatment in large urban community	m^3	0.1310	TGO (2019)
Delivery food packaging	Paper, Plastic and Foam	kg	2.9300	IPCC (2006)

Table 2. Fuel consumption of vehicles (TGO, 2019)

Vehicle of type	Fuel	Unit	Fuel consumption	Reference
Pickup truck, average size	Gas/Diesel Oil	km/L	6.369	TGO 2019
Two-stroke motorcycles, average size	Gasohol 91/95	km/L	32.435	TGO 2019

BTS sky train station, providing convenient and quick routes to the restaurants. The target customers were office workers, Thais, and foreigners in the area. As for restaurants EN3 and TH3 in Area 3, they were on the main street in an area with small and large office buildings, embassy offices, and hotels. Traveling to the restaurants was rather inconvenient since the area was densely populated, resulting in traffic jams during rush hours. The target customers were also office workers, Thais, and foreigners in the area.

The data of the fast-food restaurants were divided into two groups: dine-in service and food delivery service. The delivery services of all the restaurants were available at the same time every day from 9:01 - 12:00, 12:01 - 15:00, and 15:01-18.00. On average, the restaurants made 55 deliveries per day. The busiest time was 15:01 – 18:00, with an average of 22 delivery orders per day, followed by 12:01 – 15:00 with 16 orders and 9:01 – 12:00 with 8 orders.

The waste management system of the sampled restaurants consisted of solid waste and wastewater. Four out of the total six restaurants practiced solid waste separation. The Sathorn District Office's Public Cleansing and Public Park Section organizes the waste collection. Complying with the criteria and requirements for food businesses under the Public Health Act, B.E. 2535, the sampled restaurants' wastewater management system had a grease trap installed before releasing wastewater to the public sewer connected to the total wastewater treatment system of the Bangkok Metropolitan Administration (BMA).

3.2 GHG emission inventory from the Sathorn fast-food restaurants

3.2.1 Direct carbon dioxide emissions

The direct carbon dioxide emissions were calculated from three activities: 1) LPG consumption for cooking; 2) fuel consumption for food delivery to consumers; and 3) fuel consumption for solid waste transport to the landfill. The details are shown in Table 4.

Table 3. General information of the sampled fast-food restaurants

Aspects	Details
Size	More than 200 m^2 (215–290 m^2) in compliance with restaurant license.
Locations and target customers	- Commercial zone of the Sathorn District, Bangkok. - The target customers included office workers, Thais, and foreigners in the area.
	Area 1 Tung Wat Don sub-district is the location of restaurants TH1 and EN1.
	Area 2 Yannawa sub-district is the location of restaurants TH2 and EN2.
	Area 3 Tung Mahamek sub-district is the location of restaurants TH3 and EN3.
Types of services	dine-in service and food delivery service.
Delivery hours	9:01-12:00, 12:01-15:00, and 15:01-18.00. Every day for all restaurants.
Waste management	Solid waste and wastewater management have been complying with the criteria and requirements for food businesses under the Public Health Act, B.E. 2535.
Distances from the restaurants to the landfill	The distances from each restaurant to the landfill are as follows: EN1 is 106 km, EN2 is 106 km, EN3 is 184 km, TH1 is 106 km, TH2 is 106 km and TH3 is 184 km

Table 4 exhibits that the total direct carbon dioxide emission was equal to 13,550.48 $kgCO_2e$/year. During cooking activities in the kitchens of restaurants EN3, TH2, and TH3, LPG was used as fuel for heating, resulting in a total GHG emission of 8,435.15 $kgCO_2e$/year. The amounts of LPG used in the three restaurants were slightly different. The restaurant TH3 used the highest amount of LPG (2,484.00 kg/year), contributing to the GHG emission of 2,980.81 $kgCO_2e$/year. The restaurants EN3 and TH2 both ranked second, with the same LPG usage of 2,304.00 kg/year, equivalent to the GHG emission of 2,727.17 $kgCO_2e$/year.

