Carbon Footprint of Rice Straw Paper Plate

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ABSTRACT

The objectives of this research to study the greenhouse gas emissions (GHG) of rice straw paper plates and to compare the environmental pollution from burning rice straw to make rice straw paper plates. In addition, it is suggested as a guideline for the use of rice straw. The study was based a Carbon Footprint of Products (CFP) on the concept estimation principle of the Thailand Greenhouse Gas Management Organization (TGO). Data was recorded from rice straw paper plate production by community enterprise Arak Group from Lat Bua Khao sub-district, Ban Pong district, Ratchaburi province, Thailand. The methodology was investigated from harvest material to production process until rice straw paper plate. The result was that 20 kg of rice straw emitted 7.93 kg CO_2e; on average, 1 plate emitted 0.0441 kg CO_2e. The results of the data analysis in each process were as follows: most GHGs averagely emitted 7.29 kg CO_2e; GHGs accounted for 91.96% of process production. The second highest from raw material usage emitted 0.64 kg CO_2e of GHGs, which accounted for 8.04% of the reduction in burning as follows: CO_2, CH_4, PM10, PM2.5, Black Carbon, CO, NH_3, NO_X, SO_2, NMVOC and Organic Carbon averagely emitted 351,765.39, 1,115.52, 3,631.93, 150.47, 15,357.88, 153.06, 767.89, 155.65, 2,062.42, and 907.98 tons, respectively, of the total amount of rice straw in Ratchaburi province, Thailand.

Keyword: Carbon footprint of product/ Greenhouse gas/ Life cycle assessment/ Air pollution/ Rice straw paper plate

1. INTRODUCTION

Global warming is an important environmental problem. It is mainly caused by human activity, primarily through emitting greenhouse gases from the burning of fossil fuels and deforestation. Carbon footprint has become an increasingly popular concept for labeling goods and services. The carbon footprint is the sum of all greenhouse gases released during the life cycle of a product, expressed as CO_2 equivalents as a common unit for all greenhouse gases. It is increasingly used by businesses, governments, and other stakeholders to quantify and subsequently reduce emissions.

Thailand is an agriculture area, it covered rice planted area around 9.76 million hectares or 20 percent of the total rice planted area. It can produce 24 million-ton rice yield per year [4]. The rice straw residue is approximately 25.45 million tons per year. Furthermore, rice straw residue remains in the rice paddy area, about 16.9 million tons per year. In one rai was produced 329 kilograms of rice straw residue [5]. In general, farmers manage the rice straws by burning them because it is easy, time-consuming, and saves the budget for rice farming. The burned rice straw caused the air pollution in terms of PM 2.5, black carbon, and the other effected greenhouse emissions. The one rai (6.25 rai equal 1 hactares) emitted greenhouse gas emissions about carbon dioxide (CO_2) of 446.11 kg, methane (CH_4) of 1.41 kg. Furthermore, the air pollution from one rai of rice emitted PM10 of 4.61 kg, PM2.5 of 4.18 kg, black carbon of 0.19 kg, carbon monoxide (CO) of 19.48 kg, ammonia (NH_3) of 0.19 kg, nitrogen oxide (NO_X) of 0.97 kg, sulfur dioxide (SO_2) of 0.20 kg, NMVOC of 2.62 kg, and organic carbon (OC) of 1.15 kg [7]. The management of rice straw residue by applying them to rice straw paper plate production is one idea to reduce rice straw waste and get more value from waste. It can help farmers manage rice straw residue, reduced air pollution, and greenhouse gas emissions from biomass open burning. Accordingly, this study used the Life Cycle Assessment (LCA) concept and Carbon Footprint of Product (CFP) framework to evaluate carbon footprint and compare air pollution and GHG emissions from conventional frameworks and reduce rice straw residue by producing rice straw paper plates. The

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objective of this study is to evaluate the carbon footprint of rice straw paper plate and compare it with the conventional plastic material in terms of environmental impact based on the LCA concept.

2. METHODOLOGY

2.1 Study site

The study site is located in Lat Bua Khao sub-district, Ban Pong district, Ratchaburi Province, West of Thailand. The evaluation of rice straw paper plates by community enterprise Arak Group from Lat Bua Khao sub-district, Ban Pong district, Ratchaburi province, Thailand. The community enterprise Arak Group activities promote the product from rice straw material.

2.2 Functional unit

The functional unit, which all inputs and outputs of analysis are related to in order to allow emissions estimation for rice straw paper plate size 20 × 20 cm. These was defined as kg CO_2e. The greenhouse gases under consideration are carbon dioxide (CO_2), methane (CH_4), and nitrous oxide (N_2O). Each gas is converted into a CO_2 equivalent value using global warming potential from the latest IPCC 100-year time horizon GWP equivalent factors (CO_2, CH_4, and N_2O having GWP of 1, 25, and 298, respectively) [6].

