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RESEARCH ARTICLE

ECO-EFFICIENCY AND ENVIRONMENTAL IMPACT MEASUREMENT OF FLOUR-BASED PROCESSED CHICKEN PRODUCTION AT MSMES IN JOMBOR, SUKOHARJO, INDONESIA

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Abstract

Growth of Flour - based chicken processing MSMEs in Jombor, Sukoharjo, Indonesia make a significant contribution to the local economy. However, these activities have the potential to increase energy consumption, raw material use, transportation, the use of single-use packaging, and waste generation, all of which impact the environm ent. This study aims to evaluate the environmental impacts and eco-efficiency levels of flour based chicken processing SMEs in Jombor, Su koharjo, Indonesia. This study use the Life Cycle Assessment (LCA) method using a cradle-to-grave approach, as well as the ReCiPe 2016 method, utilizing SimaPro 9.5 software. The analysis covered the stages of raw material procurement, transportation, production, and packaging. Eco-efficiency evaluation was conducted by integrating economic and environmental indicators through Eco-Efficiency Index (EEI), Environmental Value Ratio (EVR), and Eco-Efficiency Ratio (EER). The research results indicate that the production stage is the primary environmental critical point that significantly contributes to the categories of global warming, ozone formation, terrestrial acidification, and water consumption due to the use of electricity, LPG, and the direct disposal of raw material waste into the soil. At the packaging stage, one MSME contributes up to75% to several environmental impact categories due to the use of plastic-based packaging. The eco-efficiency evaluation results indicate that all MSMEfall into the affordable and sustainable category, with EEI values ranging from 2,14 to 2,89 and EER values of 88–99%. MSMEB demonstrated the best eco-efficiency performance with an EEI of 2,89; an EVR of 0,01; and an EER of 99%.

Introduction:-

Jombor Village, Sukoharjo, Indonesia, is a busy and strategically located area due to its proximity to the Sukoharjo Regency Government, educational institutions, and densely populated residential areas. These conditions create

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significant economic opportunities for the local community, particularly for MSME owners in the food sector. MSMEs in the food sector contribute 3,94% to the Regional Gross Domestic Product (RGDP) of Sukoharjo Regency, Indonesia (Mahambari, 2024). The food sector SMEs that dominate in Jombor Village, Sukoharjo, Indonesia, are those producing flour-based chicken products. Currently, there are 37 food processing SMEs producing flour-based chicken products. The products include Kentucky-style fried chicken, “geprek goreng”, and “geprekbakar”.

Production capacity at 37 SMEs in Jombor, Sukoharjo, Indonesia continues to rise in line with high demand in the region. Dominant consumer are students, employees of institutions operating in the Jombor area, and the local community. This high production volume is directly proportional to increased energy consumption (Meidani and Maryam, 2014) and waste volume (Gholizadeh, 2020).Electricity is used continuously during production activities, such as for freezers, rice cookers, blenders, and fans. The process of frying chicken using gas stoves also contributes to increased carbon emissions (Ali et al., 2024).Previous research indicates that the use of gas stoves can produce 2,98 kg of CO2 per kg of LPG (Fitri, Putri and Retnawaty, 2020).

Another impact arises during the raw material procurement stage. MSME operators use gasoline-powered vehicles to collect raw materials. MSME operators collect raw materials at Sukoharjo Market, with an average fuel consumption of 0.43 liters per day. Carbon emissions from 1 liter of fuel are equivalent to 2.4 kg of CO2 (PT PLN Persero, 2024; Saravanakumar and Arunprasad, 2024; Rievaj, Mokrickova and Rievaj, 2016). Thus, a single trip to procure raw materials contributes to the production of 1,032 kg of CO2. Transportation contributes significantly to the overall carbon footprint of food products (Striebig, Smitts and Morton, 2019; Zhang, 2023).

Electricity consumption, gas usage, and transportation activities at flour-based chicken processing MSMEs operating in Jombor Village generate a significant carbon footprint. All MSMEs operate daily with an average production capacity of 13 kg/day. This high production capacity also contributes to increased (Raj et al., 2025). The waste generated includes 33 kg of dry flour per week, 7 kg of wet flour per week, 25 liters of used cooking oil per week, and wastewater from washing chickens and kitchen equipment

There are 2 types of flour waste: dry and wet flour waste (Asmoro, 2021).Improper disposal of flour waste can lead to significant greenhouse gas emissions, such as methane (CH_4) and carbon dioxide (CO_2) (Irozi et al., 2022). CH4 has a global warming potential 21–36 times greater than that of CO_2 (Izhar and Xuan, 2021; Siltumens et al., 2023; Alam et al., 2022). The disposal of used cooking oil also causes water contamination, clogging of sewage systems, and soil degradation(Shevchenko et al., 2023), as well as posing health risks if reused (Azmi et al., 2023). Additionally, there is plastic packaging and paper waste from cooking oil because the sales system is takeaway. Plastic packaging waste has a significant impact on soil and water pollution and harms flora and fauna. Plastic pollutes the biological environment 63% more than paper (Vargas, Mogollón and Rosa Patricia Larios-Francia, 2022).

Food waste is an issue that must be addressed because it relates to food safety and hygiene, as well as environmental sustainability (Walia and Sanders, 2019). If not properly managed, food waste can have economic and social impacts, as well as place undue pressure on natural resources and the environment (Chirsanova and Calcatiniuc, 2021). The food industry plays a crucial role in producing food that is safe for consumers. According to ISO 22000, businesses unit must ensure the safety and quality of food ingredients all the way through to the finished product (Balashov et al., 2024).Food safety must be addressed from the procurement and production processes (Lestari, Prasetyo and Hartanti, 2023; Pratama, Hartanti and Prasetyo, 2024)through to distribution (Sharif et al., 2024). Material handling, energy use (Nagy and Szabolcs, 2024), and sanitation (Li, 2024)are crucial elements in the food industry (Corigliano and Algieri, 2024).

