

Life cycle assessment (LCA) study of a milk powder product in aluminium foil packaging

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Abstract:

Dairy processing industry is one of the industries that give positive contribution to the economic growth, however it also contributes in many impacts on the environment, as well as milk powder product manufactured by PT X. The main objective of this study was to determine the most significant environmental impact caused by production and transportation of milk powder in bag 250 gram (Product X) using Life Cycle Assessment (LCA) methodology. The boundary of the LCA study is “cradle to gate”, including: materials production, materials transportation from supplier to the PT X factory, manufacture of milk powder in PT X, and distribution of the products from factory to distributor. Four impact categories will be calculated on this study: global warming potential (GWP), eutrophication potential (EP), acidification potential (AP), and photochemical oxidant creation potential (POCP). The impact assessment was calculated by software SimaPro v.8.3.2 faculty license, and the calculation result validated manually by Microsoft Excel. The result of environmental impact calculation showed the GWP, EP, AP, and POCP of 1 kg milk powder is 1.3245 kg CO₂ eq/kg, 0.0033 kg PO₄³⁻ eq/kg, 0.0066 kg SO₂ eq/kg and 0.0020 kg C₂H₄ eq/kg. The material production subsystem has the highest environmental impact on GWP, POCP, AP and EP categories. In particular, production activity in PT X also contributes to GWP. An environmental impact reduction strategy can focus on reducing GWP with electricity usage efficiency and developing a material supplier selection plan with environmental impacts of material production as one of criteria

Key Words: *Life Cycle Assessment, Life Cycle Inventory, Milk Powder, Cradle to Gate.*

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1. INTRODUCTION

Agroindustry is one industry that has been proven to contribute positively to Indonesia's economic growth [7]. One part of this industry is dairy processing with milk powder as one of its products. Among 48 milk processing companies in Indonesia, milk powder is on the second rank for the highest number of producers [7]. Dairy processing industry has a great opportunity to provide milk products for more than two hundred million Indonesians whose current consumption is below the other ASEAN countries [13]. The dairy industry must strive to reduce impacts and increase sustainability to deal with expected increase in milk production [2].

Environmental impacts can be generated in each phase of product life cycle: raw material acquisition; processing which involves materials processing and transportation to production sites; manufacturing which include product manufacture and assembly, packaging and transportation to final distribution; product life; and also waste management. Life cycle analysis (LCA) is the systematic approach of looking at a product's complete life cycle, from raw materials to final disposal of the product. It offers a "cradle to grave" look at a product or process, considering environmental aspects and potential impacts [11]. There is an international standard for LCA that lists the following applications: product and process development, identification of improvement possibilities, and also LCA-based eco-labelling [8]. Some research related to LCA of dairy product have already published, such as, LCA of six dairy products in Serbia[1], the environmental impact of milk powder and butter manufactured in the Republic of Ireland[2] LCA of yoghurt production[3], LCA and water footprint of margarine and tea product[4], and also greenhouse gases emission analysis of milk product in USA[6].

The research of life cycle assessment of milk powder product was conducted in PT X, as one of one of the foods and beverages company in Indonesia that produces milk powder as one of main product. The main purpose of the research was to analyze the environmental impacts from the manufacture of milk powder. The goals of this research were to determine amount of materials and energy in milk powder production, amount of emission generated from milk powder production, identifies environmental impact differences in the four impact categories and determines appropriate recommendations for improvement of environmental management system in PT X.

2. METHODS

PT X is a leading food and beverage company in Indonesia with some brands of milk powder product in aluminium foil packaging and has serious

commitment to achieve sustainable production by using LCA to assess the environmental impact of their product. According to ISO 14040 (2006), LCA procedure consists of following step: scope and goal definition, life cycle inventory analysis and/or life cycle impact assessment and result interpretation^[10]. This study consists of three major steps: initial identification, data collection and application of LCA method, analysis and conclusion. The LCA system boundary of LCA has determined in initial identification step, which are "cradle-to-gate" (Figure 1):

