

Comprehensive Analysis of City Carbon Footprint from Energy Consumption in a District of the Central Region of Thailand

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Abstract

A low-carbon city focuses on minimizing its carbon footprint by implementing sustainable practices across various sectors such as transportation, energy, waste management, and urban planning. The aim of this study is to evaluate city-wide Greenhouse Gas (GHG) emissions and propose mitigation strategies using Carbon Footprint evaluation. Lam Luk Ka district in Pathum Thani Province served as a site for this case study. The calculation methods and parameters were referred to the IPCC Guidelines for National Greenhouse Gas Inventories for the year 2019. The scope 1 of direct emissions from stationary and mobile combustion, the carbon footprint represents 13% of the total footprint in this city. The LPG usage for household activities was a major contributor with the 15 kg gas container being predominant, and diesel usage was also revealed as the primary contributor for mobile combustion in this direct fuel combustion in this area. The scope 2 of indirect emissions from electricity consumption, residential and commercial areas played substantial roles, with large-sized businesses contributing significantly, contributing 80% of the total scope 2 footprint in this city. The results indicate the need for energy-efficient practices, especially in residential areas, and targeted sustainability measures in the commercial sector. Scope 3, covering other indirect emissions, revealed greenhouse gas emissions from waste disposal and tap water usage, contributing 7% of the total footprint in this city. The transition of fuel types used in transportation and the adoption of solar cell technology for households are feasible approaches to reducing carbon emissions in the city.

Keywords: Carbon emission; Carbon footprint; Greenhouse gas; Low-carbon city

1. Introduction

In the 21st century, the worldwide population has marked a notable shift towards urban environments. Presently, over 50% of the global populace migrates to urban areas (United Nations, 2018). This urban expansion is primarily attributed to increasing energy demand and climate change (Li *et al.*, 2022; Zelenáková *et al.*, 2015). Some studies have shown that the expansion of cities is directly proportional to energy consumption. China's national statistics department indicated that the 1% increase in the country's urbanization

rate raises total energy consumption by at least 60 million tons of standard coal (Wang *et al.*, 2014; Zheng *et al.*, 2019). The urban expansion produces greenhouse gases, such as carbon dioxide, methane, and nitrous oxide, mainly through transportation, energy use, waste management, industrial activities, and land use changes, which contribute to climate change (Liu *et al.*, 2023). Urbanization leads to land use change, resource consumption, air and water pollution, waste generation, infrastructure development, the exacerbation

of the heat wave effect, and its significant contribution to climate change (Tafazzoli and Sadoughi, 2021; Yousaf Raza *et al.*, 2023; Wang, 2018).

Under the Paris Agreement, Thailand made commitments to achieve net zero greenhouse gas emissions by 2065 and carbon neutrality by 2050. Additionally, Thailand pledged to enhance its Nationally Determined Contributions (NDCs), lowering the target for greenhouse gas emission reduction from the previous 20 - 25% by 2030 to 30 - 40%, aligning with the goals of reaching net zero and carbon neutrality. Thailand towards lower greenhouse gas emissions and fostering climate-resilient development (ONEP, 2022).

The study of carbon footprints is crucial for understanding and addressing climate change by quantifying greenhouse gas emissions at the product, individual, household, organization, city, and country scales (Brenton *et al.*, 2008; Hillman and Ramaswami, 2010; Larsen and Hertwich, 2009; Muthu *et al.*, 2011). It promotes awareness, responsible resource management, and sustainable practices, guiding individuals, businesses, and governments in reducing their environmental impact and mitigating global warming. It also supports international cooperation and accountability in the fight against climate change (TGO, 2018; Pudcha *et al.*, 2023).

