Carbon Footprint of Food Waste Handling and Disposal: A Case Study of Sam Khok, Pathum Thani Province, Thailand

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A R T I C L E I N F O

Article history:
Received: 19 February 2023
Revised: 29 March 2023
Accepted: 15 April 2023

Keywords:
Greenhouse gases
Food waste
Waste recycling

A B S T R A C T

One-half of Sam Khok's Municipal Solid Waste (MSW) in the landfill is Food Waste (FW). This proportion of waste, accompanied by climate conditions in tropical countries, accelerates food spoilage that contributes to the emission of greenhouse gases (GHGs). This study aimed to quantify the carbon footprint following the life cycle assessment of FW management in Sam Khok, Pathum Thani province. Equations used in this study followed the methodologies provided by IPCC, USEPA, and TGO. During 2016-2019, Sam Khok generated FW of about 3,124 tons.y^{-1} (0.15 kg.cap^{-1}.d^{-1}) with only 3% recycling. The GHG emissions from FW collection, transportation, and disposal amounted to 2,386.09 $tCO_2e.y^{-1}$. About 96% of the GHG emissions resulted from controlled open dumping due to the anaerobic decomposition of compostable organics. Concurrently, turning 3% of the total FW into the animal feed and soil conditioners was instrumental in the total GHG reduction of 76.42 $tCO_2e.y^{-1}$. Therefore, the net carbon footprint of FW management was equal to 2,309.59 $tCO_2e.y^{-1}$. Based on several assumptions, increasing FW recycling via composting and animal feeding shown the potential to avoid the GHG emissions of about 66%. The benefits from FW volatilization will not only lower the amount of GHG emissions and the operating costs but will also importantly provide alternative waste management to local authorities and people in Sam Khok communities, allowing them to utilize their waste and prepare for participating in Low Carbon city.

1. INTRODUCTION

Food, a substance consumed to provide nutrients and essentials, is a vital part of our human life. Despite being one of the most fundamental needs of living things, one-third of all food produced and consumed globally becomes food waste, amounting to approximately 1.3 billion tons per year [1]. In the cities like Bangkok and Pathum Thani, the amount of food waste was around 45-60 percent [2],[3] as well as in other Asian countries such as Japan, China, and Malaysia, where food waste compositions were in the rage of 42-57 percent [4]-[6]. Disposal of food waste (FW) in tropical climates only expedites food spoilage that leads to greenhouse gas emissions [7]. For decades, there have been concerns over severe climate change and global warming resulting from increasing rates of GHG emissions [8]. Gases such as Carbon Dioxide (CO_2) are released during the combustion process or the aerobic decomposition of organic waste materials, whereas Methane (CH_4), during the anaerobic decomposition of organic waste [9]. Improper waste disposal practices such as open burning, open dumping, and landfilling have been responsible for many environmental pollutions, including GHG emission [9]-[11]. Air pollutants, i.e., CH_4 and CO_2, have substantiated and exacerbated climate change [12]. Thus, if the amount of FW increases, it may cause more negative environmental impacts.

In Thailand, the Low Carbon City policy is a voluntary initiative, referring to a city, municipality, or community that follows a systematic process to achieve GHG emission reduction. One of many processes that help localities work toward becoming a low carbon city is to prepare a GHG inventory and determine emission-reduction measures and technologies [13]. During 2011-2020, approximately 304 municipalities in Thailand participated in this project; however, only one in Pathum Thani joined. The result analysis showed that the most significant greenhouse gas emission was from waste disposal activities [14].

Sam Khok is a district in the northern part of Pathum Thani. In 2019, the amount of FW collected from households, schools, temples, markets, and other residential sources totaled up to around 3,000 tons. Only a few percent of FW was recycled as compost and animal feed, with the remainder dumped on land using the controlled open dump method. Accordingly, assessing emissions and reductions of

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GHGs throughout FW management is critical to the enhancement of local authorities' awareness and preparedness for climate change. Therefore, the purpose of this study was to quantify the amounts of emitted and reduced GHGs from source collection through final disposal under the FW management in Sam Khok district between 2016 and 2019. The advantages of the emission status evaluation will not only provide the database of GHGs from the waste sector but also obtain the mitigation ideas to reduce the GHGs emission to the atmosphere.