1. Subsystem of material and energy production (Subsystem 1). Subsystem of material production consists of raw material production (skimmed milk powder and sugar), packaging material (aluminium foil and paperboard), chemical agent (cleaning agent and printing ink), water treatment and also electricity. Every material has specific boundary depend on data availability. Chocolate powder is calculated as inventory in milk powder production at PT X but not included in environmental impact calculations due to data limitations. Table 1 summarized the source of database considered in this study.
2. Subsystem of material transportation from supplier to dairy plant (Subsystem 2)
3. Subsystem of milk powder production in PT X (Subsystem 3). The main product will be observed in this study is milk powder in bag of aluminium foil 250 gram (Product X). The functional unit of this LCA study is 1 kg milk powder product (fat content 6,3% and protein content 15%) packaged in aluminium foil as primary packaging. This study conducted at dairy plant, PT X, Bekasi district, Jawa Barat. Flow chart of milk powder production system at PT X and identification of input and output in each process unit are shown by Figure 2.
4. Subsystem of product distribution from dairy plant to distributor (Subsystem 4).

Table 1. Summary of data sources for emission of material production and transportation.

Subject	Source
Skimmed milk production	LCA Food DK (Nielsen et al., 2003)
Aluminium foil production	(BUWAL, 1996)
Paperboard production	(Franklin Assoc, 1998)
Sugar, box, chemical agent, electricity production, water treatment and transportation	Ecoinvent V3 (Wemmet dkk, 2016)

Data collection consists of primary and secondary data related to material transportation, material input and output in milk powder production in PT X and product distribution (Table 2). The next

step is inventory analysis which is applied to all data from all subsystems. Each data from every subsystem is linked to functional unit. The output from inventory analysis is the ratio of the amount of resources used to produce milk powder.

The inventory analysis is followed by the environmental impact assessment (LCIA) stage. According to LCIA methodology standard, only the classification and characterization stages defined as mandatory stages, while normalization and weighting are optional elements [10]. In this LCA study, the process of classification and characterization were undertaken while normalization and weighting were not conducted.

The characterization factors reported by the Centre of Environmental Science at Leiden

University (CML 2001 method) were used on this LCIA study [9]. The following impact potentials were evaluated: global warming potential (GWP), photochemical ozone creation potential (POCP), acidification potential (AP) and eutrophication potential (EP). The environmental impact calculations are performed using SimaPro 8.2.3.0 faculty license software and the calculation result validated manually by Microsoft Excel according to environmental impact potentials formula.

