Life Cycle CO_2 from the Waste Practices of *Tambon* Municipalities in Chiang Rai, Thailand

Noppharit SUTTHASIL[1,2*] and Pannipha DOKMAINGAM[1,2]

[1] *Environmental Health, School of Health Science, Mae Fah Luang University*
333 Moo 1 Tasud Sub District, Muang District, Chiang Rai 57100, Thailand
[2] *Circular Economy for Waste-Free Thailand Research Center, School of Science, Mae Fah Luang University*
Chiang Rai 57100, Thailand
**E-mail: noppharit.sut@mfu.ac.th*

Abstract

This study aims to evaluate the life cycle CO_2 ($LCCO_2$) of different waste management practices from *tambon* municipalities (local administrative organizations) in Chiang Rai, Thailand. "Tambon Municipality A" (TM-A) refers to a *tambon* municipality that used open dumping for final disposal. Two others, TM-B and TM-C, used small-scale incineration. The difference between the latter two is the waste collection method prior to delivery to the incinerator. TM-B used a waste compaction truck which had a greater capacity than the pickup truck used in TM-C. Finally, TM-D used mechanical biological treatment (MBT) for waste treatment and disposal. A waste composition investigation was also conducted for use in estimating GHG emissions. In parallel, waste mass flows, fossil fuel consumption and electricity consumption in the waste management process were also investigated. The $LCCO_2$ results show that the *tambon* municipality that used open dumping had the greatest GHG emissions while the municipality using MBT showed negative GHG emissions. The GHG emissions offset from TM-D is from utilizing compost and refuse-derived fuel (RDF). These results could be used to support other municipalities, waste operators or stakeholders in selecting appropriate modes of waste management from the perspective of GHG emissions reduction to reach national carbon neutrality and net zero targets.

Key words: carbon footprint, greenhouse gas emission, small-scale municipality, waste management practice

1. Introduction

Following the Paris Agreement in the year 2015, the nation members of the United Nations (UN), including Thailand, declared a goal of "achieving net zero emissions." After the COP26 meeting, Thailand announced a goal of "carbon neutrality" to be achieved by the year 2050 and "net zero emissions" by the year 2065 (ONEP, 2021). In 2020, the greenhouse gas (GHG) emissions from Thailand's waste sector accounted for about 4.26% (10,467 Gg CO_2eq) of the nation's total emissions. Moreover, over 90% of GHG emissions from the waste sector were derived from solid waste disposal (52.5%) and wastewater treatment (45.7%) (ONEP, 2022).

Under Thailand's regulations, the main entity responsible for municipal solid waste management is the local municipality. To reduce the GHG emissions from the waste sector, active action from local municipalities is key. To encourage local municipalities, the Ministry of Interior issued announcement B.E.2567 on waste management under the Act on the Maintenance of the Cleanliness and Orderliness of the Country. According to Section 4 of that, the local municipality has the right to benefit from their waste management by entering into carbon marketing (MOI, 2023). In preparing basic information before approaching the Thai Greenhouse Gas Organization to register carbon credits, the initial step is to elucidate the actual state of the life cycle of carbon dioxide ($LCCO_2$) in each local municipality.

There have been increasingly active efforts to estimate GHG emissions derived from organizations or activities in Thailand. This is occurring at various scales and scopes of work such as determining GHG emissions at cultural tourist sites, or at universities, or even at the city scale such as for the Phayao municipality (Chusuwan *et al*., 2020; Vichai & Sedpho, 2020). GHG emissions from waste management are also included in this manner. GHG emissions are calculated for all activities including waste collection, transportation, utilization and disposal. In 2019, Markphan and O-Thong studied the GHG emissions from waste management at the Nakhon Si Thammarat municipal landfill, which received waste from five nearby districts during that year and found that the total GHG emissions were 1.78 t CO_2/t waste/year and about 69% were emitted from the final disposal site (Markphan & O-Thong, 2019). In tandem, the characteristics of waste are among the most important factors influencing GHG emission potential, because each type of waste contains different amounts of biodegradable organic carbon (Edwards *et al*., 2018; Al-Wahaibi *et al*., 2020).

