Life cycle assessment of wafer biscuit production

A Ismayana*, O A Ibrahim and M Yani

Department of Agroindustrial Technology, Faculty of Agricultural Technology, IPB University. Dramaga Bogor, Indonesia

E-mail: andesismayana@ymail.com; andesismayana@apps.ipb.ac.id

Abstract. The Life Cycle Assessment (LCA) method was used to determine the amount of potential emissions generated from the production activities of the wafer biscuit. The objectives of this study were (1) to observe all of input and output of the production process, (2) to analyze the potential of environmental impacts, and (3) to provide alternative improvements in efforts to reduce the environmental impacts. The LCA method consisted of four stages: determination of goal and scope definition, inventory analysis, impact assessment analysis, and interpretation analysis. Based on observations of existing activities, the scope of this research was set for “gate to gate” and the impact analysis included global warming potential, eutrophication, and acidification. The results of the impact analysis showed that production of wafer biscuit produced greenhouse gas (GHG) emissions of 1.5161 kg-CO$_2$-eq/kg-product, acidification of 0.0115 kg-SO$_2$-eq/kg-product, and eutrophication of 0.0131 kg-PO$_4$$^3$-eq/kg-product. There were four alternative improvements that should be done to reduce environmental impacts; (1) the use of solar water heater which could decrease GHG emissions by 8%, acidification by 13%, and eutrophication by 0.56%, (2) replacement of refrigerant types could lower GHG emissions by 19%, acidification of 13%, and eutrophication of 0.57%, (3) reuse of cooling water reduced GHG emissions by 7%, acidification by 11%, and eutrophication by 32.21%, and (4) improvement in waste treatment would reduce emissions eutrophication as much as 83.86%.

Keyword: Acidification, biscuit wafer product, eutrophication, greenhouse gas, LCA

1. Introduction
Wafer biscuits production is one of the many food industries that use agricultural products as the main raw material for production. Widianingsih [1] has compiled data of the wafer biscuit market in Indonesia for six years. She reported that the market had significantly grown from IDR 3 trillion in 2009 to around IDR 6.23 trillion in 2015. This increase was due to the strong growth opportunities for Indonesian consumption in line with the people needs of comfortable food such as wafer biscuits. The consumption of wafer biscuits per-capita in Indonesia tended to increase by 24.22 percent during period of 2011-2015 [2]. This opportunity led to the growth of industries engaged in the manufacture of wafer biscuit products.

The growth of wafer biscuit industries has an impact on the surrounding environment, so the industry must have a role to protect it. Conservation of the environment could be done by treating the emission or waste produced. Another way that could be done was to reduce the amount or quantity of emissions and waste produced. Some potential emissions from the wafer biscuit industry could have impacts on the greenhouse gas, acidification and eutrophication.
Greenhouse gases (GHG) are produced because of emissions in the form of CO₂, CH₄, and N₂O. The increase in GHG emissions has caused an increase in global temperatures from year to year. Greenhouse gases that accumulate in the ozone layer induced solar energy to be trapped in the earth's atmosphere, and that is the main cause of global warming [3]. Activities undertaken by industry also produce gases such as SO₂ and NOx which could generate acidification to the environment of surface area. The acidification is an increase in acid in the environment both in the soil and water environments which could damage to the ecosystem in those area. Another problem is the emergence of wafer biscuit industrial waste which contains many organic substances in the form of nitrogen and phosphate which could make eutrophication [4]. The eutrophication is enrichment of water with nutrients needed by aquatic plants. This condition could also cause a very rapid increase in algal growth. Moreover, it increases the growth of aquatic plants such as water hyacinth which could cover the surface water. As a result, there is a decrease in water quality in the aquatic environment due to the low dissolved oxygen in water and blocking the intensity of the light entering the aquatic ecosystem [5].

Therefore, some efforts are needed to analyze the potential impacts arising from the amount of emissions produced and reduce environmental pollution. One of them is the implementation of the Life Cycle Assessment (LCA) in the production of wafer biscuits, so that it could identify and reduce the environmental impact, and then the production process becomes environmentally friendly. Interpretation based on the results of the LCA method analysis would have a positive impact because it reduces the amount of emissions and waste generated by the wafer biscuit industry.