Thailand is actively pursuing carbon neutrality goals through a multifaceted approach, including transitioning to renewable energy and implementing sustainable transportation policies, to mitigate climate change impacts and foster environmental sustainability (Sutabutr, 2024). Low-carbon cities (LCCs) are one of the crucial initiatives proposed, which benefits human behavior and national economies by decreasing reliance on carbon emitting activities and low GHG emissions (Lin *et al.*, 2013; Sreenonchai *et al.*, 2020). Additionally, it contributes to the effective management of energy and environmental aspects across diverse activities within the region. Therefore, the main objectives of this study were to identify and assess the activities contributing to carbon emissions in a city in the central part of Thailand. The assessment covered

a comprehensive analysis of stationary and mobile fuel usage, electricity and water supply consumption, and waste disposal activities. The significance of these findings lies in their role in proposing effective mitigation strategies to decrease the carbon emissions associated with diverse urban activities. These measures aim to align with both national and international sustainability policies, promoting a more environmentally responsible and sustainable trajectory for the city.

2. Methodology

Low-carbon city (LCC) can be evaluated by city carbon footprint calculations. GHG emission was used to manage low-carbon city for implementing fuel utilization, waste minimization, basic utilities such as energy efficiency and tap water consumption. The calculation methods and parameters were referred to the IPCC Guidelines for National Greenhouse Gas Inventories (IPCC, 2006), and the secondary data of the organization emission factor announced by the Thailand Greenhouse Gas Management Organization (TGO) (TGO, 2018b).

2.1 Study area

Pathum Thani Province is a province that has a rapid economic growth, changing from rural to an urban society. Pathum Thani Province was indicated as diverse socio-economic structure consisting of agriculture, industrial, residential, and commercial activities, resulting in the diversity of the population within the province and causing the attraction of a large number of transits (Iamtrakul and Chayphong, 2023; Iamtrakul *et al.*, 2022). In this study, the city carbon footprint was established in the area of Lam Luk Ka district, located in Pathum Thani Province of Thailand.

Lam Luk Ka is situated in the northern part of Pathum Thani Province, which is in the central region of Thailand. The area covers approximately 50.32 km², with 9,015 households, a population of 21,250 people, and an estimated latent population of around 10,000 people. This district comprises a blend

of urban and rural areas, characterized by its diverse landscape, including residential areas, agricultural land, and natural surroundings. The local economy in Lam Luk Ka engages in a variety of activities, encompassing agriculture, commerce, and potentially manufacturing or services. Lam Luk Ka features various commercial and service establishments, including gas stations, shopping centers, fresh markets, general stores, hotels, banks, factories, temples, and mosques (Supcharonkul and yenyuak, 2024).

2.2 Scope of study

The analysis of the city carbon footprint followed the guidelines of the Carbon Footprint Organization, a subsidiary of the Thailand Greenhouse Gas Management Organization, as a framework for assessing greenhouse gas emissions. To define the boundaries of the city and scope of study, the general structure of the city must be studied, consisting of households, government and private agencies, business and industrial sectors, and transportation systems, and waste management, utilizing a combination of primary and secondary data sources from liquefied petroleum gas stores, gas stations, district administrative organization, waste management organization, and provincial electricity and waterwork authority in the 2019 database (TGO, 2018a; TGO, 2016).

2.3 Assessing the amount of carbon emissions

The study aims to assess carbon emissions within the scope of the study to identify their potential sources and develop strategies for reducing emissions from various human activities contributing to climate change. It is essential to recognize that greenhouse gas emissions from the city are a significant factor influencing the Earth's rising surface temperatures (Sangsawang and Surachotivet, 2023).