Statement of the Problem:-

The background of this study is improper environmental management in flour-based chicken processing MSMEs. Because overlook the measurement of overall environmental impacts. MSME operators focus only on the production stage without considering the entire product life cycle, from raw material procurement and processing to energy use and waste management.This situation leads to potential resource waste and increased carbon emissions (Braun and Rothbart, 2025).

Objectives of the Study:-
This study aims to conduct an environmental impact analysis of all activities carried out by flour-based MSMEs in Jombor. The problem-solving approach in this study employs the Life Cycle Assessment (LCA) method as a tool to identify and measure the environmental impacts of energy use and all operational activities. Life Cycle Assessment (LCA) is highly effective for making quantitative assessments of environmental aspects and the potential impacts generated dihasilkan(Aviso, 2024; Firmansyah, 2018).The results of identifying and measuring environmental impacts through the Life Cycle Assessment (LCA) approach can serve as the basis for formulating more environmentally friendly and sustainable supply chain management strategies for flour-based chicken processing SMEs.

The food industry is currently required to prioritize waste management, compliance with hygiene standards (Muhammad, Zaman and Ariyantoro, 2023)and cost efficiency (Vaez-Ghasemi, Moghaddas and Saen, 2022;Adewale et al., 2024). This is stipulated in Ministry of Industry Regulation No. 39 of 2022 on Green Industry Standards for the Food Industry, which mandates that food processing be conducted in an environmentally friendly and sustainable manner. This regulation is reinforced by Presidential Regulation No. 59 of 2017 on the Achievement of Sustainable Development Goals (SDGs), which encourages Small and Medium Enterprises to contribute to sustainability and environmental management. The demand for an environmentally friendly and sustainable industry aims to reduce carbon emissions (Ramalingam et al., 2025).

The adoption of environmentally unfriendly industrial practices can accelerate environmental degradation and increase operational costs due to resource waste (Espinoza-Castro, Lara-Ramírez and Buele, 2024;Bulan and Anis, 2021).Incompliance with green industry regulations can lead to difficulties in marketing products, reduced competitiveness (Agarwal et al., 2025; Shi, Xiong and Bu, 2022), and decrease consumer trust among those increasingly concerned about sustainability (Oppong and Bannor, 2022).

Study Gaps:-
Previous studies have been conducted on the measurement of eco-efficiency and environmental impact. A review of these studies indicates that no research has yet analyzed the environmental impact using a comprehensive Life Cycle Assessment, covering the entire process from raw material procurement to packagingin flour-based chicken processing MSMEs. Most research has been conducted on large companies and formal manufacturing industries, such as the palm oil industry (Maisarah and Dian, 2024), the production process of ZA II fertilizer(Dwi and Mirwan, 2023), and the production process of white crystal sugar in Bondowoso(Brilliantina et al., 2023). However, SMEs also contribute to waste generation and carbon emissions, particularly as the number of businesses and production intensity continue to rise, as is currently the case in the flour-based chicken processing industry in Jombor Village. The novelty of this study is providing empirical data on environmental impacts based on Life Cycle Assessment (LCA) for flour-based chicken processing SMEs. The results of this study are expected to serve as a basis for decision-making in formulating sustainable environmental management strategies.

Literature Review:-

MSMEs in Food Sector:-
Micro, Small, and Medium Enterprises (MSEMs) in the food sector play a critical role in economic development, employment generation, and food security, particularly in developing countries like Indonesia. MSEMs significantly contribute to GDP and employment in Indonesia, with the food sector being a vital component of this contribution (Lukita et al., 2026; Hasibuan et al., 2026). Growth in production activities among MSMEsin the food sector is often accompanied by increased consumption of raw materials, energy use, and waste generation. These conditions can lead toincreased greenhouse gas emissions, excessive resource consumption, and various other environmental impacts(Sembiring et al., 2025; Jangde, Arjunan and Patanwar, 2025; Kukde et al., 2026).

Sustainable practices are needed to ensure that business growth up with environmental conservation.Innovationis a key driver for the sustainability of MSMEs in the food sector. This includes product and market innovations, as well as adopting sustainable practices like Green Human Resource Management and circular economy principles(Gumbi, Gumbi and Part, 2023; Farao, Bernuzzi and Ronchetti, 2023).Furthermore, the implementation of cleaner production and resource efficiency concepts has been increasingly recognized as an effective strategy for improving economic performance while simultaneously reducing environmental impacts, particularly among food-sector MSMEs.Cleaner production seeks to identify and minimize operational inefficiencies related to the consumption of water, energy, and raw materials, thereby enhancing the efficiency and sustainability of production processes(Ramos et al., 2020).

MSMEs can Focus on converting organic waste into valuable byproducts like compost or bioenergy(Thazeem et al., 2025).

Food Waste Management:-

Food waste management is a critical global issue with significant environmental, social, and economic implications. Management of raw material waste in small and medium-sized enterprises (SMEs) in the food sector is a critical issue due to its environmental, economic, and social implications. Food SMEs generate significant amounts of solid and liquid waste during production, contributing to pollution and health risks (Bhageria and Vyas, 2023).

SMEs often lack the financial and managerial resources to adopt advanced waste management practices, making them less likely to implement sustainable solutions (Ascenzo et al., 2025). Many SMEs exhibit low levels of awareness and intention regarding waste management, particularly in developing regions (Krzywonos et al., 2025).
SMEs often face financial limitations that hinder the adoption of advanced waste management technologies (Ascenzo et al., 2025). Inconsistent policies and lack of enforcement create challenges for SMEs to comply with sustainable practices (Ascenzo et al., 2025). Inadequate tracking and reporting of waste streams impede effective waste management planning (Loo, Howieson and Jackson, 2026).

Green Supply Management:-

Green Supply Chain Management (GSCM) incorporates environmental considerations into supply chain processes, aiming to reduce negative environmental impacts while achieving sustainable development (Wang, 2024). It involves practices such as eco-design, green purchasing, cleaner production, reverse logistics, and green distribution (Adam and Doumbia, 2025).GSCM implementation can supports competitive advantage, cost savings, and improved brand reputation(Adam and Doumbia, 2025). Collaboration across the supply chain, including suppliers, distributors, and consumers, is essential for successful implementation(Ning et al., 2025).