Life cycle assessment method, which is a method for evaluating and assessing all environmental impacts related to products, processes, and material flow activities in the production process [6]. LCA consists of four stages, namely determination of goal and scope, life cycle inventory, impact analysis, and interpretation analysis. The application of LCA could also be used as a benchmark whether the production process has saved energy so that it becomes a consideration in the impact on the environment.

The objectives of this study were to analyze the potential environmental impacts of wafer biscuit production by the LCA method through: (1) Identification of the inputs (raw materials, additives, and energy) used and the outputs (products, by-products, emissions, and waste) resulting from the process of wafer biscuit production, (2) Analysis of potential environmental impacts arising in the form of greenhouse gases (GHG), acidification and eutrophication, and (3) Analysis of alternative improvements in efforts to reduce to those environmental impacts.

2. Method
The LCA method was done by quantitative identification of all input-output flow (exchange flow) from the system to the environment in each stage of the life cycle. The LCA method is carried out based on the LCA implementation guidelines according to the ISO 14040 [7]. The framework consists of four stages, namely: determination of goal and scope, inventory analysis, impact assessment, and interpretation and analysis of improvement [Figure 1]. The LCA method used in this study refers to ISO 14040 [7] and IPCC [8]. The flow of this research is explained in the flow chart in Figure 1.

2.1. Source data
The required data were collected at one of food industries that produced wafer biscuit using a questionnaire. The data questionnaire consisted and included data, such as: input-output production process, material balance, energy used, and production. The completed data of questionnaire were processed using Microsoft Excel.

2.2. Determination of goals and scope
It was the stage at which the objectives and scope of the study of the LCA were determined based on the life cycle that limited the study and also the field data obtained. In addition, at this stage an objective unit of function was also determined which would be used in research using the LCA method [7].

2.3. Inventory analysis
At this stage, the product life cycle chain was identified, the data collection needed, and the quantification of data to be analyzed [8,9]. The product life cycle that had been obtained was described using a flow diagram process to find out the input, process, and output data. Data collection was carried out to obtain primary data and secondary data, both data owned by the company and from direct observation in the field. Then the quantitative inputs, processes and outputs are described in the mass balance.

2.4. Impact assessment.
Impact assessments were carried out to evaluate the resulting environmental impacts based on the results of calculations at the inventory analysis stage. Grouping the environmental impact of wafer biscuit production based on the impact on greenhouse gases, eutrophication and acidification is shown in Table 1 [7,8].

![Flowchart of research stage](image)

**Figure 1.** The flowchart of research stage.
| Category | Source          | Formula of calculation                                      | References |
|---------|----------------|------------------------------------------------------------|------------|
| CO₂     | Electricity    | Emission CO₂ = Q_L x FE                                    | [9]        |
|         | Natural gas    | Emission CO₂ = Q_F x NK x FE                               | [10]       |
| N₂O     | Natural gas    | Emission N₂O = Q_F x NK x FE                               | [10]       |
| CH₄     | Wastewater     | Emission CH₄ = V_LC x C x FE                                | [11]       |
|         | Solid waste    | Emission CH₄ = V_LP x F x 16/12                             | [12]       |
|         | Natural gas    | Emission CH₄ = Q_F x NK x FE                               | [10]       |
| HFC     | Refrigerant    | Emission HFC = C x (x/100) x T x FE                        | [13]       |
| SO₂     | Electricity    | Emisi SO₂ = Q_L x FE                                       | [9]        |
|         | Natural gas    | Emisi SO₂ = Q_F x NK x FE                                  | [14]       |
| NOₓ     | Electricity    | Emisi NOₓ = Q_L x FE                                       | [9]        |
|         | Natural gas    | Emisi NOₓ = Q_F x NK x FE                                  | [14]       |
| NOₓ     | Electricity    | Emisi NOₓ = Q_L x FE                                       | [9]        |
|         | Natural gas    | Emisi NOₓ = Q_R x N x FE                                   | [14]       |
| PO₄³⁻   | Wastewater     | Emisi PO₄³⁻ = Q_L x C x FE                                 | [11]       |

