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Analysis of Exhaust Emissions from Life Cycle Assessment in Smes Pork Skin Crackers in Tabanan

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Abstract: *One of the Micro, Small and Medium Enterprises (MSMEs) in Tabanan produces pork rind crackers on a home-based scale located among residential areas. The production capacity reaches 100 kg of pork skin/day, which in the process produces liquid waste, exhaust emissions, and leftover materials. The problem faced by this MSME is the high exhaust emissions due to the use of LPG and electricity in the production process, which contributes to environmental pollution. This study aims to analyze the exhaust emissions from pigskin cracker production and assess its impact on the environment. The Life Cycle Assessment (LCA) method was used to measure the environmental burden caused by the production stages with a gate-to-gate approach, including the use of raw materials, energy, and production by-products. The data was calculated using OpenLCA software with the IPCC 2013 GWP 100a calculation method to obtain the equivalent carbon dioxide emission value (CO_2e)Based on the results of the study, it was found that this micro, small and medium enterprise (MSME) generates total emissions of 484.24 kg CO_2e in one daily production cycle. Of the entire production process, the frying stage was recorded as the main contributor to greenhouse gas emissions, caused by the high consumption of LPG fuel. This shows that the use of energy in the form of fossil fuels still dominates and is a major factor in the formation of carbon emissions. To reduce these emissions, several mitigation strategies were proposed, including reducing LPG consumption through energy efficiency, optimizing the performance and thermal efficiency of production equipment, and installing a simple air filter system to retain particles and pollutants. OnceLiquefied Petroleum Gas(LPG) consumption has been reduced, the utilization of scrubber technology is recommended as a further solution to filter flue gas from contaminant compounds before it is released into the atmosphere. Scrubbers function as air pollution control devices that are able to reduce the content of harmful emissions, thereby reducing the negative impact on the environment. This research is expected to serve as a reference for MSME actors, especially in the food industry sector, in designing more efficient and environmentally sustainable production systems. The implementation of the results of this study is also in line with efforts to reduce greenhouse gas emissions at the local level, which contributes to sustainable development targets, particularly in the aspects of responsible production and consumption and action on climate change.*

Keywords: *Gas Emissions, Life Cycle Assessment, Pork Skin Crackers*

I. Indroduction

The growth of the tourism industry in Bali has encouraged the development of various business sectors, including traditional cuisines that reflect local culture and identity, such as pork rind crackers that have potential as a culinary tourism attraction [1]. The product is popular for its distinctive flavor and texture, especially in the Tabanan area. According to [2] the industrial sector contributed 536,830 tons of CO_2 from fuel conversion, and MSMEs such as the pigskin cracker industry contribute to this activity [3]. The industry is also economically valuable because it processes animal skin waste into value-added food products and preserves local culinary heritage.

Micro, Small and Medium Enterprises(MSMEs) play an important role in the national economy, contributing 61% to Gross Domestic Product(GDP) and absorbing 97% of the workforce [2]. The development of culinary MSMEs in Bali is driven by digital transformation, government support, and lifestyle changes, contributing up to 40% to regional GDP [2]. Previous studies show that the frying process is a major source of Green House Gases (GHG) emissions in food industries, such as cowhide crackers and tofu mainly due to the use of fuels such as Liquefied Petroleum Gas(LPG) and firewood[5].

The pigskin cracker MSME in Tabanan was chosen as the object of research due to its location in the middle of a residential area, the lack of emission-absorbing vegetation, and its high emission potential due to the use of fossil energy in the production process. Production is carried out in seven stages, using electricity and Liquefied Petroleum Gas (LPG) as the main energy sources, which produce exhaust emissions directly. Emission calculations are focused on the active production stage.

The Life Cycle Assessment (LCA) method is used to analyze the environmental impacts of production activities, with a gate-to-gate approach that assesses emissions throughout the process. The analysis covers inputs-outputs of materials, energy, waste and emissions to identify the stages with the highest emission contributions and potential improvements[6]. The evaluation follows the ISO 14067:2018 standard using OpenLCA software [4]. Therefore, this research is important to assess the exhaust emissions from the production process of pig skin crackers in Tabanan MSMEs as a whole. The purpose of this study is to obtain the calculation/analysis of exhaust emissions in the life cycle of pigskin cracker products, obtain the production efficiency of the pigskin cracker industry in improving the production process to be more energy efficient, analyze exhaust emissions in the life cycle of pigskin cracker products in Tabanan pigskin cracker UMKM and their impact on the environment.

II. Research Method

2.1 Place and Time of Research

The research was conducted at MSMEs of pig skin crackers in Tabanan. Data analysis was conducted at the Industrial Engineering Laboratory, Faculty of Agricultural Technology, Udayana University, from January to March 2025.