The carbon footprint, denoting the carbon emissions arising from various activities, is typically quantified in tons of carbon dioxide equivalent (tCO₂eq/year). The scopes of the city carbon footprint for Lam Luk Ka district, Pathum Thani province, were divided

into 3 scopes as follows: Scope 1 covered energy consumption from fuel combustion for transportation and household activities; Scope 2 included electricity consumption for all activities in the city; and Scope 3 refers to municipal waste management and water consumption for the municipality as detailed in Table 1. Under this study, only the major activities in the city were estimated in order to propose a mitigation measure to reduce the city-level carbon emission. Therefore, carbon emissions in scope 1 cover fuel consumption in household activities and fuel consumption, including diesel, gasoline 95, gasoline 91, E85, and E20. The researchers collected data in gas stations within the city in order to do a worst-case scenario analysis for conservatives. Scope 2 consisted of electricity consumption within the city of household activities and waste disposal activities, collected by district administrative organization, Sanitary landfill organization. Scope 3 refers to other major activities within the city, consisting of waste management tap and water consumption, reported by provincial electricity authority and provincial waterworks authority. Thereafter, the gathered data is utilized to compute the corresponding greenhouse gas emissions as the following equation (TGO, 2022).

$$\text{GHG emissions (tCO}_{2\text{eq}}/\text{year)} = \text{Activity data (AD)} \times \text{Emission factor (EF)}$$

3. Results and Discussion

The results presented the estimation of the carbon emission of Lam Luk Ka district. By quantifying the emissions associated with various activities and sectors, this assessment not only highlights areas of concern but also provides a basis for developing targeted strategies to reduce emissions and enhance overall environmental sustainability.

3.1 Scope 1 emission: Direct emissions of carbon emissions

3.1.1 Carbon emissions from stationary combustion

The study findings indicate that the fuel combustion of LPG for household activities

is associated with scope I’s carbon emissions. However, in the area, there are no industrial plants requiring the burning of coal or fuel oil. The consumption of stationary combustion is presented in Table 2. The annual consumption of liquefied petroleum gas (LPG) amounted to 669.12 tons, categorized into six types based on the volume of gas contained; including, 48 kg, 15 kg, 13 kg, 11 kg, 7 kg, and 4 kg of LPG containers.

The research reveals that household combustion activities result in annual carbon emissions of 792.17 tCO₂eq. Notably, the 15 kg–contained LPG container emerges as the primary contributor, accounting for 64% of the total emissions. Remarkably, this percentage aligns with findings from LPG gas usage studies conducted in other municipalities, underscoring the

consistency of LPG consumption patterns across different regions. (Chaivanich, 2021). Moreover, these results support the common use of 15 kg–contained cooking gas in medium-sized homes and smaller establishments, including small food processing shops in the area. The following contributors were the 48 kg–contained at 15%, followed by the 4 kg–contained at 10% of all carbon emissions from stationary combustion. Conversely, the 11 kg and 7 kg–contained containers have relatively lower contributions, each accounting for 2% and 3% of emissions, respectively. This prevalence was attributed to the common use of 15 kg–contained cooking gas in medium-sized homes and smaller establishments, including small food processing shops in the area.

Table 1. Classification of city carbon footprint scopes

Scopes	Activities	Information*	Sources
Scope I	Using of LPG for stationary activities	The consumption of Liquefied Petroleum Gas; LPG for stationary fuel combustion	Liquefied petroleum gas stores and stations
	Fuel consumption for transportation	Mobile fuel consumption such as gasohol 95, gasohol 91, E85, E20 and diesel.	Gas Station
Scope II	Electricity consumption	Electricity consumption in the city	District administrative organization, Sanitary landfill organization
Scope III	Waste management	the amount of waste disposal by landfill method	Provincial Electricity Authority
	Tap water consumption	Tap water consumption in the city	Provincial Waterworks Authority

* The database of activity data was collected in 2019.

Table 2. Fuel consumption and carbon emissions of stationary combustion

Sizes of LPG contained (kg)	The fuel consumption (ton)	Carbon emission* (tCO ₂ eq/year)	% Contributions
48 kg–contained	103.68	122.75	15.49
15 kg–contained	430.2	509.31	64.29
13 kg–contained	37.44	44.33	5.60
11 kg–contained	15.84	18.75	2.37
7 kg–contained	17.64	20.88	2.64
4 kg–contained	64.32	76.15	9.61
Total	669.12	792.17	100

*Emission factors (EF) of LPG for household activities is 1.1839 kg

3.1.2 Carbon emissions from mobile combustion

Carbon emissions from mobile sources refer to the carbon emission from the utilization of fuel in non-stationary activities. Thus, mobile combustion encompasses the burning of fuel employed in various transportation modes, with details provided in Table 3.