In terms of the delivery services, restaurant EN1 had the noticeably highest GHG emission of 1,356.36 $kgCO_2e$/year, followed by TH2, TH3, EN3, EN2, and TH1. It could be that restaurant EN1 is a well-known restaurant in a shopping mall on the major road close to the largest community in the Sathorn District and government facilities. Moreover, it has provided a delivery service for a long time and is easily accessible for delivery riders. Since delivery fees were calculated based on distance, a lot of customers near the restaurant possibly decided to make delivery orders due to lower delivery fees.

Table 4. Direct carbon dioxide emissions from the fast-food restaurants in the Sathorn District

Activities	GHG emission ($kgCO_2e$/year)						
	EN1	EN2	EN3	TH1	TH2	TH3	Total
LPG consumption	-	-	2,727.17	-	2,727.17	2,980.81	8,435.15
Fuel consumption for food delivery services	1,356.36	463.84	472.80	286.50	587.88	528.89	3,696.27
Fuel consumption for transportation to the landfill	332.52	204.56	172.45	332.52	204.56	172.45	1,419.06
Total	1,688.88	668.40	3,372.42	619.02	3,519.61	3682.15	13,550.48

EN1 – Western fast-food restaurant in Thung Wat Don sub-district.
EN2 – Western fast-food restaurant in Yanawa sub-district.
EN3 – Western fast-food restaurant in Thung Mahamek sub-district.
TH1 – Thai fast-food restaurant in Thung Wat Don sub-district.
TH2 – Thai fast-food restaurant in Yanawa sub-district.
TH3 – Thai fast-food restaurant in Thung Mahamek sub-district.

Table 5. The amounts of indirect GHG emissions from energy consumption (electricity)

Restaurants	Electricity consumption (kWh/Unit/year)	GHG emission ($kgCO_2e$/year)
EN1	136,364.00	81,627.44
EN2	104,146.66	62,342.13
EN3	81,103.00	48,548.16
TH1	67,439.83	40,369.51
TH2	47,340.50	28,338.01
TH3	226,093.00	135,339.25
Total	662,486.99	396,564.50

EN1 – Western fast-food restaurant in Thung Wat Don sub-district.
EN2 – Western fast-food restaurant in Yanawa sub-district.
EN3 – Western fast-food restaurant in Thung Mahamek sub-district.
TH1 – Thai fast-food restaurant in Thung Wat Don sub-district.
TH2 – Thai fast-food restaurant in Yanawa sub-district.
TH3 – Thai fast-food restaurant in Thung Mahamek sub-district.

For the transportation of solid waste to the landfill, the GHG emissions from the six restaurants totaled 1,419.06 $kgCO_2e$/year, without considerable differences in the amounts of GHG emissions among the restaurants.

3.2.2 Indirect carbon dioxide emissions from energy consumption

As displayed in Table 5, the total electricity consumption from every restaurant was 662,486.99 kWh/Unit/year, leading to GHG emission of 403,653.11 $kgCO_2e$/year. While all restaurants used the same electrical appliances, such as air conditioners, fans, televisions, and light bulbs, only restaurants EN1, EN2, and TH1 cooked on electric stoves. However, restaurant TH3 used the most electricity, consuming 226,093.00 kWh per year, followed by restaurants EN1 and EN2, which used 136,364.00 and 104,146.66 kWh per year, respectively. Although restaurant TH3 did not use an electric stove for cooking, it utilized a large water pump system for the restaurant's waterfall feature, which needed to be operational throughout the restaurant's opening hours. This led to higher electricity consumption compared to other restaurants.

3.2.3 Other indirect carbon dioxide emissions

Other indirect GHG emissions from restaurant activities, including waste from cooking and dining in restaurants, food delivery packaging, and water usage, are shown in Table 6 below. The disposal of solid waste from cooking and dining in restaurants led to the highest GHG emission, equal to 95,249.87 $kgCO_2e$/year, or 87.73%, followed by water use and food delivery packaging at 10,395.47 and 2,928.51 $kgCO_2e$/year, or 9.57% and 2.70%, respectively.