The CFP was estimated following the life cycle assessment concept and PAS 2050 methodology [1,7]. Therefore, the CFP presented in this study includes carbon emissions from raw material preparation and production up to the rice straw paper plate being stored in warehouses (consistent with the "cradle to gate" approach) [1]. Additionally, the scope of carbon footprint (CFP) is shown in Figure 1.

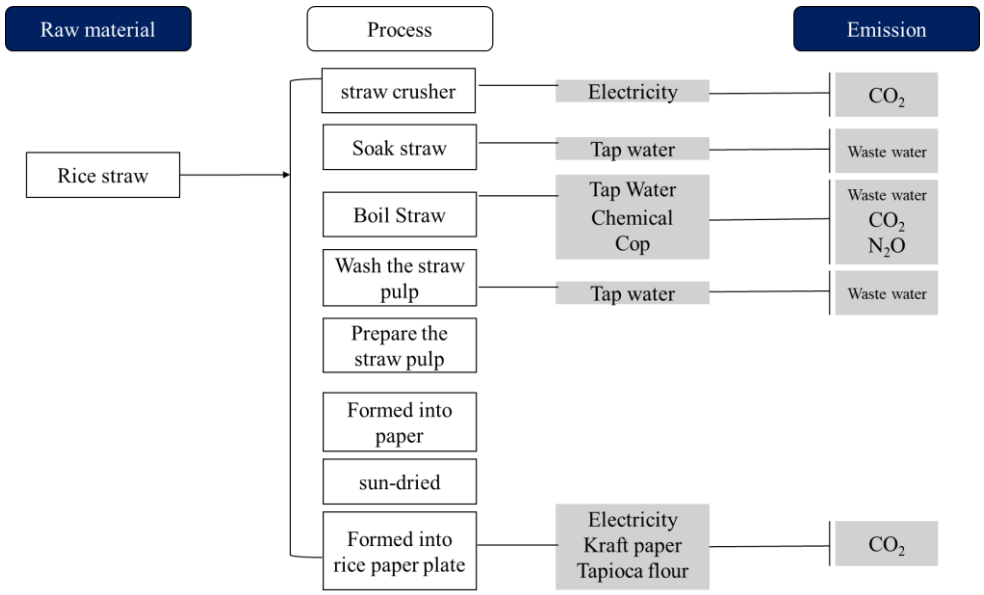

Figure 1. Scope of the study carbon footprint of rice straw paper plate

2.3 Data collection

The evaluations follow the life cycle assessment concept (cradle to gate), the IPCC 2006 guideline, and Thailand Greenhouse Gas Management Organization (TGO), (emission factor and methodology) [7]. The data used in this study were collected from interviews and relevant publications. Data were collected into two types these include;

Primary data were collected from community enterprise Arak Group about raw materials (electricity, water tap, chemicals, etc.) used for producing rice straw paper plates in 1 functional unit set up for this study. In addition, raw materials of rice straw quantity from farmer in the study area. The data shown in Table 1.

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Secondary data were recorded and reviewed from relevant publications about emission factors, air pollution from biomass open burning, global warming potentials (GWP100), and the other CFP of products from plastic and other materials. All documents used for evaluating greenhouse gas emissions and comparing the impact of open burning and greenhouse gas emissions between rice straw paper plates and the other material used for produced plates.

Table 1. Raw material for produced rice straw paper plate (Size 20 x 20 cm)

Inventory	Quantity	Unit
Raw material		
Rice straw	20	kg
Process		
Electricity	4.10	kWh
Tap water	46	L
Cob (biomass)	15	kg
Sodium hydroxide	3	kg
Tapioca flour	20	g
Kraft paper	0.90	kg

2.4 Impact assessment

The life cycle assessment concept was used for calculation. The conversion was calculated into equivalent carbon dioxide emission (CO_2e). Greenhouse gas inventories to estimate greenhouse gas emissions from these activities were used for the calculation**.** These show in equation 1.

$$CF = AD \times EF \quad (1)$$

Where; CF is carbon footprint (CO_2e per unit product), AD is activity data (mass/volume/kWh/km), and EF is emission factor GHG (CO_2e per unit) is the default emission factor of a given GHG by type of resource use. In addition, the emission factor used is shown in Table 2.

Table 2. Emission factor used to evaluate greenhouse gases in scope of raw material and production process [7].