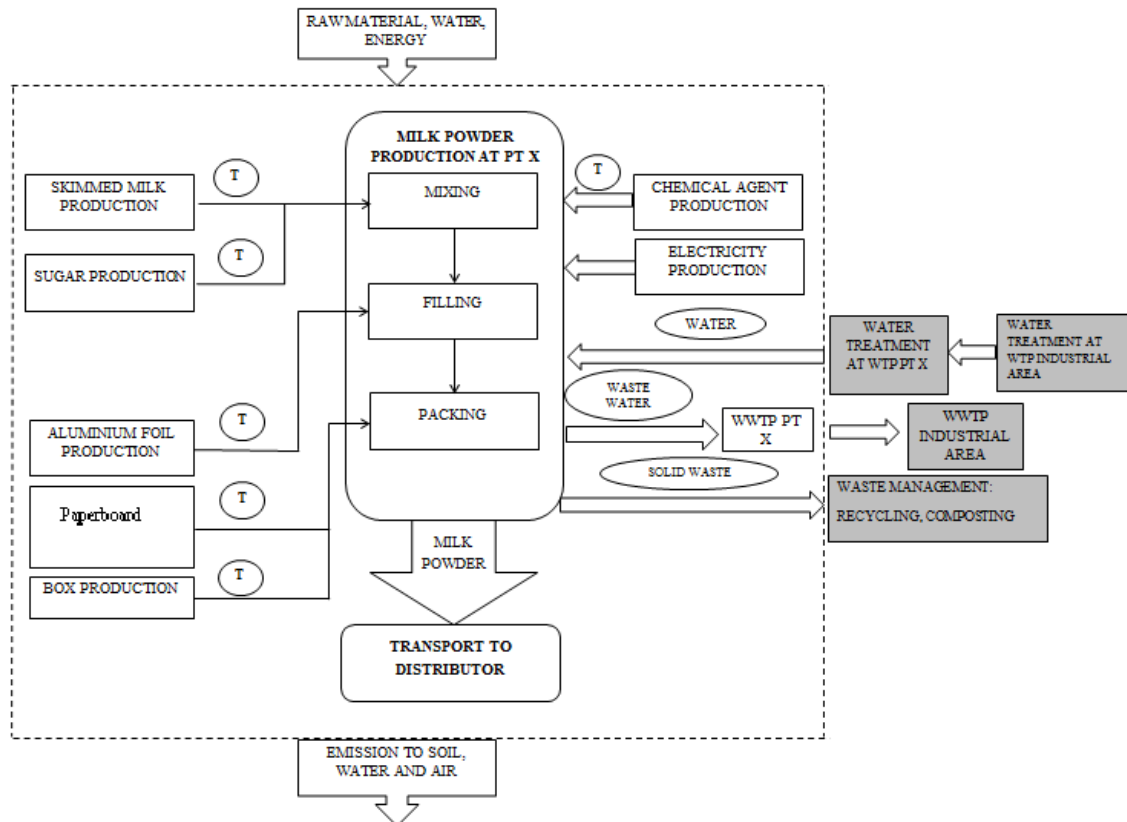


Figure 1. System boundary in LCA milk powder. T : Transportation.

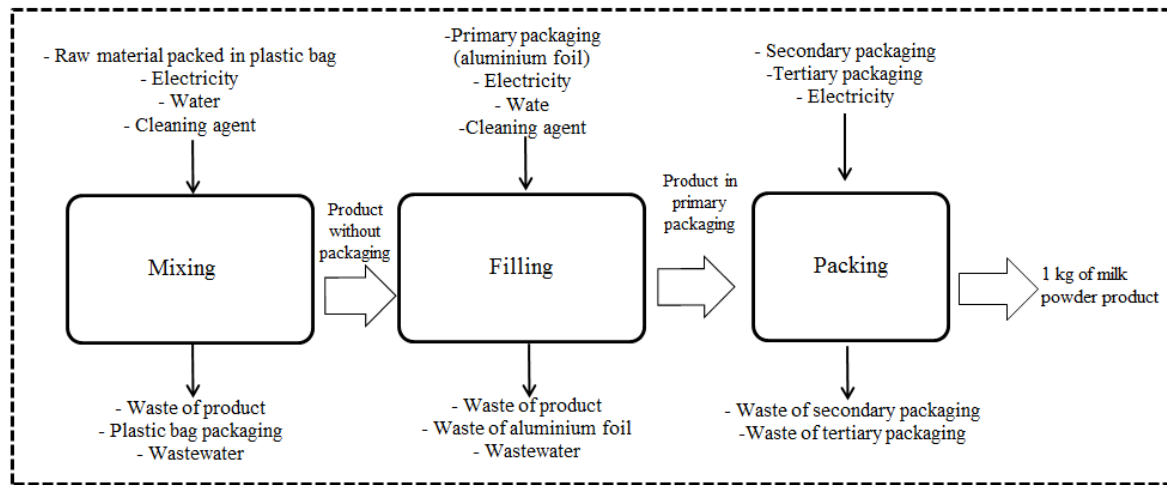


Figure 2. Flow process of milk powder production system in PT X

Figure 2 shows the production process of Product X and functional unit. The production process consists of three process units: mixing, filling and packing, and the functional unit in

this study is defined as 1 kilogram (kg) of milk powder product packaged in aluminium foil as primary packaging.

Table 2. Data collection for subsystem 2 (material transportation), subsystem 3 (milk production in PT X) and subsystem 4 (product distribution)

Subsystem	Subject	Primary Data	Secondary Data (source: PT X)
Material Transportation	Raw and packaging material, chemical agent	Type of vehicle, type of fuel	Supplier location
	Raw material (skimmed milk, sugar, chocolate powder, additional ingredients)		Average of raw material consumption ⁽¹⁾
	Packaging material (aluminium foil, paperboard, box)	Weight per pieces	Average of packaging material consumption ⁽¹⁾ , packaging specification ⁽²⁾
	Chemical agent (cleaning agent, printing ink)		Average of chemical agent, cleaning agent composition ⁽²⁾
Milk Production in PT X	Electricity		Electricity consumption per month for machine and lamp (production area)
	Water		Water consumption per month
	Solid waste (product waste, packaging waste)		Average of solid waste per production batch
	Wastewater	COD, TSS, nitrate, nitrite, ammonium, phosphate	Report of analysis for WWTP PT X output
	Product		Quantity of Product X ⁽³⁾ , product characterization (fat and protein content, density)
Product Distribution			Distributor location, product demand (%), type of vehicle, type of fuel