Green Supply Chain Management (GSCM) is increasingly recognized as a critical strategy for improving environmental sustainability, particularly in Small and Medium Enterprises (SMEs) within the food sector. GSCM practices, such as green marketing, environmental education, and sustainable supplier management, significantly enhance environmental and financial performance. In the previous research, green marketing has been shown to have a strong positive impact on economic, environmental, and social outcomes in SMEs(Chuyen, Trinh and Huy, 2025).GSCM improves operational performance by optimizing resource use, reducing waste, and enhancing supply chain processes(Adawiyah et al., 2015).

Many SMEs struggle with low awareness of GSCM benefits and insufficient support from supply chain partners and policymakers(Mankar et al., 2025). Policies and regulations play a significant role in encouraging GSCM adoption, as seen in food and beverage SMEs in regions like Vietnam(Diep et al., 2022). Proactively adopting green technologies and practices, such as green packaging and recycling, can address key barriers and improve sustainability(Arun et al., 2024).

Life Cycle Assessment:-

Life Cycle Assessment (LCA) is a widely recognized methodology for evaluating the environmental, economic, and social impacts of products, services, or processes throughout their life cycle.LCA focused on environmental impacts, LCA evaluates inputs, outputs, and potential environmental consequences across a product's life cycle, from raw material extraction to disposal(Nikolic et al., 2019).LCA has evolved into Life Cycle Sustainability Assessment (LCSA), integrating the "triple bottom line" of sustainability-environmental, economic, and social dimensions(Corona et al., 2017).This broader framework enables a more holistic evaluation of sustainability impacts(Choe et al., 2024).

Energy systems and industrial processes are prominent areas of LCA application, with a focus on decarbonization strategies and resource efficiency(Ma et al., 2023). High-quality, reliable databases are essential for accurate assessments, but data availability remains a significant barrier(Olsson, Miller and Kneifel, 2024).Developing standardized frameworks for LCSA, including better integration of social and economic dimensions, is a priority(Ma et al., 2023).

Eco-efficiency:-

Eco-efficiency is a critical concept in sustainability, combining economic performance with environmental impact to create more value with less resource use and environmental harm. Eco-efficiency is defined as the efficiency with which natural resources are used to meet human needs while minimizing environmental impact. It is a tool for sustainability analysis, linking economic activities to environmental outcomes(Penny Allen, Christophe Bonazzi, 2017).

Eco-efficiency is often measured using indicators that assess economic (e.g. cost, profit) and environmental (e.g. emissions, resource use) dimensions. These indicators can be applied at company, product, or process levels(Gotze, Pecas and Richter, 2019).Many studies integrate LCA to evaluate eco-efficiency, considering environmental impacts across a product's life cycle(Souza et al., 2021;Wichai-utcha et al., 2019;Gotze, Pecas and Richter, 2019).

The lack of standardized methods for integrating economic and environmental metrics complicates broader adoption(Gotze, Pecas and Richter, 2019).Eco-efficiency varies significantly across regions and industries, influenced by local development modes and resource availability (Huang et al., 2018). Traditional eco-efficiency assessments are relative and may not align with planetary boundaries. New frameworks aim to address this gap by linking impacts to Earth's carrying capacity(Usman et al., 2023).

Eco-efficiency is a versatile and evolving tool for promoting sustainability across various sectors. While its application has grown significantly, challenges like standardization, regional disparities, and alignment with absolute sustainability goals remain. Future research should focus on refining methodologies, integrating broader sustainability metrics, and exploring innovative applications in emerging industries.

Method:-

The subject of this study is the flour-based chicken processing system at MSMEs in Jombor Village, Sukoharjo, Indonesia.The study population consisted of 37 flour-based chicken processing MSMEs operating in Jombor, Sukoharjo. This study used purposive sampling to select the sample. 10 MSMEs were selected because they met comparable “apple-to-apple” criteria for comparison, namely activities ranging from raw material procurement and production processes to packaging. The selected MSMEs carried out routine daily operations, had similar production process characteristics, uniform production capacity, and complete operational data.

This study utilizes primary data obtained through direct field observations, as well as a literature review to gather supporting information, such as emission factors, material characteristics, and eco-efficiency indicators.The scope of this study is cradle-to-grave approach, which encompasses the entire product life cycle, starting from raw material extraction (cradle), continuing through the production process, and ending with waste disposal (grave) (Park, Lee and Won, 2024). System boundary of this study covered upstream activities (production of chicken meat, flour, cooking oil, seasonings, packaging, electricity, LPG, and water supply), core processing activities (cutting, marination, flour coating, frying, draining, and packaging), and downstream activities (distribution, consumption, waste generation, used cooking oil management, and packaging disposal).

The life cycle inventory (LCI) was compiled based on direct field observations and interviews conducted in ten selected MSMEs. All input and output data were normalized to the functional unit of 1 kg of ready-to-eat flour-based chicken product. The inventory included raw material consumption, energy use, water consumption, transportation activities, packaging materials, and waste generation. These inventory data were subsequently modeled in SimaPro 9.5 using the ReCiPe 2016 (H) method to calculate the environmental impact categories. Table 1 presents the summarized life cycle inventory used in this study.

Table 1. Life Cycle Inventory

Life Cycle Stage	Inventory Item	Quantity	Unit	Data Source
Transportation	Distance	0,19	km	Field survey
	Gasoline	0,08	L	Field survey
Raw material	Chicken meat	0,08	kg	Field observation
	Wheat flour	0,08	kg	Field observation
	Cooking oil	1,38	L	Field observation
	Seasoning	0,01	kg	Field observation
	Cucumber	0,02	kg	Field observation
Production	Electricity	0,80	kWh	Field observation

	Liquefied Petroleum Gas	0,23	kg	Field observation
	Water	50	L	Field observation
Output	Product	1	kg	Production record
	Flour waste	0,03	kg	Field observation
	Wastewater	2,5	L	Field observation
	Used cooking oil	0,01	L	Field observation
	Packaging waste	1	pcs	Field observation

Note: The inventory values represent the average input and output data collected from the ten selected MSMEs and were normalized to the functional unit of 1 kg of ready-to-eat flour-based chicken product.