2. MATERIALS AND METHODS

2.1. Study area

Sam Khok is a district in the northern part of Pathum Thani. Its area covers approximately 95 square kilometers, divided into eleven sub-district municipalities [15]. The population number is 56,000 with 30% of non-registered commuters [16]. The municipal solid waste (MSW) management is self-administered by the division of Public Health. MSW, containing food waste (FW) generated from households, schools, temples, markets, and other residential communities, were collected daily by solid waste collectors using six-wheel trucks with 6 tons of capacity. Only a few percent of the FW has currently been utilized within the district, while the remainder has not. These non-utilized wastes were collected from each sub-district municipality and transported separately to a landfill in Phra Nakhon Si Ayutthaya province without sorting and/or recycling. Since 2007, the landfill has received MSW from many provinces, including Pathum Thani.

2.2. Quantification methodology

This study was conducted in five steps as follows: (1) defining the system border and functional units, (2) collecting the data, (3) calculating the carbon footprint, (4) interpreting the results, and (5) providing alternative FW management options. The system border of this study encompassed GHG emissions and reductions from FW utilization, collection, transportation, and disposal. Firstly, the values of GHGs would be reported in the functional units of "tons carbon dioxide equivalent per year (tCO2e.y-1)" and "kilograms carbon dioxide equivalent per ton of FW (kgCO2e.t-1)". The former functional unit represented the rates of GHG emission or reduction over a period of time, whereas the latter expressed the amounts of GHGs that could be released or reduced when a ton of FW was generated or utilized, respectively. The second step was to gather all relevant data to be used for the quantification. The data on wastes composition, waste generation, waste utilization including food waste, collection frequency, type and number of trucks, type of fuel consumption, route, and distance of waste transportation were obtained from the statistical books, recording forms, and online database. The recording forms were delivered and gathered from local officers directly responsible for the waste reporting system. The data on fuel consumption such as diesel and management procedure, was done by phone interviews and employee inquiries. Emission factors, constant values, unit conversions, GWP values, and assumptions were from research studies, theses, and reliable online databases. The next step was to calculate the carbon footprint. The equations used in this study followed the methodologies provided in the 2006 IPCC Guidelines for National Greenhouse Gas Inventories [17], the Greenhouse Gas Emissions Estimation Methodologies for Biogenic Emissions from Selected Source Categories [18], and the Carbon Footprint Guideline for Municipality [19].

The following equation (Eq.1) is for the carbon footprint at source utilization which indicates GHG reduction by converting FW to compost and animal feed.

$$GHG_{reduction} = f_{utilization} \times Q_{utilization} \times EF_{utilization} \quad (1)$$

where, $GHG_{reduction}$ is the reduction rate of GHGs from converting FW to compost or animal feed ($tCO_2e.y^{-1}$); $f_{utilization}$ is the fraction of utilizing FW as compost and animal feed (%); $Q_{utilization}$ is the total amount of FW at source utilization ($t.y^{-1}$); $EF_{utilization}$ is the emission factor for organic waste composting (0.2552 $kgCO_2e.kg^{-1}$) [20] or animal feeding (1.14 $kgCO_2e.kg^{-1}$) [21].

The carbon footprint from source collection to disposal center includes GHG emissions from FW collection (Eq.2) and transportation (Eq.3a or Eq.3b)

$$GHG_{collection} = (Q_{FW} \times EF_{collection}) \quad (2)$$

$$GHG_{transportation} = (Q_{FW} \times Fuel\ consumption \times EF_{diesel}) \quad (3a)$$

$$GHG_{transportation} = (Q_{FW} \times D_{outbound} \times EF_{outbound}) + (D_{inbound} \times EF_{inbound}) \quad (3b)$$

where, $GHG_{collection}$ is the emission rate of GHGs caused by FW collection ($tCO_2e.y^{-1}$); Q_{FW} is the collected amount of FW in Sam Khok district ($t.y^{-1}$); $EF_{collection}$ is the emission factor for waste collection (0.0079 $kgCO_2eq.kg^{-1}$) [20]; $GHG_{transportation}$ is the emission rate of GHGs caused by FW transported to the disposal site ($tCO_2e.y^{-1}$); Fuel consumption is the rate of diesel consumed for FW transportation ($L.t^{-1}$); EF_{diesel} is the emission factor for mobile diesel combustion (2.7446 $kgCO_2eq.L^{-1}$) [20]; $D_{outbound}$ is the distance from source to the disposal site (km); $D_{inbound}$ is the distance from the disposal site back to source (km); $EF_{outbound}$ is the emission factor for the six-wheel trucks with 100% waste loading (0.0674 $kgCO_2eq.t^{-1}.km^{-1}$) [20]; $EF_{inbound}$ is the emission factor for six-wheel trucks with 0% waste loading (0.4246 $kgCO_2eq.km^{-1}$) [20].