⁽¹⁾ Average of consumption per month on 4th quarter of 2016

⁽²⁾ According to *Certificate of Analysis* (CoA)

⁽³⁾ On 4th quarter of 2016

3. RESULTS

3.1. Inventory Analysis

The life cycle inventory phase generally consists of three activities: flow model construction based on goal and scope that has been previously defined; data collection for each activity in the product system including input and output data, for example raw materials, products, solid waste, emissions to water and air; and calculation refers to the amount of resources used and emissions on the system associated with a particular unit of function[8].

The milk powder production in PT X involves a variety of materials that come from different suppliers using different types of vehicles. Table 3 summarizes the types of vehicles and the distance from suppliers location to PT X factory for each material used in the powdered milk production process. Table 4 shows inventory data input and output material to produce 1 kg of product. For product distribution subsystem, the distance between the PT X plant to Distributor B (West Java) was chosen as the basis for life cycle impact assessment (LCIA) calculation because Distributor B has the highest average product demand (20%).

Table 3. Summary distances and type of vehicle

Material	Country of origin	Type of vehicle	Distance (kg.km)
Skimmed milk powder	Denmark	Transocean ship	3875.3
		Truck diesel 16 - 32 t	15.9
Sugar	Indonesia	Truck diesel 7,5 - 16 t	81.1
Chocolate powder	Indonesia	Truck diesel 7,5 - 16 t	2.5
Aluminium Foil	Indonesia	Truck diesel $\leq 7,5$	0.6
Paperboard	Indonesia	Truck diesel $\leq 7,5$	5.9
Box	Indonesia	Truck diesel $\leq 7,5$	1.7
Cleaning agent A	Indonesia	Truck diesel $\leq 3,5$	0.003
Cleaning agent B	Indonesia	Truck diesel $\leq 3,5$	0.001
Printing ink	Indonesia	Truck diesel $\leq 3,5$	0.003

In general, PT X uses a total of 1.472 kg of material and 0.343 kWh of electricity to produce 1 kg of milk powder packed aluminum foil bags 250 grams (Product X). Materials used include raw materials, packing materials, chemicals and water. Production of 1 kg Product A produces emissions to the air of 0.288 kg CO₂. Inventory analysis also serves to determine the hotspot of the highest

material and energy use or the largest source of waste. Figure 3 shows the comparison of electricity usage inventory in the mixing, filling and packing unit to produce 1 kg of Product X. The energy hotspot is in the mixing unit. Product design by considering energy efficiency of the machines can serve as the basis of consideration of PT X in designing upcoming products as well as continuous development plans.

In addition to the product, the milk powder production also generates other outputs to the technosphere which are solid waste consist product waste and packaging waste. Figure 4 shows the inventory of solid waste to produce 1 kg of Product X. The product waste indicates the residual product left on mixing and filling machines. The waste of aluminum foil defined as the residues of aluminum foil that is not successfully formed into bags or sachet on the filling process unit. Aluminum foil waste in the filling process unit can be caused by the activity of aluminum foil roll replacement in the machine or the change of machine settings. The utilization of high efficiency (less waste) machine for production can serve as a basis consideration of PT X in designing upcoming products as well as continuous development plans (eg, aluminum foil bag packaging process). The efficiency potential can be prioritized to the efficiency of product waste in the mixing and filling units compared to the packaging efficiency as the percentage of product waste in the mixing and filling units is still above 1%.