The study was conducted by collecting secondary data from the gas station within the city boundary in order to represent the worst-case scenario. The data presents the annual consumption and associated carbon emissions of various fuel types within the studied area. The usage of diesel emerges as the predominant fuel with an extensive consumption of 11,727,841 liters; contributing to a substantial carbon emission of 32,188.23 tCO₂eq/year; accounting for 73% of all carbon emission from mobile combustion. Among biodiesel fuel types, Diesel B20 exhibits notable consumption at 268,361 liters; resulting in a GHG emission of 0.73 tCO₂eq/year. Gasohol 95 and Gasohol 91 collectively contribute significantly to the overall fuel consumption, with 2,246,462 and 1,637,665 liters consumed, generating GHG emissions of 5.11 (accounting for 12%) and 3.7 (accounting for 8%) tCO₂eq/year, respectively.

The findings highlight the environmental impact of diverse fuel types, with diesel being a primary contributor to both fuel consumption and GHG emissions. Notably, the introduction of biodiesel variants, such as Diesel B10

and Diesel B20, demonstrates efforts toward incorporating cleaner fuel options. The significant consumption of Gasohol 95 and Gasohol 91 emphasizes the need for targeted strategies to reduce emissions associated with these widely used fuels.

3.2 Scope II emission: indirect emissions of greenhouse gases

These emissions are generated indirectly as they stem from the consumption of energy produced elsewhere but used within the city boundaries, including electricity consumption from the grid. Understanding and managing Scope 2 emissions is crucial for cities aiming to reduce their overall carbon footprint and mitigate climate change impacts by promoting energy efficiency, renewable energy adoption, and sustainable resource management practices.

Direct greenhouse gas emissions from electricity consumption

According to the calculations presented in Table 4, residential houses, particularly medium-sized and large-sized ones, emerge as one of the significant contributors to both consumption and emissions. This highlights the importance of implementing energy-efficient practices and technologies in residential areas to reduce overall emissions.

The substantial contributions from large-sized businesses and specific businesses emphasize the need for targeted sustainability measures within the commercial sector with

Table 3. Consumption and carbon emission of mobile combustion

Types of fuels	Fuel consumption (L/Year)	EF	Carbon emission (tCO ₂ eq/Year)	% Contributions
Diesel	11,727,841	2.7446	32,188.23	73.47
Diesel B10	4,506	2.7328	12.31	0.03
Diesel B20	268,361	2.721	730.21	1.67
Diesel Plus	430,547	2.7446	1,181.68	2.70
Gasohol Plus	153,330	2.2763	343.09	0.78
Gasohol 95	2,246,462	2.2763	5,113.62	11.67
Gasohol 91	1,637,665	2.2763	3,727.82	8.51
Gasohol E20	268,361	1.89558	508.70	1.16
Total	16,737,078		43,811.61	100

large-sized businesses consuming 109,275,185 kWh and generating 65,412.13 tCO₂eq, accounting for 24% of the total emissions. The medium-sized houses also contribute to electricity consumption and GHG emissions, with 107,056,399 kWh consumed, resulting in 64.08 tCO₂eq and representing 23% of the total emissions. The smallest contribution comes from office building electricity, with 138,674 kWh consumed and 0.08 tCO₂eq emitted of the total emissions.

3.3 Scope III emissions

3.3.1 Carbon emissions from waste disposal activities

The survey revealed that the waste disposal management within the urban area was through landfill, resulting in a total of 25,219.73 tCO₂eq/year in greenhouse gas emissions from landfills. The specifics of waste volume and corresponding greenhouse gas emissions are provided in Table 5.