Unfortunately, several municipalities still lack the necessary basic information for investigating $LCCO_2$. There are several reasons for this, such as lack of staff or accessibility of data or calculation methods, especially in small or local municipalities. Therefore, this study aimed to determine $LCCO_2$ from waste management practices in several *tambon* municipalities in Chiang Rai Province that were using different waste management practices. Additionally, to complete the basic data requirement for determining $LCCO_2$, investigations of waste and waste mass flow were also conducted.

2. Methodology

2.1 Local Municipalities and their Waste Management Practices

Chiang Rai Province, in northern Thailand, consists of 144 local authorities. The scale of each municipality is classified according to the sizes of its population and finances. A *tambon* municipality is a small-scale authority that covers a population of between 7,000 and 15,000 people with a budget of over 20 million THB/year. Most of the 77 *tambon* municipalities in Ching Rai have to deal with waste management problems arising from budget limitations and a lack of staff to oversee waste management. In addition, the municipalities have different waste management practices such as open dumping, open burning, incineration or even curbside disposal. The waste management scheme in each municipality was designed according to the results of public hearings. The selected technology needed to be approved by the residents. Therefore, the *tambon* municipality is a good candidate for comparing $LCCO_2$ in different types of waste management. Moreover, it provides a good opportunity to promote this initiative to the people in charge.

Tambon Municipality A (below, TM-A) is located in the northern part of the urbanized area (the central zone of Chiang Rai). TM-A consists of 20 villages with 16,000 residents. The population tends to be increasing due to progressive urbanization from the center of Chiang Rai. The citizens of TM-A make their living mainly through business and agriculture. Their waste, about 31 t/d, is collected daily using a municipal waste truck. From there, the waste is disposed of at an open dumping site located approximately 5 km from the center of TM-A.

Tambon Municipality B (TM-B) is located in the eastern part of central zone of Chiang Rai. This *tambon* consists of 14 villages and has a total population of 8,200. Approximately 3.7 t/d of waste is generated. The amount of waste generated daily is small because the main occupation in this area is agriculture and half of the residents work outside the village in the daytime. Waste is collected from households using a municipal waste truck. All the waste is delivered to small-scale incinerators located about 11 km from TM-B. The waste is manually hand-sorted before being loaded into the incinerators, which have a combined capacity of 900 kg/hour.

Tambon Municipality C (TM-C) is located in the northern part of the central area, about 20 km away. It covers 16 villages and has a total population of about 12,000. The waste generation conditions in TM-C are similar to those in TM-B because both *tambon* are located at the periphery of the central area. They differ, however, in that there are multiple waste collection and disposal systems in TM-C that have been designed and are managed by each village. The *tambon*'s waste management is thus divided into five clusters, with each cluster using different waste management methods such as open dumping, provision to the private sector or small-scale incineration. The only task TM-C is responsible for is to provide small-scale incineration for three clusters (using an incinerator owned and operated by the municipality). In this study, only Cluster 4 was selected as representative because it was the only one that could collect complete data.

The waste generated in Cluster 4 is 0.6 t/d. After the waste is collected using a personal pickup truck, it is delivered to an incineration plant with a capacity of 120 kg waste/hour.

Tambon Municipality D (TM-D) is located about 50 km from the central area. The waste generated there, 20.6 t/d, is transported by a waste truck. The waste management facility owned by TM-D consists of mechanical segregation with a biological treatment process, also known as “mechanical biological treatment” (MBT). It transforms input waste into recyclable material, compost, refused-derived fuel (RDF), leachate and a remainder disposed of in landfills, accounting, respectively, for about 2.1%, 15.7%, 16.2%, 7.0% and 59.0% of the total.

2.2 Waste Composition Analysis

A waste composition analysis was conducted in all municipalities to confirm the actual waste composition in each. This investigation was conducted from October to November 2023. Waste samples were selected using a waste quartering method. The type of waste was classified following *Guideline for waste composition analysis at final disposal site*, prepared by the Pollution Control

Department or PCD (PCD, 2022).