2.5. Interpretation analysis
Interpretations were carried out to improve and reduce the impact on the environment. At this stage, identification was carried out to determine the processes that had a significant effect on the environment, then an analysis was carried out to provide several alternative improvements that can be potentially applied. Recommended options for improvement based on analysis were derived from references, such as books, journals, and reports. Alternative recommended improvements would have a positive impact in the form of a reduction in the environmental impact.

2.6. Data analysis
Data analysis was performed using Microsoft Excel. The data from the results of the LCA study would be entered into the inventory data as quantitative data so that the input and output results were generated. Then an analysis of the impact of the inventory data was carried out into groups according to the emissions of pollutants released; GHG, acidification and eutrophication. The calculation method used formulations as described in ISO 14040 [7], IPCC [8], and BSN [22]. The interpretation stages were analyzed as quantitatively and descriptively which would be presented with graphs and tables, so that the results could easily be understood and the resulting comparisons could be seen.

3. Result and discussion
The biscuit wafer industry observed produced two types of wafer biscuits, flat-shaped and stick-shaped wafer biscuits. The process of making flat-shaped wafer biscuits was mixing dough, baking, cooling, cream coating, cooling, cutting, and packaging. While the process of making stick-shaped wafer biscuits was mixing the dough, baking, rolling, filling cream, cutting, and packaging. The waste water was treated by waste water treatment plant (WWTP). The WWTP consisted of equalizing tanks, sedimentation tanks, Imhoff tanks, aeration tanks, and sludge treatment.
3.1. Goal and scope of LCA

Based on observations of the material flow process contained in the industry, the purpose of this LCA was to analyze the potential environmental impact of wafer biscuit production, identify production inventory data, and analyze alternative improvements in efforts to reduce environmental impacts. The scope of this study was limited to the production process activities in the manufacturing industry of wafer biscuits (gate to gate) products. In addition, the environmental impacts assessed were GHG potential, acidification and eutrophication. The scope of the study can be seen in Figure 2.

![Diagram of the production process]

**Figure 2.** The scope of LCA of wafer biscuit production.

3.2. Inventory analysis

This stage contained the inputs and outputs produced during the life cycle of wafer biscuit products. The inputs analyzed included the raw material for making dough, the raw material for making cream, water and the energy needed, while the output produced were in the form of products, by-products and emissions. Inventory data was needed to be the basis for analyzing the impact produced and determining alternative improvements that could be done. The data used in the LCA study of the wafer biscuit production industry was the average input in November and December in 2017. The average input data is shown in Table 2.

### Table 2. The average input of raw materials per-month.

| Input            | Unit | Amount/month |
|------------------|------|--------------|
| Wheat flour      | Kg   | 22 821.60    |
| Sugar            | Kg   | 11 694.20    |
| Edible oil       | Kg   | 5 202.58     |
| Lecithin         | Kg   | 265.38       |
| Salt             | Kg   | 119.77       |
| Flavor           | Kg   | 168.30       |
| Skim             | Kg   | 959.84       |
| Starch           | Kg   | 410.73       |
| Maltodextrin     | Kg   | 2 384.20     |
| Food dye         | Kg   | 26.92        |
| Cold water       | L    | 32 150.00    |
Table 2 shows the energy used in the wafer biscuit making industry in the form of electricity and natural gas. The use of water served to wash the equipment while the refrigerant functions had to cool the water and the room. The resulting average output data is shown in Table 3.