The carbon footprint at the disposal center focuses on two major emitted gases during the decomposition: CH_4 and CO_2. This study estimated the GHG emissions from landfilling or open dumping by using Eq.4-6 as follows:

$$Landfill_{\_CH4\ emission} = (W_x L'_x (e^{-k\,(T-x-1)} - e^{-k\,(T-x)})) \quad (4)$$

$$L'_x = MCF \times DOC \times DOCF \times F \times 16/12 \quad (5)$$

where, Landfill$_{_CH4\ emission}$ is the methane emission ($tCH_4.y^{-1}$); W_x is the quantity of waste disposed at the solid waste disposal site ($t.y^{-1}$); L'_x is CH4 generation potential which equals MCF×DOC×DOCF×F×16/12 when *MCF* = CH4 correction factor (assumed to be 1 for landfilling) *; DOC* = degradable organic carbon (assumed to be 0.15 g of C/g of FW); *DOCF* = fraction of DOC decomposed (assumed to be 0.5 for landfilling); *F* = fraction by volume of CH4 in landfill gas (assumed to be 0.5 for landfilling); k is the decay rate constant (assumed to be 0.4 y^{-1} [22]); T is Inventory year (unitless); x is the year in which waste was disposed (unitless).

$$Landfill_{\_CO2\ emission} = (CH_4 \times [(1-F)/F + OX] \times 44/16) \times GWP_{CO2} \quad (6)$$

where, Landfill$_{_CO2\ emission}$ is carbon dioxide ($tCO_2.y^{-1}$); CH_4 is CH4 generation from Eq.4 ($tCH_4.y^{-1}$); *OX* = Soil oxidation fraction, typically 0.1; 44 = Molecular weight of CO2 (kg/kg-mol); 16 = Molecular weight of CH4 (kg/kg-mol) [17].

Landfill_CH4 emission and landfill_CO_2 emission calculated from Eq.4 and 6 were equivalent to "$tCO_2e.y^{-1}$" by multiplying with GWP; 28 and 1 for CH_4 and CO_2, respectively [23]. Lastly, the GHG emission from landfill site is the summation between equivalented CH_4 and equivalented CO_2.

Then, the net GHG emission was estimated from the difference between the emission and the reduction. To identify the procedure contributing the most to the overall GHG emission, every portion of the emissions per ton of FW was compared. Lastly, a simple model on GHG reduction from alternative FW management was performed by increasing the rate of FW utilization.

3. RESULTS AND DISCUSSION

3.1. Carbon footprint of FW in Sam Khok

In Sam Khok, approximately 3,124 tons of FW were generated from food preparation, processing, and leftovers in households, schools, temples, markets, and other residential communities between 2016 and 2019. The FW generation rate was about 0.15 $kg.cap^{-1}.d^{-1}$, which was comparable to other countries, such as Bangladesh, India, China, Japan, and Russia, which had rates ranging from 0.1-0.4 $kg.cap^{-1}.d^{-1}$ [24]. Of 3,124 tons, only 3% of the total generated FW was used as compost and animal feed in the sub-district municipalities of Sam Khok, Khlongkhwai, and Kachang. Using Eq.1, the portion of GHG reduction was calculated to be 76.42 $tCO_2e.y^{-1}$ or 830 $kgCO_2e.t^{-1}$.

As previously mentioned, only a small amount of FW was utilized, with the remaining 97 percent accounting for 3,032 tons.y-1 of the FW was collected, transported and disposed of in the landfill. Food waste collection was the first activity that contributed to the GHG emission. This portion of GHG emission, denoted as "GHG collection" in Eq.2, was estimated to be 23.96 $tCO_2e.y^{-1}$ or 7.9 $kgCO_2e.t^{-1}$.