The method applied is Life Cycle Assessment (LCA), integrated with eco-efficiency. The analysis was conducted using SimaPro 9.5.0 software. System boundary and research flowchart is presented in Figure 1 and Figure 2.

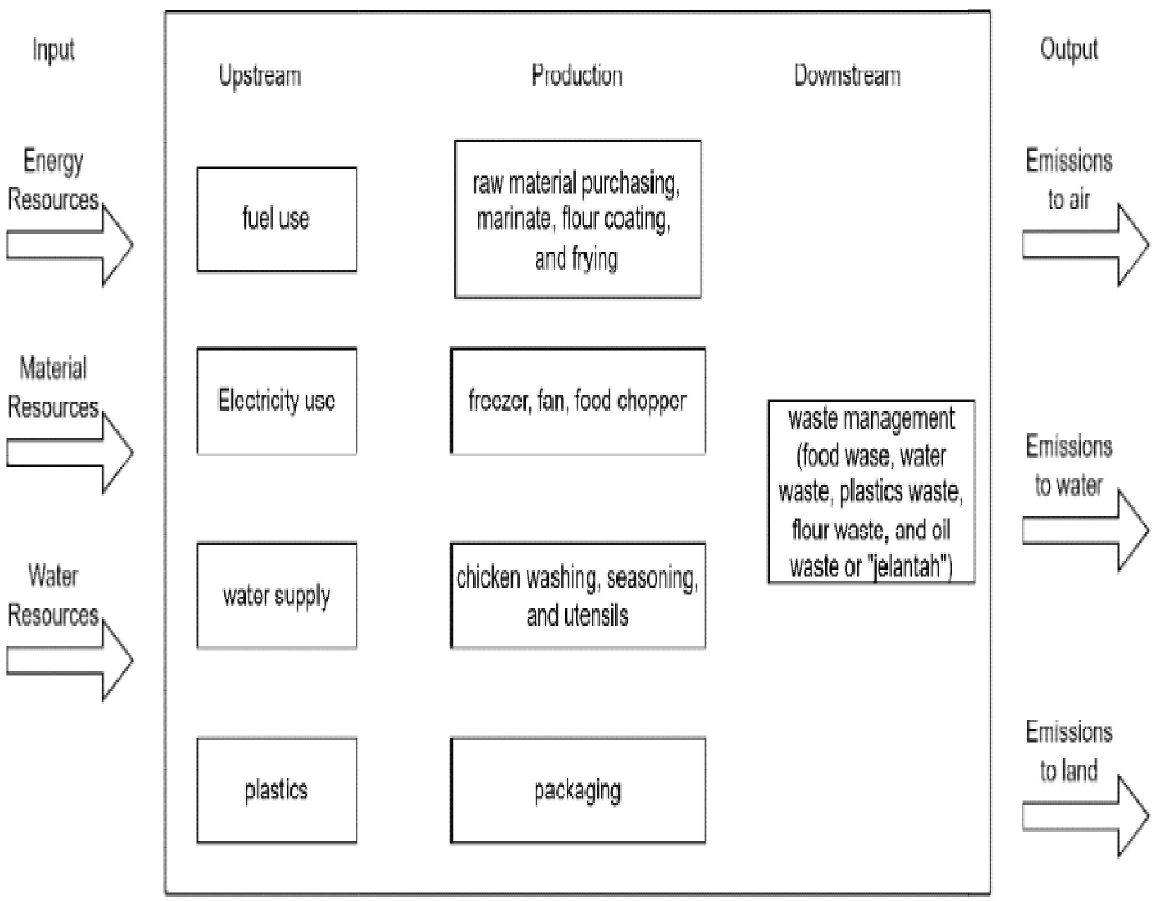

Figure 1. System Boundary

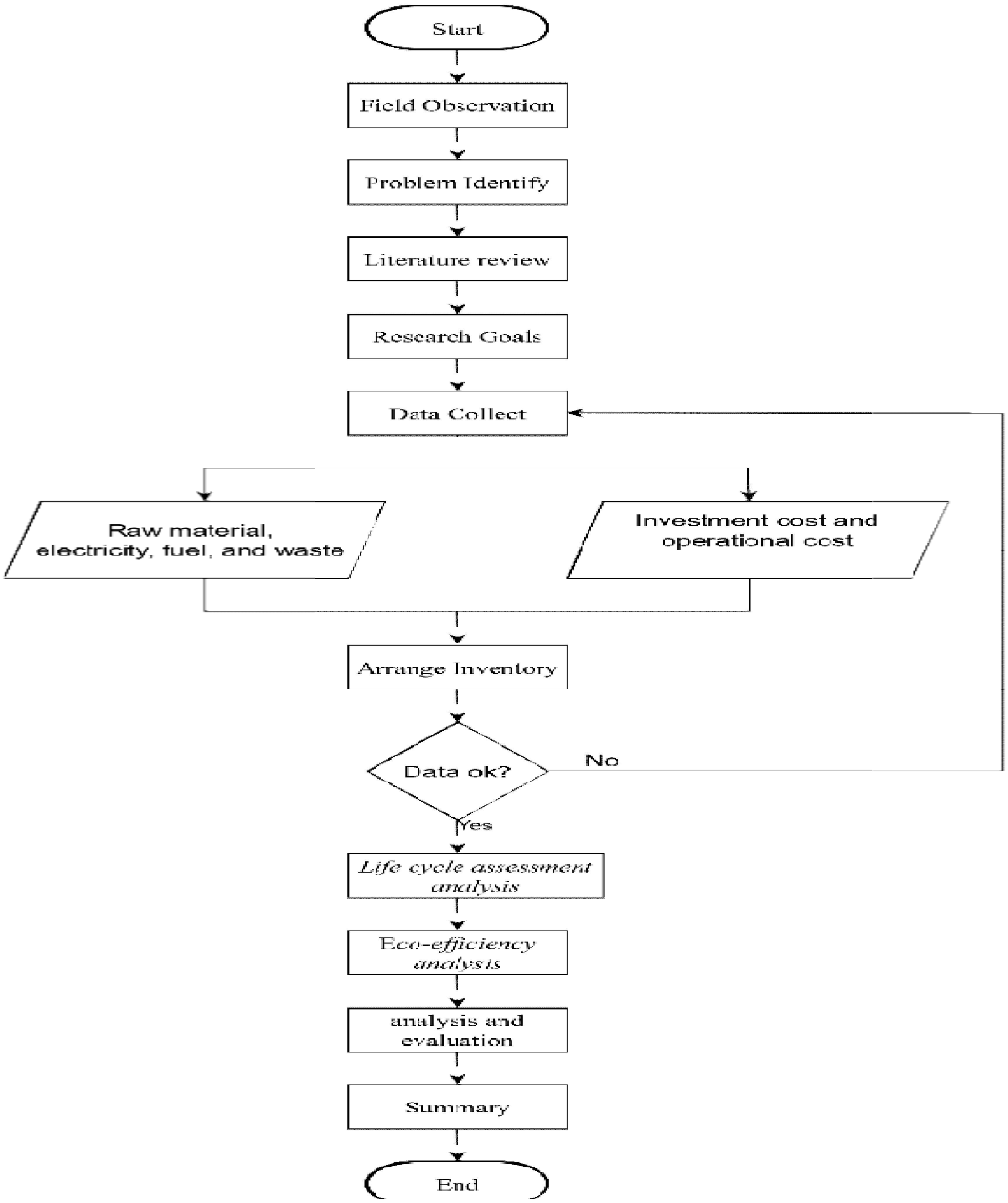

Figure 2. Research Flowchart

The next step after the LCA is to conduct an eco-efficiency analysis. Step in calculating eco-efficiency analysis there are:-

Eco-EfficienyIndek (EEI), to determine the affordability and sustainability of the production process at flour-based chicken processing MSMEs. The eco-efficiency calculation involves the following (Mahastuti, 2017):

1. EEI > 1 = affordable & sustainability.
2. EEI = 0~1 = affordable, but not sustainability.
3. EEI < 0 = not affordable & not sustainability.

Step for calculating the Eco-Efficiency Index (EEI):-

Eco-costs Value Ratio (EVR), measuring economic and environmental efficiency by comparing eco-costs with net value:-

$$\text{EVR} = \frac{\text{Eco} - \text{Cost}}{\text{NetValue}}$$

A low value indicates high efficiency, while a high value indicates the need for a more sustainable design. Eco-Efficiency Ratio (EER), to determine the eco-cost-to-net-present-value ratio. $\text{EER} = (1 - \text{EVR})\text{x } 100\%$

Result:-

Life Cycle Transportation:-

An analysis of the transportation stage was conducted to identify the contribution of raw material distribution, as the majority of MSMEs in the Jombor, Sukoharjo area purchase their raw materials at traditional markets. Transportation is a key aspect of supply chain management because it involves the use of petroleum-based fuels in vehicles. The life cycle assessment approach, using Software 9.5.0 with the ReCiPe 2016 method, is useful for evaluating the extent to which energy use contributes to environmental impacts.