2.3 Estimating GHG Emissions from Waste Management

The GHG emissions from waste management were calculated using a tool entitled "Estimation Tool for Greenhouse Gas (GHG) Emissions from Municipal Solid Waste (MSW) Management in a Life Cycle Perspective, Version III," developed by the Institute for Global Environmental Strategies (IGES) in collaboration with the United Nations Environment Programme International Environmental Technology Centre (UNEP IETC). This version was launched in 2021 to simulate GHG emissions in the context of China (IGES, 2021). A review by the author, however, found that this version is available for use in the Thai context because 1) This version was developed from version 2013 which has been used in the context of Thailand previously (Menikpura *et al*., 2013), and 2) Constant values and emission factors were also available for conditions in Thailand.

3. Results and Discussion

3.1 Waste Compositions from *Tambon* Municipalities

The waste compositions from the four municipalities are shown in Table 1. It was found that food waste and plastic waste were the main components in all municipalities, accounting for over 40%–50% of the total waste. Food waste content was in the range of 22.9%–32.8% while plastic waste content was 19.9%–28.7%.

In this classification, tissue paper content from households was in the range of 3.3%–11.6%. The tissue-paper content in wastes from TM-A and TM-D was greater than 10%. Both of these municipalities, in fact, were already urbanized and there were many restaurants and public spaces generating large portions of tissue paper. This situation is also related to the onset of an aging society, because the residents are starting to be concerned about personal sanitation, so they use more tissue paper. The diaper waste generation rate is similarly related. Diaper waste was in the range of 1.9%–11.5%. Higher diaper waste generation rates were observed in TM-A and TM-D, located in the urban area.

3.2 GHG Emissions from *Tambon* Municipalities

The GHG emissions from the four municipalities are shown in Fig. 1. The net GHG emissions from TM-A, TM-B, TM-C, and TM-D were 846.35 kg CO_2eq/t waste, 487.12 CO_2eq/t waste, 494.56 CO_2eq/t waste, and −84.78 CO_2eq/t waste, respectively. The dominant GHG emissions source of each municipality was the same as in the final disposal (open dumping, landfilling or incineration).

Transportation using fossil-fuel-consuming vehicles is revealed to account for about 0.5%–9.4% of the total GHG emissions. The maximum GHG emissions from transportation came from TM-C which waste collection was conducted by the villagers themselves, using their own small pickup truck. Due to the separate individual collection of the waste, the fossil fuel consumption was larger than that from the other waste collection method using a waste compaction truck (owned by the municipality).

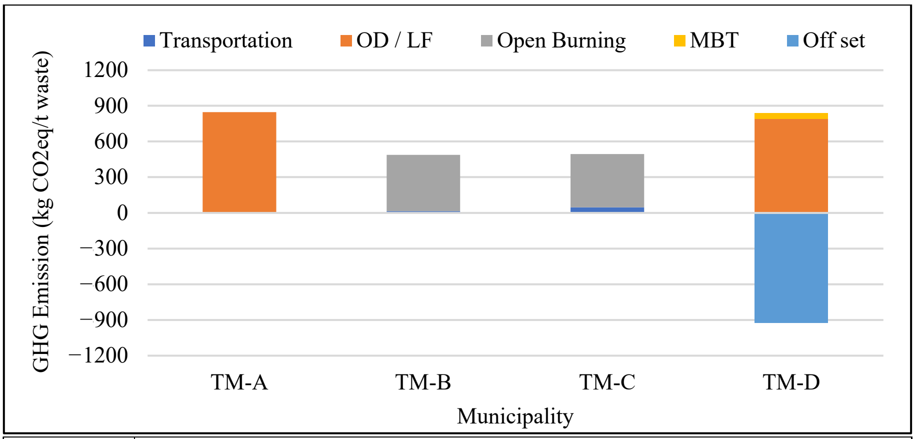
The GHG emissions from the open dumping in TM-A were greater than those from the landfilling practice in TM-D. Typically, the GHG emissions from landfilling are greater than those from open dumping because the methane correction factor of open dumping is 0.8 while that of landfilling is 1.0. In this study, however, the waste landfilled in TM-D contained a reduced amount of organic waste due to the prior mechanical separation process. Therefore, the amount of biodegradable carbon was less than in the open dumping in TM-A.