3.3.2 Carbon emissions from water supply

The carbon emission from water supply was also estimated in the study. Notably, residential houses, both small and large, exhibit varying levels of water consumption, with large residential houses contributing the highest tap water usage at 334,953.14 cubic meters and corresponding greenhouse gas emissions of 181.21 tCO₂eq/year. Among businesses, large-sized enterprises lead in both tap water consumption (341,895.17 cubic meters) and greenhouse gas emissions (184.97 tCO₂eq/year), emphasizing their significant environmental impact. Additionally, specific businesses and medium-sized businesses closely follow in terms of both consumption and emissions, reflecting the substantial role of businesses in water resource utilization and environmental consequences. Temporary tap water, although exhibiting a notable consumption figure of 22,995.48 cubic meters, contributes relatively lower

Table 4. Carbon emission from electricity consumption

Electricity consumption type	Electricity consumption (kWh)	Carbon emission (tCO ₂ eq)	% contributions
Small-sized residential house	2,681,032	1,604.87	0.58
Medium-sized and large-sized residential house	107,056,399	64,083.96	23.17
Small-sized business	66,979,586	40,093.98	14.50
Medium-sized business	66,609,789	39,872.62	14.42
Large-sized business	109,275,185	65,412.13	23.65
Specific business	101,925,458	61,012.58	22.06
Temporary electricity	7,349,726	4,399.55	1.59
Office building electricity	138,674	83.01	0.03
Total	462,015,849	276,562.69	100

*The emission factor is 0.5986

Table 5. Quantity of greenhouse gas emissions from waste disposal

Waste type	Quantity (kg/Year)	EF	Carbon emission (tCO ₂ eq)	% Contribution
General household waste	3,732,000	3.27	12,203.64	48.39
Organic waste	3,138,000	2.53	7,939.14	31.48
Recyclable waste	1,732,000	2.93	5,074.76	20.12
hazardous waste	700	3.13	2.19	0.01
Total	8,602,700		25,219.73	100

emissions at 12.44 tCO₂eq/year. Similarly, office tap water, with a consumption of 433.88 cubic meters, registers minimal emissions at 0.23 tCO₂eq/year. In total, the summarized data underscores the diverse patterns of tap water usage across different user types, with varying implications for greenhouse gas emissions, emphasizing the importance of tailored environmental strategies for residential and business water consumers. The large residential houses stand out as significant consumers, utilizing 334,953.14 cubic meters of tap water and contributing 181.21 tCO₂eq/year, representing 23% of the total emissions. Following closely, large-sized businesses demonstrate substantial consumption, using 341,895.17 cubic meters of tap water and generating 184.97 tCO₂eq/year, contributing to 24% of the total emissions. Conversely, office tap water exhibits the smallest contribution, with only 433.88 cubic meters consumed and 0.23 tCO₂eq/year emitted, less than 1% of the total emissions.

The findings emphasize the considerable impact of tap water consumption, particularly in large residential houses and large-sized businesses, on overall greenhouse gas emissions. This emphasizes the need for sustainable water management practices and the implementation of water-saving technologies in both residential and commercial sectors.

3.4 Carbon footprint of the city and the recommendations

In examining the city-level carbon footprint of Lam Luk Ka District, Pathum Thani Province, the researcher categorized the carbon footprint assessment into three scopes following the criteria set by the Greenhouse Gas Management Organization. The first scope encompasses direct greenhouse gas emissions, further divided into mobile and non-mobile combustion, as well as municipal waste disposal. The second scope involves indirect greenhouse gas emissions, specifically related to the utilization of various types of electricity. Finally, the third scope encompasses other indirect greenhouse gas emissions, such as those resulting from the use of tap water.