Name	Unit	Emission Factor ($kgCO_2e$)	References	Date update
Cob	kg	0.0319	IPCC Vol.2 Table 2.2, DEDE	UPDATE_1Apr22
Sodium hydroxide	kg	1.1148	Ecoinvent 2.2, IPCC 2007 GWP 100a	Update_24Sep12
Sodium hydroxide diaphram	kg	1.3711	Ecoinvent 2.2, IPCC 2007 GWP 100a	Update_24Sep12
Tapioca flour	kg	0.5410	Ecoinvent 2.2, IPCC 2007 GWP 100a	Update_24Sep12
Electricity, grid mix	kWh	0.5986	Thai National LCI Database, TIIS-MTEC-NSTDA (with TGO electricity 2016-2018)	Update Dec2019
Tap water	m^3	0.2843	Thai National LCI Database, TIIS-MTEC-NSTDA (with TGO electricity 2016-2018)	Update Dec2019
Kraft paper	kg	1.6324	Thai National LCI Database, TIIS-MTEC-NSTDA	

3. RESULTS AND DISCUSSION

3.1 Inventory assessment

The inventory and raw materials used for 1 paper plate size 20 × 20 cm as show in Table 3. These include raw materials; rice straw, in process product; electricity, tap warer, fire wood, sodium hydroxide, tapioca flour and kraft paper.

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Table 3. Raw material used for 1 rice straw paper plate size 20 × 20 cm [7].

Boundary	Inventory	Emission Factor	Unit
Raw material	Rice straw	0.0319	kg
Process	Electricity, grid mix (Electricity)	0.5986	kWh
	Tap water	0.2843	m^3
	Fire wood (biomass)	0.0000	kg
	Sodium hydroxide	1.1148	kg
	Tapioca flour	0.5410	kg
	Kraft paper	1.6324	kg

3.2 Carbon footprint of rice straw paper plate

The 20 kilograms of rice straw produce 180 rice straw paper plates size 20 × 20 cm. The greenhouse gas emissions from this product emitted 7.93 kg CO_2e. Based on the use and source of fuels (chemicals, tap water, tapioca flour), rice straw paper plates and raw materials are used. The greenhouse gas emissions from the raw material emitted about 0.64 kg CO_2e (8.04% of total emissions). In the part of rice straw paper plate product process is 7.29 kg CO_2e (91.96%) of total emissions. (Figure 2 and Table 4). Thus, the average emission from 1 rice straw paper plate is 0.044 kg CO_2e.

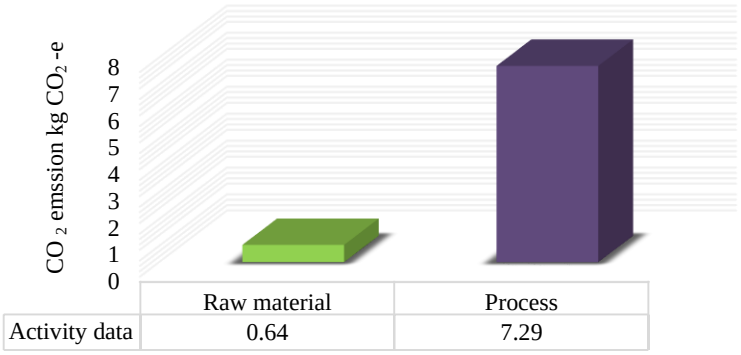

Figure 2. Greenhouse gas emission of 180 rice straw paper plates size 20 × 20 cm.

Table 4. The 1 rice straw paper plate size 20 × 20 cm.

Rice straw paper plate						
Product picture	Product name	Owner	Scope	Carbon footprint (kg CO_2e)		GHG emission (kg CO_2e)
				Raw material	Process	
	Rice straw paper plate size 20 × 20 cm.	Community enterprise Arak Group	Cradle to gate	0.0035	0.0405	0.0441

3.3 Comparison air pollution from open burning and product of rice straw paper plate

In 2021, Thailand can produce 31,329,655 tons of rice yield. The rice straw waste is approximately 37,282,289.45 tons per year. Ratchaburi Province produced 218,003 tons of rice. The rice straw waste is approximately 259,423.57 tons per year [4].

If all waste gets into open burning, these emit air pollution and greenhouse gas emissions: CO_2, CH_4, PM10, PM2.5, black carbon, CO, NH_3, NO_X, SO_2, NMVOC, and organic carbon. When thinking about reducing biomass burning, it could be reducing emissions, as shown in Table 5.

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Table 5. The quantity of air pollution from rice straw open burning in Ratchaburi province, Thailand**.**

Air pollution	Air pollution from rice straw open burning	
	Ratchaburi Province Air pollution (tons per year)	Whole area of Thailand Air pollution (million tons)
CO_2	351,765.39	50.55
CH_4	1,115.52	0.16
PM10	3,631.93	0.52
PM2.5	3,299.87	0.47
Black Carbon	150.47	0.02
CO	15,357.88	2.21
NH_3	153.06	0.02
NO_X	767.89	0.11
SO_2	155.65	0.02
NMVOC	2,062.42	0.03
Organic Carbon	907.98	0.13

Note: Carbon dioxide (CO_2), Methane (CH_4), Particulate matter 10 micrometers or less in diameter (PM10), Particulate matter 2.5 micrometers or less in diameter (PM2.5), Carbon monoxide (CO), Ammonia (NH_3), Nitrogen oxides (NOx), Sulfur dioxide (SO_2), Non methane volatile organic compounds (NMVOC)

3.3.1 Comparison of rice straw paper plate and rice straw open burning

Rice straw paper plate clouds help reduce emissions from rice straw open burning, as shown in Table 6.