After the collection process, the collected FW as well as other MSW were transported to the disposal site. This step was identified as the next activity in the GHG emission, denoted as "GHG transportation". This portion of the GHG emission was produced by mobile sources as fuels are burned along the way. Data on diesel consumption obtained from nine sub-district municipalities revealed that diesel consumption rates ranged between 2-8 $L.t^{-1}$. There were obvious differences in these rates due to the vehicle lifetime. Using Eq3a, the GHG transportation from nine sub-district municipalities was equal to 37.35 $tCO^2e.y^{-1}$. For the remaining two sub-district municipalities, Bangkabue and Banpathum, where fuel consumption data was unavailable, GHG transportation was calculated using other transportation information including truck type, outbound and inbound distances, and waste loading size. Both areas were approximately 23 kilometers away from the disposal site, and both used diesel six-wheel trucks. As a result, the GHG transportation from these two sub-district municipalities was 19.79 $tCO_2e.y^{-1}$. Thus, the total GHG emission from FW transportation was summed to be 57.14 $tCO_2e.y^{-1}$ or 19 $kgCO_2e.t^{-1}$.

Table 1. Summary of GHG emissions and reductions in 2019 by sub-district municipality

Sub-district	Reduction	Emission		
		Collection	*Transportation*	*Disposal*
Bangtoey	0	4.74	5.21	456.07
Samkhok	0.37	0.13	0.17	12.77
Krachang	3.06	0.07	0.07	6.89
Khlongkhwai	72.99	5.59	4.69	538.16
Chiengraknoi	0	0.00	0.00	0.23
Chiengrakyai	0	8.91	21.40	857.41
Taykoa	0	0.61	1.10	59.14
Bangkabue	0	0.28	9.61	27.36
Bangphonua	0	1.36	4.24	130.74
Banngew	0	0.78	0.46	74.87
Banpathum	0	1.47	10.19	141.38
Overall	**(-)76.42**	**(+)23.96**	**(+)57.14**	**(+)2,305.01**

Remarks: (-) represents the overall reduction of GHGs by turning FW into compost or animal feed. (+) represents the overall emission of GHGs from fuel and natural resource consumption activities. The values are reported in the unit of tCO_2e.

The last activity was the GHG emission from FW landfilling. The carbon footprint at the disposal center addressed two significant gases emitted during organic matter decomposition. In the absence of oxygen, organic waste, in particular, can be easily digested by anaerobic microbes throughout hydrolysis, acidogenesis, acetogenesis, and methanogenesis process. This mechanism usually occurs in the lower layer of the waste pile while the aerobic decomposition process mostly takes place in the upper layer. CH_4 and CO_2, hence, were released. Following the First Order Decay (FOD) method-Tier 2 suitable for national and regional estimates of all solid waste deposited in disposal sites, the GHG emission from this portion, denoted as "GHG landfilling", was calculated to be 2,305.01 $tCO_2e.y^{-1}$ or 760 $kgCO_2e.t^{-1}$. The summary of GHG emissions and reductions under the FW management in Sam Khok, Pathum Thani province, varied by sub-district municipality, are shown in Table 1.

The current FW management of Sam Khok district caused the total GHG emission of approximately 2,386.09 $tCO_2e.y^{-1}$ or 787 $kgCO_2e.t^{-1}$. Around 96 % of the GHG emission came from the final disposal. The rest was shared by FW transportation (3%) and collection (1%), as illustrated in Fig.1. The results of this study were consistent with many previous studies conducted in Thailand [25]-[27] and other countries [28]-[30] which mostly concluded that waste landfilling and transportation were the major contributors to GHG emissions.

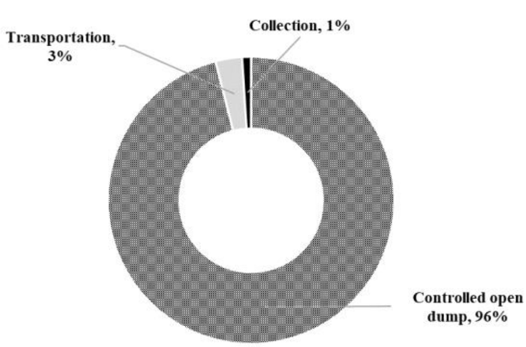

Fig. 1. Share of GHG emission by FW management activity.

Meanwhile, the total reduction of GHGs was 76.42 tCO_2e. In Sam Khok communities, FW is commonly converted into animal feed and soil conditioner, consequently, the current net carbon footprint of FW management in Sam Khok district, Pathumthani province was equal to 2,309.59 $tCO_2e.y^{-1}$ or 739 $kgCO_2e.t^{-1}$.