3.3 The GHG emission points (hotspots) of the fast-food restaurants

The hotspots of the Western restaurants, EN1 (TD), EN2 (YN), and EN3 (TM) are shown in Figure 3.

Figure 3 illustrates the total emission from every hotspot of the Western restaurant EN1, EN2, and EN3, with the highest GHG emission from electricity consumption, which accounted for 192,517.73 $kgCO_2e$/year or 79.63% of all investigated activities. The second GHG emission contributor was waste from activities inside the restaurants,

Table 6. Activities and the amounts of other indirect GHG emissions

Activities	GHG emission ($kgCO_2e$/year)						
	EN1	EN2	EN3	TH1	TH2	TH3	Total
Organic waste and solid waste	15,179.64	12,121.45	8,606.10	2,210.15	22,313.87	34,818.66	95,249.87
Food delivery packaging	954.96	541.13	381.98	190.99	222.82	636.63	2,928.51
Water Supply (Metropolitan Waterworks Authority)	1,669.08	1,344.80	2,060.12	1,144.51	1,802.61	3,710.13	11,731.25
Wastewater	220.08	177.32	271.64	150.91	237.69	489.21	1546.85
Total	17,803.68	14,007.38	11,048.20	3,545.65	24,339.30	39,165.42	111,456.48

EN1 – Western fast-food restaurant in Thung Wat Don sub-district.
EN2 – Western fast-food restaurant in Yanawa sub-district.
EN3 – Western fast-food restaurant in Thung Mahamek sub-district.
TH1 – Thai fast-food restaurant in Thung Wat Don sub-district.
TH2 – Thai fast-food restaurant in Yanawa sub-district.
TH3 – Thai fast-food restaurant in Thung Mahamek sub-district.

including solid waste from food preparation and dining inside restaurants, which totaled 35,907.19 kgCO_2e/year or 14.85%.

Figure 4 depicts the hotspots of the Thai restaurants, TH1, TH2, and TH3. Electricity consumption was the source of the hotspots that generated the highest GHG emission in the Thai restaurants, accounting for 204,046.77 kgCO_2e/year or 72.94% of all investigated activities. Similar to the Western restaurants, waste from activities inside restaurants accounted for the second highest GHG emission at 59,342.68 kgCO_2e/year or 21.21%. However, the amount of GHG emission from the Thai restaurants was higher than the Western restaurants. It could be that the Thai restaurants tended to be more diligent in preparing ingredients for cooking and decorating; yet, consumers often avoid eating food decorations, leading to a higher amount of food waste compared to the Western restaurants.

As shown in Figures 3 and 4, the highest GHG emission hotspots for both Thai and Western sample groups of restaurants were from electricity consumption, which is indirect GHG emission. The electricity consumption caused the highest GHG emission at 396,654.50 kgCO_2e/year in total or 76.05% of all activities This is consistent with the results of the study by Boriboon (2015) at Chokchai Hospital, which applied the same conceptual framework as this study to assess GHG emissions of organizations, revealing that indirect GHG emissions from electricity consumption in the hospital released the most GHG, equal to 56.97% of the total GHG emissions. In addition, the results of this study also support the study of the carbon footprint at the Department of Ordnance Engineering, Education Section, Chulachomklao Royal Military Academy (Chaivanich, 2020), which found that the activity in the academy that emitted the highest GHG was electricity