The small-scale incineration operations in TM-B and TM-C were conducted manually by the operator. The waste was manually separated to remove hazardous materials (such as compressed spray cans, lighters or

Table 1 Waste compositions of four different *tambon* municipalities in Chiang Rai.

Component	*Tambon* Municipality							
	A		B		C		D	
Food	22.9	*5.7*	32.8	*4.8*	30.7	*6.6*	22.9	*5.7*
Garden Waste	3.8	*1.5*	1.5	*0.6*	4.7	*3.6*	2.7	*0.2*
Paper	10.2	*1.2*	6.7	*0.7*	9.0	*1.1*	2.9	*1.8*
Wood	1.6	*0.5*	0.3	*0.1*	1.1	*0.6*	1.8	*0.8*
Textiles	1.0	*0.7*	2.6	*1.6*	5.5	*0.4*	2.4	*0.1*
Leather & Rubber	0.8	*0.5*	0.6	*0.3*	4.4	*0.9*	0.5	*0.3*
Diapers	4.4	*1.2*	1.9	*1.2*	6.6	*0.1*	11.5	*2.3*
Plastics	21.0	*4.1*	28.7	*0.7*	26.6	*5.5*	19.9	*6.2*
Foam	1.1	*0.1*	0.5	*0.2*	0.3	*0.0*	1.1	*0.1*
Metal	0.6	*0.2*	0.9	*0.1*	0.8	*0.1*	0.6	*0.3*
Glass	6.4	*1.3*	7.6	*1.0*	2.8	*1.5*	3.9	*1.3*
Hazardous	1.8	*0.5*	0.8	*0.4*	1.0	*0.2*	1.3	*0.9*
E-waste	0.0	*1.0*	3.0	*2.5*	1.3	*0.2*	0.3	*0.3*
Tissue paper	11.1	*2.1*	3.3	*1.5*	4.4	*0.4*	11.6	*4.4*
Others	13.5	*1.1*	8.7	*0.8*	0.7	*0.7*	16.5	*2.0*
Total	100.0		100.0		100.0		100.0	

Remark: *Italics* indicate standard deviation (SD).



Municipality	GHG Emission from the Waste Management Activity (kg CO2/t waste)					
	Transportation	OD / LF	Open Burning	MBT	Off set	Total
TM-A	5.3	841.05	-	-	-	846.35
TM-B	14.7	-	472.42	-	-	487.12
TM-C	46.35	-	448.21	-	-	494.56
TM-D	4.36	786.85	-	48.65	−924.64	−84.78

Remark: OD/LF = Open Dumping/Landfilling, MBT = Mechanical Biological Treatment

Fig. 1 GHG emissions from waste management activities.

bulky waste) prior to being fed into the combustion chamber. After that, the waste was manually thrown continuously into the combustion chamber. Since the tools for calculating GHG emissions from incineration were suggested for use with large-scale incineration (indicating closed combustion systems, e.g., Stoker grate or fluidized bed), they include a GHG offset for recovery of energy from waste incineration. The small-scale incineration process used in TM-B and TM-C, on the other hand, results in incomplete combustion with no energy recovery. Thus, the GHG emissions calculation for open burning technology would be the appropriate choice in this case. The results, however, showed that the GHG emissions from small-scale incineration in TM-B and TM-D were very similar values. The slightly higher emissions in TM-B resulted from a higher percentage of plastic and other wastes with a 100% fossil carbon fraction.

The MBT practice in TM-D provides benefits via the production of compost and RDF. The compost is utilized to replace commercial compost. Meanwhile, the RDF is sold to the cement industry to replace natural coal as an alternative fuel. Thus, composting and RDF production from MBT can offset the GHG emissions from commercial composting production and natural coal combustion with a value of −924.64 kg CO_2eq/t waste. Therefore, the net GHG emissions from TM-D were −84.78 kg CO_2eq/t waste, indicating negative emissions.