Based on the provided data, the carbon footprint of Lam Luk Ka district is quantified at 347,168.23 tCO₂eq/year. Scope 2, which involves the use of electricity, stands out with a substantial carbon footprint of 276,562.69 tCO₂eq/year, constituting a significant 79.66%. Following closely is Scope 1, totaling 44,603.78 tCO₂eq/year, representing 12.85%. Lastly, Scope 3 accounts for 26,001.76 tCO₂eq/year, making up 7.49% of the total carbon footprint as presented in Table 7. In this study, the researcher has proposed two strategies for mitigating greenhouse gas emissions.

Table 6. Quantity of greenhouse gas emissions from water consumption

Type of tap water usage	Tap water consumption (cubic meters)	Carbon emission* (tCO ₂ eq/year)	% Contributions
Small residential house	8,388	4.54	0.58
Large residential house	334,953	181.21	23.17
Small sized business	209,562	113.37	14.50
Medium sized business	208,405	112.75	14.42
Large sized business	341,895	184.97	23.65
Specific business	318,899	172.52	22.06
Temporary tap water	22,995	12.44	1.59
Office tap water	433	0.23	0.03
Total	1,445,533	782.03	100

*Emission factor of tap water is 0.541

Table 7. Carbon footprint of the city

Scopes	Carbon footprint of the city (tCO ₂ eq/Year)	% Contributions
Scope I	44,603.78	12.85
Scope II	276,562.69	79.66
Scope III	26,001.76	7.49
Total	347,168.23	100

1. Launching a campaign within Lam Luk Ka district to encourage the transition from oil in the diesel group to diesel B20 and from oil in the gasohol group to Gasohol E20. This shift, driven by the lower greenhouse gas emissions coefficient of these alternatives, is estimated to result in a total reduction of 1,824.13 tCO₂eq/year. The diesel group was reduced by 286 tCO₂eq/year, accounted for 1% and Gassohol group was reduced by 1537.14 tCO₂eq/year, accounted for 15.85%.
2. Implementing a campaign to install 3kW office rooftop solar panels, with a recommendation of 10 panels per household roof. This method, utilizing clean energy, is anticipated to lead to a reduction of 3.74 tCO₂eq/year. Considering the 8,835 households in Lam Luk Ka district using electricity, the installation of solar rooftops across each household has the potential to decrease greenhouse gas emissions by a total of 33,042.9 tCO₂eq/year.

4. Conclusion

This comprehensive assessment of the carbon footprint in Lam Luk Ka district, Pathum Thani Province, provides valuable insights into the emissions associated with various activities, including stationary and mobile combustion, electricity consumption, waste disposal, and water usage. The findings highlight the significance of diverse factors contributing to the overall carbon footprint and lay the foundation for targeted strategies aimed at reducing emissions and promoting environmental sustainability.

In Scope I, which includes direct emissions from stationary and mobile combustion, the carbon footprint represents 13% of the total footprint in this city. The study identifies LPG consumption for household activities as a major contributor, with the 15 kg gas container being predominant, constituting 64% of carbon emissions from stationary combustion and diesel emissions from stationary combustion and diesel revealed as the primary contributor for mobile combustion. In Scope 2, indirect emissions from electricity consumption, residential and commercial areas played substantial roles, with large-sized businesses contributing significantly, contributing 80% of the total footprint in this city. The results underscore the need for energy-efficient practices, especially in residential areas, and targeted sustainability measures in the commercial sector. Scope 3, covering other indirect emissions, revealed greenhouse gas emissions from waste disposal and tap water usage, contributing 7% of the total footprint in this city. The data emphasized the importance of sustainable waste management practices and tailored environmental strategies for different user categories in water consumption. The study recommends targeted initiatives for reducing emissions, such as promoting cleaner fuels, adopting energy-efficient practices, implementing sustainable waste management, and encouraging water conservation. These measures align with national and international sustainability goals, providing a roadmap for enhancing the environmental resilience of urban areas.

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