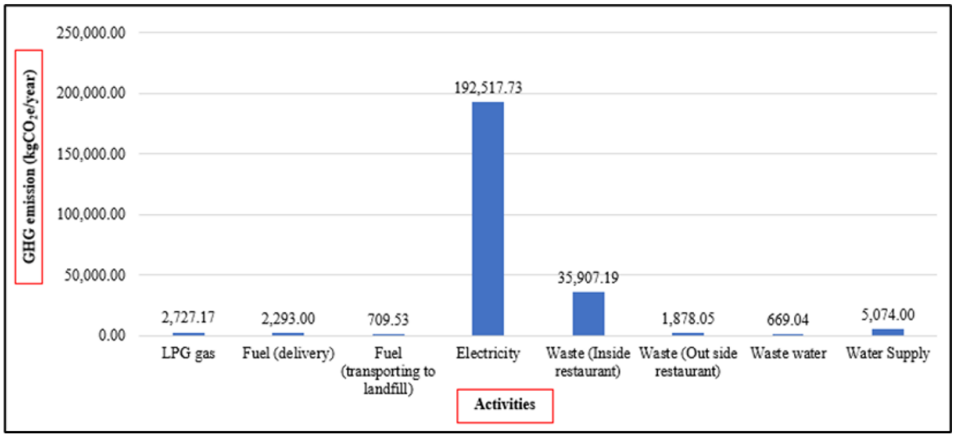

Figure 3. The GHG emission hotspots of the Western restaurants

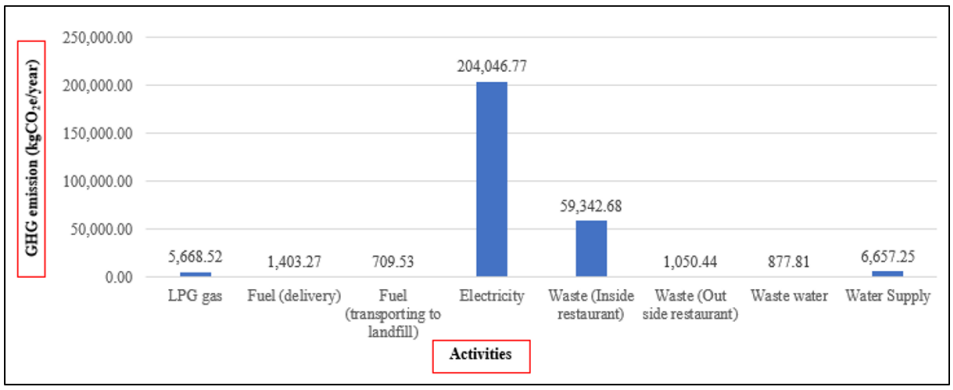

Figure 4. The GHG emission hotspots of the Thai restaurants

consumption, accounting for 47.77% of the total GHG emission. Moreover, the results of this study also agree with the study of energy consumption efficiency in restaurants in Malta (Noel *et al.,* 2018), which reported that electricity consumption in the cooling process accounted for up to 40.00% of total electricity consumption and contributed to 70.00% of the GHG emissions from all restaurant activities. For this reason, the public and private sectors should set up measures to promote energy-saving campaigns in fast-food restaurants to reduce global warming in the future.

The second highest GHG emissions for both restaurant groups were also the hotspots from waste from activities inside restaurants. Most of the waste was organic, including raw ingredients such as vegetables and meat that must be processed before being cooked and served to consumers, therefore, the organic waste mainly consisted of food waste. When comparing the portions of organic and solid waste, the former accounted for 96.00%, but the latter took up only 4.00%. The results were similar to the study by Dagiliūtė and Musteikytė (2019), which investigated the generation of solid food waste, restaurant information, and customer attitudes and found that food waste had the highest portion compared to solid waste, accounting for 89.00% of all waste in the restaurant. Furthermore, the results of this study are also consistent with the case study in Sweden about food waste and the effects of food consumption on global warming, which examined the types of solid waste, including cereals, root vegetables, fruits and vegetables, meat products, dairy products, seafood, beverages, and solid waste, and discovered that food waste from vegetables, fruits, and meat products accounted for the highest portion of GHG emissions, equal to 1,208.00 $kgCO_2e$/year or 67.00% of all solid waste.