2.2 Experimental Design

This study was conducted in accordance with the Life Cycle Assessment framework, which focuses on the exhaust emissions of MSMEs of pig skin crackers. The stages of this research are defining the objectives and scope, inventory, environmental impact assessment and interpretation of results. OpenLCA software series 1.11.0 was used to model the life cycle of pigskin crackers within the scope of gate-to-gate and the IPCC 2013 GWP 100a method. The result of the data analysis using the software is the value of climate change in kg CO_2e.

2.3 Variables Observed

This research focuses on exhaust emissions from the use of electricity, LPG, and labor exhaust emissions with assumptions referring to literature studies that the same type of work is between 0.5-2kg/hour. The variables observed in this study include.

2.3.1 CO_2 Emissions Electricity

The manufacture of pigskin crackers involves the use of electrical devices that are operated due to electrical energy. This process produces emissions in the form of CO_2, which in environmental impact assessments is one of the indicators of air pollution. The formula used to calculate the amount of emissions from the machine refers to the Intergovernmental Panel on Climate Change (IPCC) (2006) as follows:

$$CO_2 \text{ emissions} = W \times FE \quad [1]$$

$$W = \text{engine power} \times \text{usage time} \quad [2]$$

Description:

CO_2 emissions	: CO_2 emissions from electricity use (kg CO_2)
W	: Total electrical energy consumption (kWh)
FE	: Bali region electricity emission factor (kg CO_2/kWh)
Engine power	: Electricity demand by the engine (kWh)
Usage time	: Duration of engine operation (hours)

Based on data from the 2019-2028 Electricity Supply Business Plan (RUPTL), the CO_2 emission factor of power plants for Bali and surrounding areas can be seen in table 1.

Table 1. CO_2 Emission Factor of Electricity Network

Electricity System	Emission Factor (kg CO_2/kWh)
Java-Bali and Nusa Tenggara	0,817

Source: Ministry of Energi and Mineral Resources (2019)

2.3.2 LPG Combustion Emissions

Pork skin frying was conducted using a gas stove with Liquefied Petroleum Gas (LPG) as fuel. The calculation of carbon dioxide emissions due to the use of LPG referring to IPCC (2006) [7] is as follows, and the Carbon Emission Factor and Net Colorific Value values can be seen in table 2.

CO_2 emissions = FC x CEF x NCV [3]

Description:
CO_2 emission: Total CO_2 emissions of LPG gas usage (kg CO_2)
FC : Amount of biomass used (kg)
CEF : Carbon Emission Factor (kg CO_2/TJ)
NCV : Net Colorific Value (TJ/Kg)

Table 2 Carbon Emission Factor and Net Colorific Value

Fuel	Carbon Emission Factor(kg CO_2/TJ)	Net Colorific Value(TJ/Gg)
LPG	63.100	47,3

Source: IPCC 2006

2.3.3 Yield

Yield is the ratio of input and output of a production activity. This value shows the production efficiency and effectiveness of converting raw materials into the resulting product. The calculation to determine the yield according to the process of making pork skin crackers is [8]:

$$Yield = \frac{Number\ of\ products\ produced\ \ (kg)}{The\ amount\ of\ raw\ materials\ used\ \ (kg)}\ x\ 100\ kg \qquad [4]$$

III. Result and Discussion

3.1 Purpose and Scope

The purpose of the Life Cycle Assessment (LCA) of pigskin cracker MSMEs in Tabanan is to identify and analyze exhaust emissions from the life cycle of pigskin cracker products and their impact on the environment. The scope determined in the environmental impact assessment is gate-to-gate, where the analysis will focus on the entire use of raw materials, processes, tools, as well as the results in the form of products, and emissions at the factory.

Pigskin crackers MSMEs carry out eight processes to process pork skin raw materials into pork skin crackers, namely cleaning, washing, cutting, seasoning, frying I, frying II, and packaging. During the process, salt and spices are added as additional ingredients. The presence of electricity and LPG also makes it easier for the pigskin to be fried, but produces exhaust emissions that pollute the air. Data collection in this study used assumptions to address the complexity of the production system, such as estimating labor exhaust emissions and emission levels also obtained through literature studies.

3.2 Inventory of Pork Rind Cracker Making

The inventory is based on direct observation and calculation of the mass use of raw materials, water, energy, waste and emissions in kilograms (kg) and kilowatt hours (kWh). This measurement and recording covers all stages of production of pigskin crackers. The inventory of each process is shown in table 3.