### Table 3. The average output was produced per-month.

| Product or non product | Units | Type of Biscuit | Volume/month |
|------------------------|-------|-----------------|--------------|
|                        |       | Stick Wafer     | Flat Wafer   |
| Product                | Kg    | 9 891.37        | 29 535.70    | 39 427.07    |
| Broken                 | Kg    | 392.00          | 4 273.80     | 4 665.80     |
| Solid waste            | Kg    | 280.05          | 2 902.60     | 3 182.65     |
| Wastewater             | L     |                 | 75 850.00    |
| Sludge                 | Kg    |                 | 540.00       |
| Oil waste              | L     |                 | 100.00       |

### 3.3. Impact assessment

The impact assessment was needed in knowing the potential environmental impacts that could be caused. The inventory data obtained calculated potential emissions generated based on environmental impacts in the form of greenhouse gases, acidification, and eutrophication. The results of the analysis of the impact of the LCA on the production of wafers can be seen in Table 4.

### Table 4. The value of impact assessment of wafer production.

| Category of impact | unit          | Volume/month |
|--------------------|---------------|--------------|
| GHG                | kg-CO$_2$eq   | 59 775.73    |
| Acidification      | kg-SO$_2$eq   | 451.91       |
| Eutrophication     | kg-PO$_4$$_3$eq | 514.67      |

Based on Table 4, the highest impact produced by the wafer biscuit industry is the GHG, followed by the impact of eutrophication and acidification. Based on the calculation, the emission of one kg of wafer biscuits could produce GHG emissions of 1.5161 kg CO$_2$-eq/kg-products, acidification of 0.0115 kg-SO$_2$-eq/kg-product and eutrophication emissions of 0.0131 kg-PO$_4$$_3$eq/kg-product.

### 3.4 Greenhouse gas (GHG)

The greenhouse gas emissions produced by the wafer biscuit production industry came from CO$_2$, N$_2$O, CH$_4$ and HFC gases (Figure 3). The results of the calculation of GHG impact categories based on emissions produced can be seen in Figure 3 which show that CO$_2$ emissions contribute the most to GHG emissions, then CH$_4$, HFC, and N$_2$O emissions. The CO$_2$ emissions were generated from the use of electricity and natural gas. The CH$_4$ emissions were generated from the use of natural gas and the resulting degradation of sewage sludge and waste water. The HFC was produced from refrigerant which was used for cooling while N$_2$O emissions came from the use of natural gas.
3.5. Acidification
The acidification was caused by the presence of SO$_2$ and NOx gases in the atmosphere. During the air oxidation reaction occurs between SO$_2$ and NOx with water vapor producing acid rain [15]. The results of the calculation of the impact classification category based on emission sources in the biscuit wafer industry can be seen in Figure 4, where the SO$_2$ emissions produced are higher than NOx. Both SO$_2$ and NOx emissions were generated from the use of electricity and natural gas during the production process.

3.6. Eutrophication
Organic substances dissolved in water had an impact on the environment [16]. One of these organic substances was in the form of nitrogen and phosphate which could cause eutrophication [4]. The results of the calculation of the impact category of eutrophication based on the emission source at industry can be seen in Figure 5. PO$_4^{3-}$ emissions contributed the most to the eutrophication. PO$_4^{3-}$ emissions from waste water were generated during the production process. NOx emissions were generated from the use of electricity and natural gas.
3.7. Interpretation analysis

Based on the LCA result, there are four alternative improvements that could be done to reduce the impact on the environment (Table 5), as follow:

3.7.1. Use of solar water heater (SWH). Water heating could be done using a SWH equipment that utilizes solar energy. According to Frengky [17], the use of SWH was able to heat the water up to a temperature of 56°C. Based on calculations, the use of the SWH equipment can replace the electric heaters and reduce electrical energy consumption by 14%. The decrease in electrical consumption will reduce the impact of GHGs by 8%, acidification 13% and eutrophication 0.56%, respectively.

3.7.2. Change of type of refrigerant. The use of natural refrigerant was one alternative to reduce the impact on the environment, and One of the natural refrigerants was Hydrocarbons (HC). HC had a value of Ozone Depleting Potential (ODP) of zero with a low GWP value of 3 CO₂ eq [18]. In addition, the use of HC was only 30% of the use offluorocarbon refrigerant with the same engine and saved electricity usage by 20% [19]. The HC substitution will reduce the impact of GHGs by 19%, acidification by 13% and eutrophication by 0.57%, respectively.