3.4 Environmental costs of fast-food restaurant activities in the Sathorn District

Table 7 shows the environmental costs of waste transportation from the restaurant collection points to the landfill, while Table 8 displays the costs of wastewater treatment for each restaurant. The total environmental cost of the sampled fast-food restaurants was equal to 124,799.89 THB per year. The annual costs of waste transportation from the restaurant collection points to the landfill and wastewater treatment were 65,759.80 THB and 59,040.00 THB, respectively. Wastewater treatment was the most expensive activity, accounting for 47.30% of all environmental costs, followed by fuel costs of 31,666.37 THB (25.37%) and waste collectors' salaries of 30,789.45 THB (24.67%).

The total environmental cost from the Sathorn fast-food restaurants was 124,799.89 THB per year; solid waste transportation activities equaled 65,759.89 THB per year; and wastewater treatment activities equaled 59,040.00 THB per year. The most expensive activity in terms of environmental costs was wastewater treatment, which accounted for 47.30% of all environmental costs, followed by fuel costs and garbage collectors' salaries, which equal 31,666.37 THB and 30,789.45 THB per year, or 25.37% and 24.67%, respectively. The results support the study of the environmental impact and cost of food waste in the cafeteria of Taiyuan University, China (Li *et al.,* 2021), which found that

Table 7. The environmental costs of waste transportation to the landfill

Environmental cost detail	Cost (THB/year)	Cost (THB/year/average per store)
Waste collectors' salaries	30,789.45	6,157.89
Fuel costs from the district to the transfer stations	31,666.37	6,333.27
Fees for waste transportation to landfills	1,102.17	220.43
Equipment and machinery maintenance costs	2,201.00	4,403.80
Total	65,759.89	

Table 8. The environmental costs of wastewater treatment fees

Restaurants	Water usage (m^3/year)	Fee rate (THB/m^3)	Cost (THB/year)
EN1	2,100	4	8,400.00
EN2	1,692	4	6,768.00
EN3	2,592	4	10,368.00
TH1	1,440	4	5,760.00
TH2	2,268	4	9,072.00
TH3	4,668	4	18,672.00
	Total		59,040.00

EN1 – Western fast-food restaurant in Thung Wat Don sub-district.
EN2 – Western fast-food restaurant in Yanawa sub-district.
EN3 – Western fast-food restaurant in Thung Mahamek sub-district.
TH1 – Thai fast-food restaurant in Thung Wat Don sub-district.
TH2 – Thai fast-food restaurant in Yanawa sub-district.
TH3 – Thai fast-food restaurant in Thung Mahamek sub-district.

the highest environmental cost is fuel used in the cooking process, followed by waste disposal costs and wastewater treatment system fees. A review of the literature on food delivery platform services and their impact on sustainability in various aspects of stakeholders (Li *et al.,* 2020) found that as the number of food delivery businesses increased during the COVID-19 pandemic, the amount of solid waste in China increased by more than 75 times. In contrast to developed countries such as England, which has little plastic waste, equaling 51.00% of all solid waste, the solid waste in China is mostly single-use plastic and wooden chopsticks. Furthermore, transportation also generates GHGs through the direct combustion of fuels, causing air pollution problems. However, the Chinese government pays a large amount of waste management costs each year, accounting for 50.00% of total environmental management costs.

In terms of water usage, the fast-food restaurants use tap water for cleaning utensils and equipment and preparing food, producing wastewater, which is a GHG emission factor. As shown in Table 8 above, restaurant TH3 had the highest cost of water usage because the restaurant was a garden-style restaurant and used water not only for cleaning but also for the garden waterfall circulating system. The water consumption assessment found that it emitted 1.98% of GHG, which is comparable with the study of the carbon footprint of pizza restaurants in Naples, Italy (Falciano *et al.,* 2022), which reported that tap water was used not only for cooking and equipment washing but also maintenance of the restaurant area such as cleaning of glass, floor, and toilet. From all the pizzeria activities, the water consumption emitted GHG at a rate of 0.27%.