Table 3 Inventory of Each Process

Input	Output	Number of	Unit
Pork skin		100	kg
Electricity		5,63	kWh
Labor		19	people
Water		200	kg
Garam		1	kg
Bumbu racikan		1,5	kg
LPG		24	kg
	CO_2 emissions	91,173	kgCO_2e
	Liquid waste	200	kg

Pigskin crackers MSMEs carry out seven processes of processing pork skin raw materials into pork skin cracker products, namely cleaning, washing, cutting, seasoning, frying I, frying II, packaging.The existence of electricity and LPG also makes it easier for pigskin in the frying process, but produces exhaust emissions that pollute the air. Data collection in the study used assumptions to overcome the complexity of the production system, for example estimating labor exhaust emissions during the production process.

3.3 Environmental Impact Assessment of Exhaust Gas Emissions from Pigskin Crackers Manufacturing

The results of the calculation of the environmental impact assessment, namely the life cycle of pork rind cracker products by MSMEs in Tabanan at the gate-to-gate limit, causes exhaust emissions equivalent to 484.24 kg CO_2e. The contribution of each process as in the table 4.

Table 4 Process Contribution to Greenhouse Gas emissions

Process	Presentation (%)
Cleaning	2,57
Washing	4,18
Cutting	10,65
Seasoning	0,83
Frying I	50,26
Frying II	16,60
Packaging	14,91

Based on the table above, it is known that the four processes that contribute the highest exhaustemissionsare frying I, frying II, packaging and cutting.

3.4 Yield

Based on the calculation, the total yield of pork skin cracker products is 4.70% for one production. The expected yield is as high as possible, or close to 100% [9]. The yield value of pigskin crackers MSMEs in Tabanan shows that the production process is not efficient, which is more waste than product produced.

IV. Interpretation of Analysis Result

The environmental impact analysis in Open LCA software shows that the production of pork rind crackers by Tabanan MSMEs with gate-to-gate restrictions results in exhaust emissions equivalent to 484.24 kg CO_2e/production. The inputs of 100 kg of pork skin, 1 kg of salt and 1.5 kg of seasoning to produce 100 kg of pork skin crackers are an inventory of the environmental impacts obtained. This value is greater than the research of [10] which stated that the life cycle of cradle to gate cowhide crackers with a capacity of 300 kg of leather crackers produced within a month caused GHGemissions equivalent to 258.98 CO_2e. The difference in value is due to the different amount of raw materials and fuel in one production, as a result the amount of emissions produced is lower.

The contribution tree explains that the process that contributes the largest exhaust emissions is frying I, which is 50.26% and produces gas emissions of 243.38 kg CO_2e. This is because the first frying process requires 18 kg of LPG. The high carbon content in propane and butane in LPG causes the formation of CO_2 during combustion. However, compared to other fossil fuels such as coal and kerosene, burning LPG results in lower CO_2 emissions per unit of energy produced. According to data, CO_2 emissions from burning LPG are about 81% of those produced by oil and 70% of those produced by coal. Thus, LPG is an efficient fuel with high energy content and lower carbon emissions than some other fossil fuels.

The entire process of making pigskin crackers by Tabanan MSMEs contributes to exhaust emissions due to the use of raw materials and fuel. According to PLN (2021), if the exhaust emissions of Tabanan MSMEs are compared to Indonesia's totalGHGemissions in 2021, namely 259.1 million tons of CO_2e, it indicates that MSMEs are one of the small contributors to GHG emissions. However, exhaust emissions in the form of CO_2 that are carelessly released into the air have a lifespan of tens of thousands of years in the atmosphere and have the potential to continue to increase the earth's temperature [11]. emissions must still be minimized to anticipate the long-term impact of carbon emissions.

4.1 Efforts to Minimize Exhaust Gas Emissions in the Life Cycle of Pigskin Crackers

Suggested mitigation efforts include: substituting LPG with biomass briquettes [12] engine maintenance for emission efficiency [13] planting carbon sink plants such as Sanseviera sp around the factory [14] and MSMEs can switch

to using scrubber equipment, which is used to clean industrial exhaust gases from contaminants and pollutants before being released to the environment.

V. Conclusion

The production of pigskin crackers by Tabanan MSMEs generates CO_2 emissions from the use of raw materials and energy, with the largest contributions coming from frying I (53,757 kg CO_2e) and frying II (18,161 kg CO_2e). The production efficiency of Tabanan MSMEs is determined by the balance between inputs and outputs, using 100 kg of pork skin, 1 kg of salt, and 1.5 kg of seasoning to produce 85 kg of pork skin crackers. Production efficiency was recorded at 4.70%, indicating that the production process is still inefficient, with more waste generated than the final product. Total gate-to-gate emissions of 484.24 kg CO_2e or 0.809 kg CO_2e/kg of product show that Tabanan MSMEs are medium emitters nationally, but still need control to prevent long-term environmental impacts. Solutions that can be done by MSMEs can switch to using scrubber equipment, to clean industrial exhaust gases before being released into the environment.

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