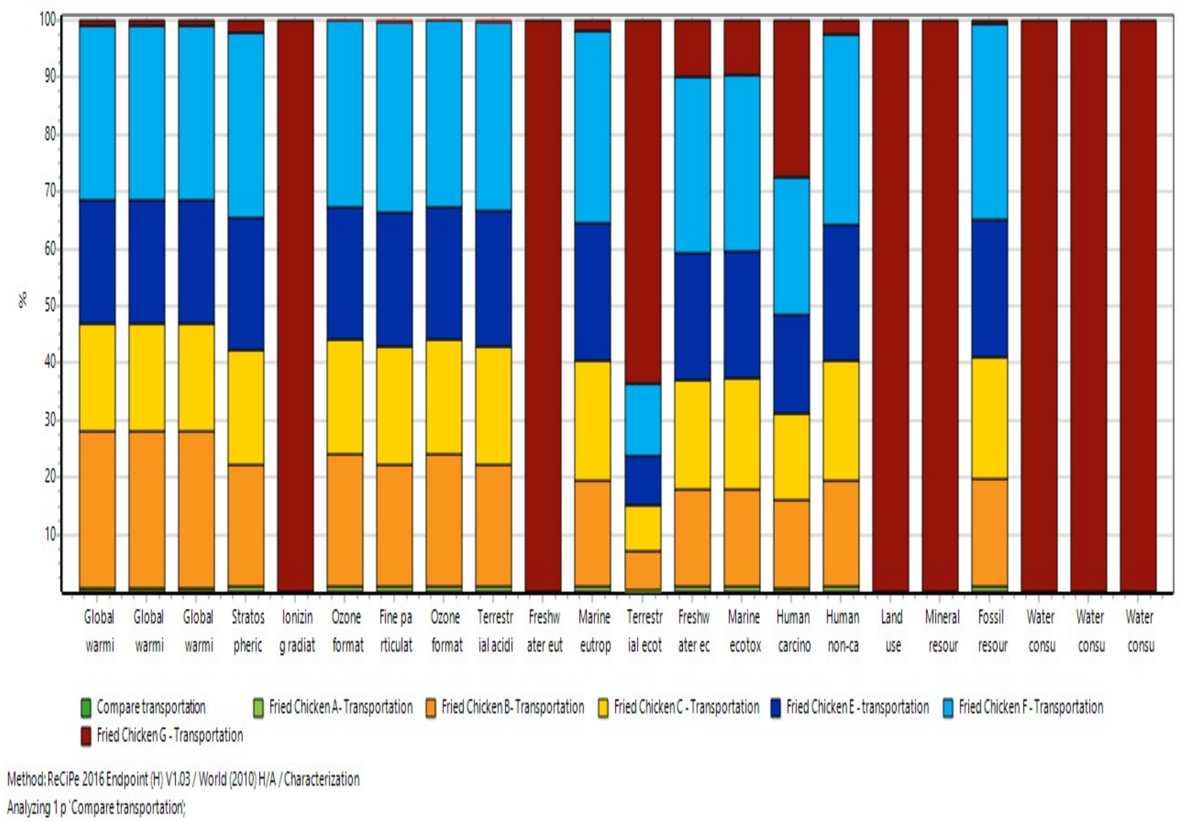

Figure 3. Impact assessment from transportation aspect

Figure 3 illustrates the contribution of environmental impacts across all MSMEs. The figure shows variations in environmental burden characteristics across each category of environmental impact. MSME A contributes to increases in global warming, ozone formation, fine particulate matter formation, and terrestrial acidification. This means that the largest source of emissions stems from a combination of energy-related activities. Global warming can increase the Earth's average temperature. This finding is supported by a study in Pakistan, which indicates that transportation activities, such as freight transport and logistics significantly contribute to carbon emissions. A 10% increase in transportation activities by MSMEs results in a 5% in CO_2 emissions (Adeel et al., 2025). SMEs in

Jombor, Sukoharjo face challenges in optimizing logistics due to small-volume, high-frequency purchases. This increases fuel consumption and carbon emissions (Moutaoukil et al., 2014).

Transportation activities contribute significantly to ozone (O_3) formation through the emission of volatile organic compounds (VOCs) and nitrogen oxides (NO_x), which are precursors to ozone. On-road vehicle emissions are identified as a major source of ozone and particulate matter, with light-duty trucks and buses contributing significantly to ozone-related health impacts (Anenberg et al., 2021). Road transport is consistently identified as a significant contributor to PM2,5 emissions in urban areas. Emissions stem from vehicle exhaust, brake wear, tire wear, and road dust (Askariyeh et al., 2020). PM2,5 from transportation has severe health implications, including respiratory and cardiovascular issues, as it penetrates deeply into the lungs (Camatini et al., 2016).

This situation indicates that the current raw material procurement system still requires a relatively high volume of vehicle travel, so make increasing fossil fuel consumption and exhaust emissions. The extent of the environmental impact during the transportation phase is influenced not only by the distance traveled for distribution but also by the frequency of raw material purchases, vehicle carrying capacity, and the efficiency of distribution routes. Most MSMEs in Jombor still purchase raw materials independently in small quantities but with high frequency. This procurement pattern results in higher fuel consumption per unit of product compared to when purchases are made on a scheduled or collective basis.

Life Cycle Production:-

The analysis of the production stage is used to identify energy consumption, raw material usage, and the amount of waste generated. Most MSMEs in the Jombor, Sukoharjo area use fans during operations, freezers for 24 hours, and other electronic devices. The life cycle assessment approach using Software 9.5.0 with the ReCiPe 2016 method is useful for evaluating the contribution of energy use to environmental impacts. The analysis results can identify environmental hotspots during the production stage, thereby enabling the formulation of improvement strategies focused on resource efficiency and the application of cleaner production principles. The analysis results are presented in Figure 3.

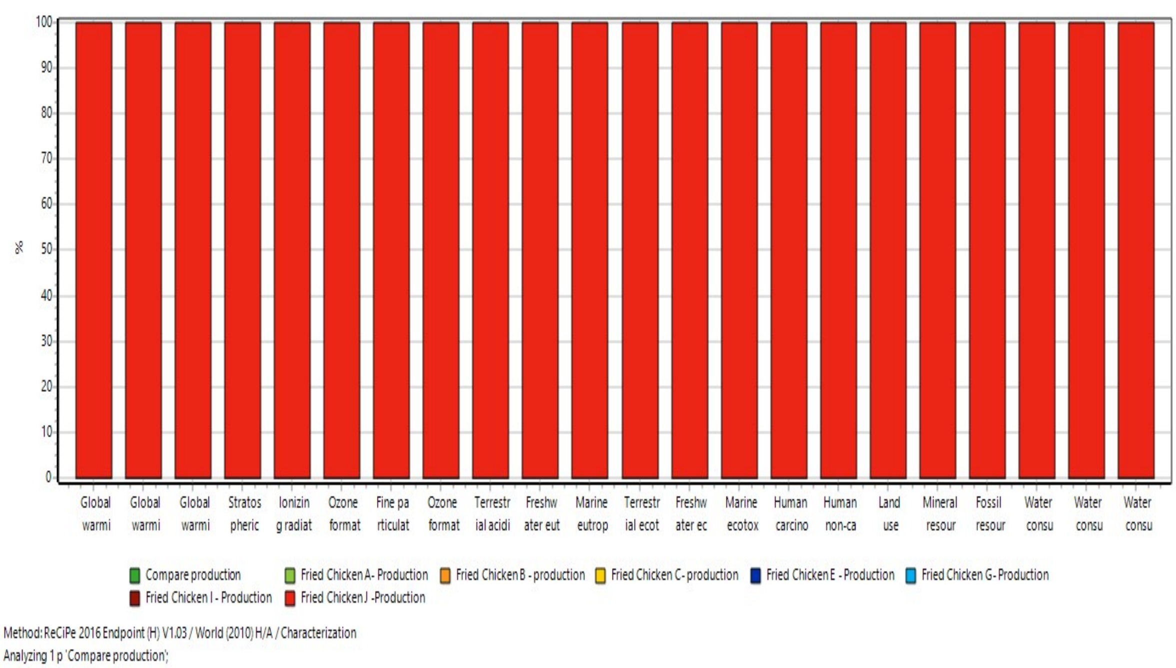

Figure 4. impact assessment from production aspect

Based on the results of the Life Cycle Assessment (LCA) using the ReCiPe 2016 Endpoint (H) method, it was found that the production stage is the primary source of environmental impact. All of these production activities contribute to environmental impacts across various categories, including global warming, ozone formation, terrestrial acidification, and water consumption.