Considering both inside and outside activities of the fast-food restaurants, inside activities had the highest GHG emissions, equal to 530,431.31 $kgCO_2e$/ year, or 98.47%, while outside activities had GHG emissions accounting for 7,418.65 $kgCO_2e$/year, or 1.53%. The results are consistent with the study on the carbon footprint of Friends & Brgrs, a Finnish food restaurant chain (Byggmästar *et al.,* 2019), which found that inside restaurant activities generated 99.00% of GHG, while delivery activities generated only 1.00%. Moreover, the most significant source of GHG emissions was electricity consumption.

4. Conclusion

The assessment of GHG emissions and environmental costs of the fast-food restaurants in the Sathorn District applied the concept and method of life cycle assessment (LCA). Six sample restaurants from all three sub-districts were selected. The quantitative analysis and evaluation of the impact of resource utilization considered everything from ingredient preparation, food cooking, and food delivery to consumers to solid waste transportation for disposal in the landfill. The results showed that all the investigated activities at the sample fast-food restaurants released GHG for a total of 521,571.46 $kgCO_2e$/year. The total environmental cost of the restaurants' activities was equal to 124,799.89 THB per year. The analysis of GHG emission points

found that electricity consumption caused the highest GHG emission, accounting for 74.05%. The assessment of GHG emissions and environmental costs of the fast-food restaurants in the Sathorn District can be a database for inspection and evaluation in future studies involving fast-food restaurants. To achieve Goal 13 of the Sustainable Development Goals (SDGs), which is to take urgent action to combat climate change and its impacts, the public and private sectors should devise measures to promote energy-saving campaigns in restaurants, solid waste sorting, and creating incentives for business owners to use innovations that reduce GHG emissions, such as lowering import taxes on solar cell equipment and enacting regulations on the use of circular delivery packaging, or organizing an innovation contest to reduce electricity consumption in fast food restaurants. The significant factor contributing to climate change is greenhouse gases, which consist of carbon dioxide (CO_2) and methane (CH_4) as important elements. The main sources of GHG are the combustion of fossil fuels in human economic activities. The activities in fast-food restaurants are one source of high GHG emissions from the service sector, especially for electricity consumption for business operations. The government and private sectors should collaborate to find solutions to properly reduce GHG emissions, which can lead to achieving the goal of the SDGs in the future.

There are limitations to this study due to the COVID-19 pandemic and the temporary closure of establishments following the order of the BMA. As a result, restaurants in the Bangkok area, including those in the Sathorn District, were unable to serve customers at the restaurants. Some restaurants that the researcher intended to study had temporarily closed, which required a change in the sample group. In addition, the data collected from private companies were not complete or lacked continuity because some specific data were confidential to the companies and considered as in-depth information such as delivery distances, fuel quantities, and fuel types used from the transfer stations to the landfill. Furthermore, the scope of the study was rather narrow and the duration for study was also limited.

The future study should broaden its scope, such as by increasing the sample size and examining other delivery service areas or groups of restaurants, such as hawker centers, small restaurants, flea markets, or other food establishments, to discover other hotspots and the amount of GHG emissions from other important sources. Additional research on electric consumption activities, which account for the majority of GHG emissions at fast-food restaurants, is also necessary for identifying hotspots and providing guidelines or suggestions for GHG emission reduction.

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References

Arunan I, Crawford RH. Greenhouse gas emissions associated with food packaging for online food delivery services in Australia. Resources, Conservation and Recycling 2021;168:105299.

Armstrong KO. Analysis of live cycle assessment of food, energy, waste system and development and analysis of microalgae cultivation, wastewater treatment inclusive system [master's thesis]. Fort Collins (CO): Colorado State University; 2013.

Boriboon P. The assessment and reduction of greenhouse gases emissions of Chokchai hospital in Nakhon Ratchasima province. [master's thesis]. Pathum Thani: Thammasat University; 2015.