3.7.3. Reuse of cooling water. The reuse of cooling water into washing water could reduce the amount of waste water produced by 35%. According to [20], the difference in heating temperature would affect the electrical energy used so that it reduced electrical energy by 12% of the total electricity usage. The reuse of cooling water will reduce the impact of GHGs by 7%, acidification by 11%, and eutrophication by 32%, respectively.

3.7.4. Improvement of wastewater management. The operational condition of waste water Treatment Plant (WWTP) was not optimal yet, however the effluent flowed to water bodies. The secondary treatment of aeration tank can be improved by utilizing the activated sludge process as reported by Sudaryati et al. [21]. The processing of activated sludge system could reduce the effluent parameter of COD 96.1% and BOD 95.92%. The application of this alternative can reduce the impact of eutrophication by 83.86%, but increase GHG by 4% and acidification by 0.17%. The increase in GHG and acidification impacts are caused by the active sludge system producing sludge that produce CH₄ gas.
Table 5. The calculating result of improvement alternative to environmental impacts.

| Alternative                        | Environmental impacts | units | Existing Emission (1) | Proposed improvement Emission (2) | Difference between (1) – (2) | Percent improvements (%) |
|------------------------------------|-----------------------|-------|-----------------------|-----------------------------------|-----------------------------|--------------------------|
| Use of solar water heater (SWH)    | GHG                   | Kg-CO₂(eq) | 59,775.73            | 55,278.37                        | 4,497.36                    | 8                        |
|                                    | Acification           | Kg-SO₂(eq) | 451.91               | 392.91                           | 59.00                       | 13                       |
|                                    | Eutrofikation         | Kg-PO₄³(eq) | 514.67               | 511.77                           | 2.90                        | 0.56                     |
| Change of type of refrigerant      | GHG                   | Kg-CO₂(eq) | 59,775.73            | 48,515.56                        | 11,260.17                   | 19                       |
|                                    | Acification           | Kg-SO₂(eq) | 451.91               | 392.79                           | 59.12                       | 13                       |
|                                    | Eutrofikation         | Kg-PO₄³(eq) | 514.67               | 511.76                           | 2.91                        | 0.57                     |
| Reuse of cooling water             | GHG                   | Kg-CO₂(eq) | 59,775.73            | 55,613.46                        | 4,162.26                    | 7                        |
|                                    | Acification           | Kg-SO₂(eq) | 451.91               | 402.66                           | 49.24                       | 11                       |
|                                    | Eutrofikation         | Kg-PO₄³(eq) | 514.67               | 348.92                           | 165.76                      | 32                       |
| Improvement of wastewater management| GHG                   | Kg-CO₂(eq) | 59,775.73            | 62,387.40                        | (2,680.67)                  | (4)                      |
|                                    | Acification           | Kg-SO₂(eq) | 451.91               | 452.66                           | (0.75)                      | (0.17)                   |
|                                    | Eutrofikation         | Kg-PO₄³(eq) | 514.67               | 83.06                            | 431.61                      | 83.86                    |

4. Conclusions
Wafer biscuit production activities produced environmental impacts such as greenhouse gases, acidification, and eutrophication. The results of the impact analysis showed that the highest impacts produced are GHG with CO₂, CH₄, HFC, and N₂O sources, Eutrophication with PO₄ and NOx sources, and acidification caused by SO₂ and NOx emissions. There were four alternative improvements to reduce the environmental impact: the use of SWH to reduce GHG, acidification and eutrophication, (2) the change in type of refrigerant to reduce GHG, acidification and eutrophication, (3) the use of cooling water to reduce GHG, acidification and eutrophication, and (4) improvement of waste management to reduce the impact of eutrophication.

LCA studies require comprehensive observations so that the measurement of environmental impacts could be properly identified. The interpretation phase requires further research to reduce the impact. In addition, the proposed interpretation still has not considered the economic aspects so there is a need for further calculations to consider the application of the alternatives provided.

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