3.2. Avoided GHGs emission from FW recycling

The valorization of FW by elevating the FW utilization rate has been accepted for sustainable FW management. Instead of disposal of FW by landfilling, technologies that provide both environmentally friendly and economic benefits have been explored [24]. The examples are donation [31], animal feeding [32], composting [33] and anaerobic digestion [34]. These technologies have both pros and cons. A recent study on sorting household FW in Japan found that 16.8% and 51.9% of the food waste were leftovers and intentionally removed FW, respectively [35]. Which can be turned into valuable materials i.e. soil conditioner, animal feed and biogas [36]. Moreover, in Bangkok and Pathumthani, leftovers are widely utilized as animal feed, especially for local swine and poultry farms while intentionally removed part of food waste such as fruit peels, fish skin, vegetable roots, seeds, and stems are usually composted to produce soil conditioner. Also, results from this study revealed that in order to reduce GHGs emission, utilization of FW is becoming the key. Thus, the most local practices, animal feeding and composting, were chosen for this study because they are applicable and currently carried out.

Applying those FW portions obtained from study conducted in Japan, a total of 3,124 t of FW generated in Sam Khok district can be assumed as 525 t of leftovers and 1,621 t of intentionally removed part which appropriate for FW utilization. The amount of GHGs emission can be avoided as summarized in Table 2.

Table 2. Avoided GHGs emission by source recycling

Calculation list	Current practice	New practice
Generated FW (t/y)	3,124	3,124
Amount of FW utilization (t/y)	92	2,149[a]
Remaining FW to landfill (t/y)	3,032	975
GHGs emission (tCO_2e/y)		
• Collection	23.96	23.96[b][c]
• Transportation	57.14	18.53[c]
• Disposal	2,305.01	767.32[c]
∴ **Avoided GHGs emission**		1,576.3[d]

Remarks [a] 2,149 t of FW were assumed as recycling leftovers of 515 t for animal feed and intentionally removed FW of 1,634 t for composting. [b] GHGs emission from collection was assumed to be the same. [c] estimated by multiplying 975 t of FW with their following emission rates (19 $kgCO_2e$ per 1 t of transported FW and 787 $kgCO_2e$ per 1 t of disposed FW). [d]estimated from the difference between current GHGs emission (2,386.09 tCO_2e) and new GHGs emission (809.81 tCO_2e).

Based on Table 2, it can be estimated that GHGs emission of approximately 66% could be avoided by recycling FW as animal feed and compost since it reduces the GHGs emission from transportation and final disposal. However, this value is obtained based on several assumptions and does not include GHGs emission during the utilization process such as emission from organic matter degradation in biological fermentation.

4. CONCLUSIONS

Presently, the net carbon footprint under the FW management in Sam Khok district, Pathumthani province accounted for 2,309.59 $tCO_2e.y^{-1}$ which equaled 739 $kgCO_2e.t^{-1}$. With this figure (2,309.59 $tCO_2e.y^{-1}$), the disposal of FW by landfilling contributed to 96 percent of the total GHG emission. Volatilization of FW by boosting FW utilization through composting and animal feeding has numerous environmental and economic benefits. Apart from lowering the amount of GHG emissions during the transportation and final disposal, as well as the operating costs of FW transportation, most importantly, it encourages local authorities and people in Sam Khok communities to utilize their waste with the alternative waste management. The result estimated that utilizing FW could avoided 66% of current GHGs emission. However, this value was calculated based on several assumptions and works of literature. Therefore, further study should focus on FW sorting into leftovers, edible FW, and non-edible FW. Moreover, additional projects, i.e., Zero Food Waste campaign, knowledge of 3Rs, and stakeholder participation, can facilitate Sam Khok to successfully become a Low Carbon City and assist other local authorities with similar solid waste management policies and conditions.

ACKNOWLEDGEMENTS

This work is part of a 2019 research project, "Evaluation of Greenhouse Gas Emissions from Food Waste Management: A Case Study of Sam Khok District, Pathumthani Province, Thailand" supported by the Faculty of Public Health, Thammasat University Research Fund, Contract No. 1/2019. Data provision and assistance from anonymous officers at the Division of Public Health in Sam Khok District, Pathum Thani province, are also greatly appreciated. The authors would like to thank the anonymous reviewers for their incredibly thorough critique of the paper and extensive feedback.

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