Byggmästar A. Carbon footprint calculation in the restaurant sector: Case Friends & Brgrs [master's thesis]. Vaasa: University of Vaasa; 2019.

Chaivanich K. Carbon footprint of an organization: A case study of the department of ordnance engineering academic division, Chulachomklao Royal Military Academy. Science and Technology Nakhon Sawan Rajabhat University Journal 2020; 12(15): 48-57.

Chancharoonpong P. Life cycle assessment and eco-efficiency of different riceberry products to move towards sustainability [master's thesis]. Bangkok: Kasetsart University; 2020.

Crippa M, Solazzo E, Guizzardi D, Monforti-Ferrario F, Tubiello FN, Leip A. Food systems are responsible for a third of global anthropogenic GHG emissions. Nature Food Journal 2021; 2:198-209.

Dagiliūtė R, Musteikytė A. Food waste generation: Restaurant data and consumer attitudes. Environmental Research, Engineering and Management. 2019; 75(2): 7–14.

Falciano A, Cimini A, Masi P, Moresi M. Carbon Footprint of a Typical Neapolitan Pizzeria. Sustainability 2022; 14(5): 1-23.

Herdhiansyah D, Sari SA, Sakir S, Asriani A. The implementation of life cycle assessment (LCA) in the processing industry Tofu: A case study of Konawe Selatan district, Indonesia. Asia-Pacific Journal of Science and Technology 2022;27(4): APST–27.

Hu X, Liu C, Zhuo Q, Moon D. Assessing CO2 Emissions of Online Food Delivery in Japan. Sustainability 2023;15(10):8084.

IPCC. IPCC Guidelines for National Greenhouse Gas Inventories, Volume 2: Energy. Hayama, Japan: IPCC; 2006.

IPCC. IPCC Guidelines for National Greenhouse Gas Inventories, Volume 5: Waste. Hayama, Japan: IPCC; 2006.

Li C, Mirosa M, Bremer P. Review of Online Food Delivery Platforms and their Impacts on Sustainability. Sustainability 2020; 12(14): 5528.

Li J, Li W, Wang L, Jin B. Environmental and cost impacts of food waste in university canteen from a life cycle perspective. Energies 2021;14(18):5907.

Lohsomboon P. Combating climate change with carbon pricing. The National Defence College of Thailand Journal 2019; 61(1): 87-92.

Messier JM. The restaurant GHG guidelines: an operational greenhouse gas emissions accounting protocol for restaurants [thesis]. Minneapolis, MN: University of Minnesota; 2016.

Noel BF. P¬rofiling energy use and efficiency in restaurants. [dissertation]. Malta: University of Malta; 2018.

Özgen I, Binboğa G, Güneş ST. An assessment of the carbon footprint of restaurants based on energy consumption: A case study of a local pizza chain in Turkey. Journal of Foodservice Business Research 2021; 24(6): 709-729.

Pollution Control Department (PCD). Action Plan on Plastic Waste Management Phase I (2020 - 2022). Bangkok: He's company limited; 2021.

Rakos lS, Antohe A. Environmental cost-An Environment management accounting component. International Journal of Academic Research in Accounting, Finance and Management Sciences 2014; 4(4), 224–237.

Sathorn District Office. Data report of Environment and Sanitation Section. Bangkok, Thailand; 2018.

Tchobanoglous G, Burton F. Wastewater engineering: Treatment disposal, and Reuse, 3rd Ed. New York: McGraw-Hill; 1991.

Thailand Greenhouse Gas Management Organization. The National Guideline Carbon Foot printing for organization. Bangkok, Thailand; 2019.

UN DESA. The Sustainable Development Goals Report 2022 - July 2022. New York, USA: UN DESA; 2022.

Wakeland W, Cholette S, Venkat K. Food transportation issues and reducing carbon footprint. In: Joyce I. Boye, Yves Arcand, editors. Green technologies in food production and processing. New York: Springer New York; 2012. p. 211-236.