Table 6. The ability of rice straw paper plate help to reduce air pollution and greenhouse gas emission.

Air pollution	1 rice straw paper plate size 20 × 20 cm. Reduce air pollution (kg)	180 rice straw paper plates (rice straw 20 kg) Reduce air pollution (kg)
CO_2	0.1506	27.12
CH_4	0.0005	0.09
PM10	0.0016	0.28
PM2.5	0.0014	0.25
Black Carbon	0.0001	0.01
CO	0.0066	1.18
NH_3	0.0001	0.01
NO_x	0.0003	0.06
SO_2	0.0001	0.01
NMVOC	0.0009	0.16
Organic Carbon	0.0004	0.07

3.3.2 Comparison air pollution between rice straw paper plate and plastic PP plate

The previously study presented the rice straw paper plate cloud, which helps reduce emissions from plastic PP plates, as shown in Table 7.

Table 7. Comparison air pollution between rice straw paper plate and plastic PP plate [8].

Air pollution	Rice straw paper plate		Plastic PP plate	
	Rice straw 20 kg Emitted air pollution (kg)	Rice straw 0.11 kg (1 rice straw paper plate) Emitted air pollution (kg)	Plastic PP 20 kg Emitted air pollution (kg)	Plastic PP 0.11 kg (1 plate) Emitted air pollution (kg)
CO_2	27.12	0.1506	37	0.2035
CO	1.18	0.0066	0.0144	0.0001
SO_X	0.01	0.0001	0.2588	0.0014
NO_X	0.06	0.0003	0.1914	0.0011

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3.3.3 Comparison carbon footprint of rice straw paper plate and product certify by TGO

Comparison of greenhouse gas emissions of rice straw paper plates in Table 8 with plastic plates that have been approved for the product's carbon footprint label by TGO in the same assessment scope, “Cradle to Gate or B2C”. It was found that the greenhouse gas emissions of one rice straw paper plate have the lowest greenhouse gas emission value, with a value of 0.0441 kg CO_2e. When considering each step, the step of obtaining raw materials will have lower greenhouse gas emissions than plastic plates. However, the production process has 2 types of plastic plates that emit slightly less greenhouse gases: a 16 oz. natural bowl with a natural color lid and a 13 oz. white cup with a white lid. The reason for this is because rice straw biomass is a plant with a strong fiber structure**.** In the production process, chemicals and energy are required to break down the fibers so that they are soft enough to be molded. This is different from plastics that are very soft and can be blown into shape faster than rice straw paper plates.

Table 8. Carbon footprint of product certify by TGO [**7**].

Product picture	Product name	Scope	Ratio of CFP (kg CO_2e)		GHG emission (kg CO_2e)
			Raw material	Process	
	16 oz. natural bowl with a natural color lid	Cradle to gate	0.0523	0.0376	0.0899
	16 oz. bowl white	Cradle to gate	0.0542	0.0426	0.0968
	with lid white	Cradle to gate	0.0497	0.0633	0.1130
	shrimp wonton cup 16 oz. white	Cradle to gate	0.0554	0.0576	0.1130
	with Lid	Cradle to gate	0.0963	0.0197	0.1160
	shrimp wonton cup 425 ml	Cradle to gate	0.0578	0.0602	0.1180
	black with lid	Cradle to gate	0.0773	0.0607	0.1380
	13 oz. white cup with a white lid.	Cradle to gate	0.0814	0.0566	0.1380
	15 oz. cup white	Cradle to gate	0.1920	0.0480	0.2400

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4. CONCLUSIONS

This study has tried to estimate the CFP from rice straw paper plate size 20 × 20 cm. in community enterprise Arak Group from Lat Bua Khao sub-district, Ban Pong district, Ratchaburi Province, Thailand. The data used were taken from surveys, interviews, and statistics, covering the majority of farmers and community enterprise Arak Group in the study area. Rice straw 20 kg cloud produced 180 rice straw paper plates and emitted greenhouse gases about 7.93 kgCO_2e. Thus, the estimated CFP was 0.0441 kgCO_2e per 1 rice straw paper plate size 20 × 20 cm. More than 91% of greenhouse gas emissions come from the production process in manufacture. We found that rice straw management cloud helps to reduce greenhouse gas emissions and air pollution from biomass open burning in rice planted areas.

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