The contribution of production activities to these environmental impacts indicates that the use of raw materials, energy consumption, water use, as well as emissions and waste generation during the production process play a significant role in determining a product's environmental performance. In the global warming category, energy consumption during the production process is the primary cause of environmental impact. Production activities and energy consumption account for approximately 76% of total global greenhouse gas emissions (Kiviluoma et al., 2022). Global warming from the production aspect in the Jombor SMEs results from the use of electricity and fuel, particularly the use of LPG. The combustion of these fuels produces CO_2, methane (CH_4), and nitrous oxide (N_2O) emissions that contribute to climate change(Dutta, 2021). Additionally, 60% of SMEs dispose of flour waste directly into the soil, which can affect soil chemistry(Zhang et al., 2025).

These findings identify the production stage as an environmental hotspot in the product life cycle. Therefore, environmental improvement strategies should focus on this stage by increasing energy efficiency, reducing the consumption of raw materials and water, utilizing more environmentally friendly energy sources, and applying the principles of cleaner production. These efforts are expected to reduce the environmental impact across various categories while improving the overall sustainability performance of the production system.

Life Cycle Packaging:-

The packaging stage is a crucial part of a product's life cycle. However, the use of packaging materials contributes to increased environmental impact, particularly in terms of the volume of solid waste generated. Most SMEs in the Jombor area of Sukoharjo use plastic packaging for takeaway. A life cycle assessment approach using Software 9.5.0 with the ReCiPe 2016 method is useful for evaluating the contribution of various types of packaging used to different categories of environmental impact. This evaluation aims to identify more environmentally friendly packaging alternatives and support the implementation of sustainability principles in the supply chain. The analysis results are presented in Figure 4.

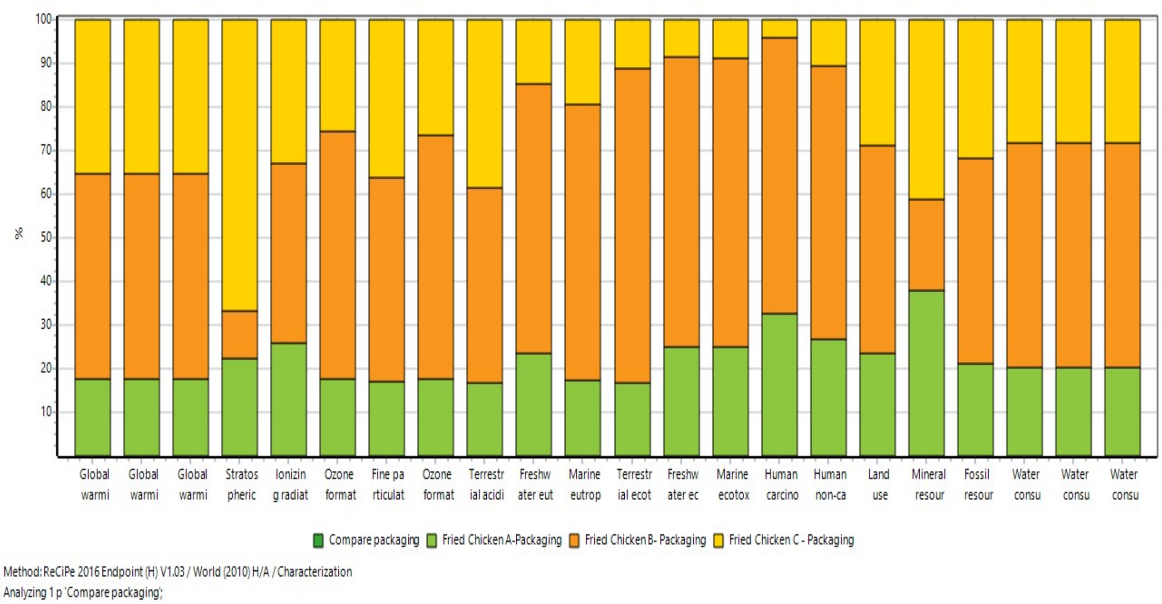

Figure 5. impact assessment from packaging aspect

This study sampled 10 MSMEs in the Jombor area of Sukoharjo. As shown in Figure 4, the results of the environmental impact characterization during the packaging stage indicate that Fried Chicken B is the primary contributor in most environmental impact categories, with 75% contribution. Fried Chicken B's contribution to the global warming category is relatively high, about 45% to 65%, indicating that the packaging materials used have a greater environmental impact intensity compared to other MSME.

Meanwhile, Fried Chicken A has the lowest environmental impact contribution, at 30% in most categories. These results indicate that environmental impacts during the packaging stage are significantly influenced by the type and quantity of packaging materials used. Therefore, improvement efforts should be focused on Fried Chicken B through reducing packaging material usage and selecting more environmentally friendly materials to lower the resulting environmental burden.Improvementstrategies can be implemented by selecting materials with a lower environmental footprint, such as certified paper-based packaging, biodegradable packaging, or lightweight packaging designs. These strategies also have the potential to enhance the product's image as a more environmentally friendly product.

The results of this study indicate that selecting packaging suppliers who implement environmentally friendly production practices (green suppliers) is a crucial factor in improving the sustainability of MSME supply chains. Therefore, decision-making regarding the selection of packaging materials should consider environmental aspects in addition to cost considerations.

Eco-efficiency:-

An eco-efficiency evaluation was conducted to assess the balance between economic performance and environmental impact across each MSMEs.This approach uses environmental indicators represented by the Ecological Efficiency Index (EEI), the Environmental Value Ratio (EVR), and the Ecological Efficiency Ratio (EER). This analysis aims to determine the extent to which MSMEcontribute to generating optimal economic value while minimizing the resulting environmental impacts. So, each MSMEcan be classified into sustainability categories, specifically the affordable and sustainable category.