3.3 Suggested Practices for Reducing GHG Emissions

The results of this study show the benefits of appropriate waste management practices. The selection of waste transportation methods can affect GHG emissions. The use of waste compaction trucks leads to reduced gas emissions. Following the results shown from TM-D, if the waste can be separated and utilized correctly, the total GHG emissions can be reduced drastically. In addition, the GHG emissions from landfilling from the MBT process are lower than those of fresh waste due to the processing to remove organic wastes. Furthermore, the utilization of compost and RDF can provide additional income if the municipality can sell these products.

These good practices, however, also come with investment costs such as the cost of waste compaction trucks or MBT facilities. In this manner, small municipalities lack sufficient potential without support from the central government. The key factor to reducing GHG emissions, however, is to reduce the amount of waste reaching the final disposal site. Therefore, source separation is a good option for local municipalities but also needs good support from the residents.

In addition, the quality and user acceptance of waste-derived compost and RDF need to be considered. For composting, there are no exact regulations for compost produced by waste treatment plants. It is possible, however, to use criteria provided from the Department of Agriculture (DOA) to obtain standard values for organic compost. Previous research has shown that most waste-derived compost could not meet those standards. The main reason is high contamination with heavy metals. Users may accept the poorer quality of waste-derived compost, but only if it is free of charge. Thus, waste-derived compost faces big obstacles when trying to achieve a sustainable market (Sonklin & Dechowanich, 2014).

For RDF, the PCD has announced standard values for its use in cement plants or the waste-to-energy industry. There are several projects in local municipalities to produce RDF for sale. The problem, however, is how to control the quality of RDF, especially the moisture content. In the current situation, municipalities that have been able to prepare RDF could send it to the plants but they wouldn't receive any money in return, because the

RDF quality is substandard. Nonetheless, at least the municipality could reduce the amount of waste needing disposal in its area.

4. Conclusions

$LCCO_2$ results from four different waste management practices were studied. The results showed that the net GHG emissions from municipality TM-A which used open dumping for final disposal were the highest at 846.35 kg CO_2eq/t waste. Meanwhile, TM-B and TM-C, which used small-scale incineration, exhibited the second and third largest GHG emissions. The difference between these two values was the result of different waste compositions. Lastly, TM-D, which selected an MBT process for its waste management practice showed negative net GHG emissions due to the offset of composting and RDF utilization. These results suggest *tambon* municipalities should select appropriate waste management practices from the perspective of GHG emission mitigation. Such selections, however, also require financial consideration. Appropriate selection of waste management methods in conjunction with source separation could support GHG emission mitigation to reach the central government's goals for carbon neutrality and net-zero emissions.

This study, however, covered only the investigation of waste composition in just one season (dry season). Therefore, further study will focus on waste composition throughout a whole year to gain a good representative waste composition for each municipality.

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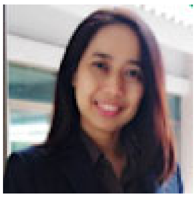
Noppharit SUTTHASIL

Noppharit Sutthasil, Ph.D., graduated with a bachelor degree from Thammasat University, Thailand, continuing for his master's and doctoral degrees at Kasetsart University in the Environmental Engineering Department.
He started his career as a research associate at the National Institute for Environmental Studies (NIES) in Japan during 2017–2022. He currently works as a lecturer in the Environmental Health program, School of Health Science, Mae Fah Luang University, Thailand. His focus is on reducing greenhouse gas emissions from waste management under Asian conditions. In addition, he is strongly focused on final disposal such as at semi-aerobic landfills or through mechanical biological treatment (MBT).



Pannipha DOKMAINGAM

Asst. Prof. Pannipha Dokmaingam, Ph.D., serves as a lecturer on environmental health at Mae Fah Luang University, Thailand. She possesses extensive expertise in environmental and energy research, particularly in waste management and renewable energy initiatives. Her current research encompasses biomass valorization, greenhouse gas storage assessments for agricultural crops, and biogas production from agricultural waste. Additionally, she has successfully led multidisciplinary projects, including consultancy for the Green Destinations Award in Chiang Khan, Thailand under the Global Sustainable Tourism Council (GSTC) framework, showcasing her commitment to sustainable development practices.

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