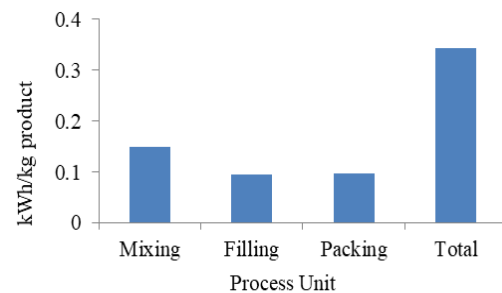


Figure 3. Electricity usage of the mixing, filling and packing unit

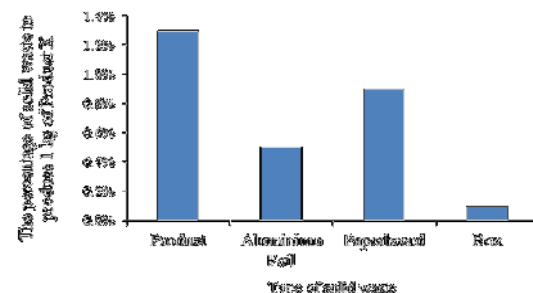


Figure 4. The percentage of solid waste per material consumption

Table 4. Inventory data in production of 1 kg milk powder

Material	Product X	Unit	%
Raw Materials			
Skimmed milk	0.353	kg	24%
Sugar	0.313	kg	21%
Chocolate powder	0.031	kg	2%
Additional	0.304	kg	21%
Packaging Materials			
Aluminium foil	0.018	kg	1%
Paperboard	0.165	kg	11%
Box (Corrugated board)	0.085	kg	6%
Chemicals			
Anionic surfactant	1.45E-05	L	0.001%
Acetic acid	1.92E-05	L	0.001%
Hydrogen Peroxide	1.05E-05	L	0.001%
Ink	6.63E-05	L	0.005%
Water	0.202	L	14%
Electricity	0.343	KWh	
Milk powder product	1	kg	
Waste to treatment			
Wastewater to WWTP PT X	0.202	L	
Waste to composting	0.013	kg	
Waste to recycling	0.004	kg	
Emission in water (Waste water to WWTP PT X)			
Ammonium	2.35E-06	mg/L	
Phosphate	8.39E-05	mg/L	
Nitrite	5.87E-08	mg/L	
Nitrate	2.00E-04	mg/L	
COD	7.09E-04	mg/L	
TSS	8.80E-05	mg/L	
Emission to air			
CO ₂	0.288	kg	

3.2. Life Cycle Impact Assessment

The purpose of life cycle impact assessment is providing additional information to assess the results of the life cycle inventory (LCI) analysis resulting a better understanding of the significant environmental impacts caused by a product system [10]. The specifications of relevant environmental impacts are determined based on the objectives and scope that has been defined [8]. Cradle-to-gate life cycle milk powder not only contributes to economic growth but also produces various emissions to the environment. Table 5 below summarizes the emissions with the greatest value and classification in each category of environmental impact. Cradle-to-gate life cycle of

milk powder produce emissions other than those listed in Table 5 but in smaller amounts.

Table 5. Emission inventory associated with *cradle-to-gate* life cycle of milk powder

Substance (kg)	Impact Category	Material Production	Material Transportation	Production in PT X	Product Distribution
CO ₂	GWP	7,4E-01	6,3E-02	2,9E-01	1,0E-01
N ₂ O	GWP	9,2E-05	1,8E-06	3,7E-15	2,8E-06
CH ₄	GWP	5,0E-04	2,0E-05	3,0E-13	1,0E-04
SF ₆	GWP	3,5E-08	2,0E-09	0,0E+00	5,1E-14
NH ₃	AP, EP	5,5E-04	4,3E-06	4,6E-17	6,4E-07
NO	AP, EP	2,9E-03	8,1E-04	6,8E-13	1,4E-03
SO ₂	AP, POCP	2,0E-03	5,5E-04	0,0E+00	5,2E-05
COD	EP	5,9E-03	1,4E-04	7,1E-10	4,0E-06
P	EP	1,5E-03	1,4E-05	8,4E-11	7,6E-08
Nitrate	EP	7,0E-03	1,0E-04	2,0E-10	3,7E-08
CO	POCP	2,4E-03	4,3E-05	1,9E-13	2,5E-04

The calculation results per category of environmental impact (characterization stage) for the cradle-to-gate life cycle of 1 kg of Product X is shown by Table 6. The research on dairy products in Ireland showed the average environmental impact assessment of 1kg milk powder production for potential environmental impacts of GWP and AP was 1.482 kg CO₂ eq/kg and 0.00584 kg SO₂ eq/kg.[2]