Table 2. Eco-efficiency

MSME	Eco-efficiency				Indicator
	Gross Profit/unit (IDR)	EEI	EVR	EER	
A	9.750	2,14	0,12	88%	affordable, sustainable
B	9.750	2,89	0,01	99%	affordable, sustainable
C	5.250	2,60	0,05	95%	affordable, sustainable
D	5.250	2,60	0,05	95%	affordable, sustainable
E	5.250	2,18	0,12	88%	affordable, sustainable
F	5.250	2,18	0,12	88%	affordable, sustainable
G	9.750	2,64	0,05	95%	affordable, sustainable
H	9.750	2,64	0,05	95%	affordable, sustainable
I	9.000	2,68	0,04	96%	affordable, sustainable
J	9.000	2,44	0,08	92%	affordable, sustainable

Based on the results of the eco-efficiency evaluation, all MSMEs fall into the affordable and sustainable category, indicating that each MSME is capable of generating positive economic value while keeping environmental impacts at a relatively low level. This is show by Eco-Efficiency Index (EEI) above 2 and an Eco-Efficiency Ratio (EER) ranging from 88% to 99%. These conditions indicate that all MSMEs have achieved a good balance between economic performance and environmental performance, therebysupporting the application of sustainability principles in their operational activities. This means that all MSMEs are capable of generating greater economic value than the environmental costs incurred during the production process.

MSME B demonstrated the best eco-efficiency performance with an EEI of 2,89; an EVR of 0,01; and an EER of 99%. These values indicate that MSME B is capable of generating high economic value with the relatively lowest environmental impact compared to other MSME. A very low EVR value indicates that the proportion of environmental costs relative to the economic value generated is relatively small. It's mean MSME B is able to optimize its use of resources, thereby generating high economic returns with a relatively low additional environmental burden.Additionally,MSME G, H, and I also demonstrate excellent performance with EEI values ranging from 2,64 to 2,68 and EER values of 95-96%, indicating relatively optimal resource efficiency and environmental management.

Meanwhile, MSME A, E, and F have relatively lower eco-efficiency values compared to other MSME, with EEI values ranging from 2,14 to 2,18; an EVR of 0,12, and an EER of 88%. Although they still fall within the sustainable category, these values indicate that these three MSME generate a relatively greater environmental impact for every unit of economic value produced. A higher EVR value indicates that the proportion of environmental costs relative to the economic value generated remains relatively large; therefore, any improvement in the efficiency of energy use, raw material use, or waste management has the potential to increase overall eco-efficiency.Therefore, there remains an opportunity to improve environmental efficiency through the optimization of resource use, waste reduction, and the adoption of more environmentally friendly technologies or materials.

MSME C and D show that similar eco-efficiency characteristics with an EEI of 2,60; an EVR of 0,05; and an EER of 95%. MSME J also have fairly good performance with an EEI value of 2,44 and an EER of 92%, indicating an adequate level of sustainability although there is still opportunity for improving environmental efficiency.

Differences in eco-efficiency values among MSMEs indicate that sustainability is determined not only by the magnitude of economic gains but also by each MSME's ability to manage resources efficiently throughout the product life cycle. Therefore, the EEI, EVR, and EER indicators can be used as evaluation tools to determine priorities for operational and environmental improvements. SMEs with higher EVR values should be prioritized in the implementation of energy efficiency programs, waste reduction initiatives, and the adoption of cleaner production technologies.

Overall, the results of this study indicate that Life Cycle Assessment (LCA) and eco-efficiency analysis complement each other in evaluating the sustainability of SMEs. LCA can identify process stages that are environmental hotspots, while eco-efficiency indicators show the extent to which these environmental impacts are still acceptable compared to the economic value generated. The integration of these two approaches provides a stronger foundation for developing Green Supply Chain Management strategies, particularly in setting priorities for improvements in transportation, production, and packaging to enhance the overall sustainability of SMEs.

Study Limitations:-

This study has some limitations that should be considered when interpreting the results. First, this study was conducted only on 10 selected flour-based chicken-processing MSMEs in Jombor, Sukoharjo. Therefore, the results maybe not full represent the environmental and operational characteristics of similar MSMEs in other regions with different production conditions, business scales, or supply chain systems. Second, the Life Cycle Inventory (LCI) was compiled based on primary data obtained through field observations, interviews, and production records; thus, there remains the possibility of variations in data reporting and operational practices among MSMEs. Third, the environmental impact assessment in this study is limited to the impact categories analyzed using the ReCiPe 2016 Endpoint (H) method and the eco-efficiency indicators.

This study also doesn't include sensitivity or uncertainty analysis, so the reliability of the estimated environmental impacts remains limited. Furthermore, although this study has integrated environmental and economic aspects through eco-efficiency analysis, broader dimensions of sustainability, such as social and governance aspects. So, the future research is recommended to involve a larger number of MSMEs from various regions, conduct sensitivity and uncertainty analyses, and integrate environmental, economic, and social aspects to obtain a comprehensive sustainability assessment.

Conclusion:-

This study demonstrates that the application of Life Cycle Assessment (LCA) integrated with eco-efficiency can provide an analysis of the environmental and economic performance of flour-based chicken processing MSMEs in Jombor Village, Sukoharjo. The LCA analysis results indicate that the production stage is an environmental hotspot, contributing the most to the impact categories of global warming, ozone formation, terrestrial acidification, and water consumption. These impacts are primarily caused by the use of electricity, LPG, water consumption, and waste generation during the production process. Additionally, transportation activities and the use of plastic packaging also contribute to increased environmental burdens across several impact categories.

The results of the environmental impact characterization indicate variations in contributions among MSME. During the packaging stage, MSME B was the largest contributor in most environmental impact categories,75% contribution, while MSME A had the lowest contribution, at less than 30% in most categories. The eco-efficiency evaluation indicates that MSME B has the best eco-efficiency performance with an EEI value of 2,89; an EVR of 0,01 and an EER of 99%, demonstrating the ability to generate high economic value with relatively low environmental impacts. The results of this study underscore the importance of implementing Green Supply Chain

Management, energy efficiency, the use of more environmentally friendly packaging materials, and the adoption of cleaner production to enhance the sustainability of SMEs while strengthening business competitiveness in the long term.

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