Table 6. Impact assessment results (characterization step) associated with the cradle-to-gate life cycle of 1 kg of milk powder

Impact Category	Unit	Total
Global Warming Potential (GWP)	kg CO ₂ eq/ kg	1.3245
Photochemical Oxidant Creation Potential (POCP)	kg C ₂ H ₄ eq/kg	0.0020
Acidification Potential (AP)	kg SO ₂ eq/ kg	0.0066
Eutrophication Potential (EP)	kg PO ₄ ³⁻ eq/kg	0.0033

Figure 5 and Figure 6 shows the relative contributions of each subsystem for each impact category, consist materials production, material transport, milk powder production at PT X and product distribution. The result of impact calculation was conducted using SimaPro 8.2.3.0 faculty licence software and verified by Microsoft Excel. Both calculation techniques generate similar results. According to these result, the subsystem of material production contributed the highest environmental impact in four categories. The production of milk powder in PT X contributes to the impact on GWP related to electricity consumption that indirectly produces CO₂ emissions due to the use of fossil fuels in power plants. While in the material transport subsystem, the largest environmental contributor is derived from importing skimmed milk from Denmark by transoceanic ship. On cradle-to-grave life cycle of 1-ton yoghurt in Portugal also showed that the production process of yoghurt included raw materials, packaging materials and chemicals production gave

high contribution to GWP and POCP by 50%, however in AP and EP, the activity of dairy farm contributed higher impact [3]. In this LCA study conducted, activity on dairy farm did not consider into the scope. Meanwhile, in Indonesia, research on LCA of fresh milk supply chain showed the environmental impact caused by extraction process and milk production is higher than material transport and product distribution process [5]. The production of packaging, sugar and electricity are the main activity that contributes the highest impact on all four categories.

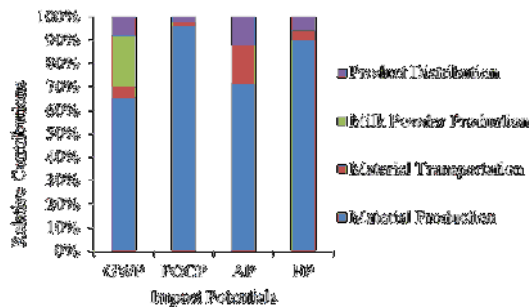


Figure 5. Relative contributions per subsystem to each impact category (GWP, POCP, AP and EP) calculated by using software SimaPro

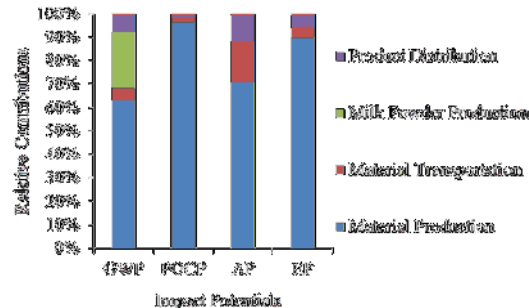


Figure 6. Relative contributions per subsystem to each impact category (GWP, POCP, AP and EP) calculated manually by Microsoft Excel

4. CONCLUSIONS

To produce milk powder products in bag 250 gram (Product X), PT X uses 1.472 kg of material and 0.343 kWh of electricity. Materials used include raw materials, packing materials, chemicals and water. The process of producing powdered milk not only produces a product, but also emissions to air and water. Production of 1 kg of milk powder generates emissions to air of 0.288 kg CO₂. As for emissions to water, production of milk powder also contributes to the load of WWTP output. Based on the cradle-to-gate life cycle study of 1 kg of milk powder, Product

X provide environmental impacts in the GWP, POCP, AP and EP category of 1.3245 kg CO₂ eq/kg, 0.0020 kg C₂H₄ eq/kg, 0.0066 kg SO₂ eq/kg, 0.0033 kg PO₄³⁻ eq/kg. Environment are one of the main factors in achieving sustainable development, so the integration between the three pillars of sustainability which are economic development, social equity and environmental protection in company's decision making is an important strategy. In the case of sustainability of milk powder production in PT X, the environmental impact reduction strategy can focus on reducing GWP with electricity usage efficiency and developing a material supplier selection plan with environmental impacts of material production as one of criteria.

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