Eco-efficiency analysis of waste cooking oil recycling into liquid dish soap using life cycle assessment

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Abstract. Waste Cooking Oil (WCO) is an oil with a chemical composition containing carcinogenic compounds formed during frying and unsaturated fatty acids. Improper handling of WCO can cause environmental pollution, especially water and soil. However, several studies have provided information that WCO can be recycled into products that are more value-added and have economic potential. Previous research has succeeded in finding the best combination of treatments for making soap from waste cooking oil that meets the standards of SNI 06-2048-1990, namely with a concentration of 22.5% KOH, cooling method and adsorption of activated charcoal and kepok banana peels. This study intends to analyze the environmental impact if WCO is recycled into liquid dish soap. The analysis was carried out using Life Cycle Assessment with the help of simapro software. The recycling process has the most significant impact on indicators of climate change and acidification. The eco-efficiency index is included in the affordable and sustainable categories.

1. Introduction
The management of used cooking oil that has not been optimal causes the amount of WCO discharged into the environment to be still high and dangerous [1]. Therefore, the management of WCO has become a public concern in recent years [2]. Based on a survey in Semarang, 90% of households and 67.6% of culinary businesses dispose of noodles into sewers, soil, or garbage [3]. WCO waste is spread throughout Semarang City [4]. WCO can damage the water and soil environment [5], damage aquatic communities [6] and endangers human health. The discarded WCO waste causes the economic potential not to be utilized [7]. From previous studies, WCO disposed of without going through a recycling process contains a compound with an ecotoxicity effect (freshwater) of 0.43 PAF.m3.day. This value is equivalent to an eco-cost of 2.39x10⁻⁶ euros [8].

WCO recycling can produce more valuable products. WCO contains unsaturated fatty acids such as oleic acid, linoleic acid and triglyceride acid, which can be utilized in oil-based products, such as solid or liquid bath soap [9]. Bath soap is a compound of sodium or potassium with fatty acids from vegetable oils or animal fats in solid, soft, liquid and foamy and is used as a cleanser [10]. WCO can be used as raw material for making liquid soap after being filtered to remove spices, neutralized with KOH and the bleaching process. Hartini et al. [8] have conducted an experimental design for making liquid dish soap with 12 treatment combinations. The combination of treatments gave different effects on each parameter used. The pH parameter is influenced by the method of manufacture and KOH concentration, where the
cold method and the concentration of KOH 22.5% produces a lower pH. The parameters of free alkali are influenced by the process of manufacture and the concentration of KOH, where the cold method and a concentration of 22.5% produces lower free alkali levels. Free fatty acids are affected by the manufacturing method and purification materials, where the cold method and activated carbon purification materials make lower free fatty acid values. However, very few studies still measure the environmental impact when WCO is recycled into soap.

This study aims to measure the environmental impact of the recycling process of WCO into soap, specifically liquid dish soap with banana peel as an adsorbent using Life Cycle Assessment (LCA). Based on a survey conducted in Semarang, people tend to choose dish soap as a WCO recycled product [3], [8].

2. Methodology

2.1. Life cycle assessment

LCA is one of the frameworks to estimate the environmental burden of a product/process in an environmental impact assessment study [11]. LCA is used to quantitatively analyze environmental impacts based on material/energy consumption and the waste generated. LCA includes four steps: definition of objectives and scope, life cycle inventory analysis, life cycle impact assessment, and interpretation.

2.1.1. Goal and scope. The Goal and scope include determining system boundaries, functional units and analysis period. Available units are references related to inputs and outputs [13]. The system boundary determines the unit of the process being analyzed. The analysis period significantly affects the LCA results because of the energy consumption during the operation phase. The accuracy of the data strongly influences LCA results.

This research aims to recycle WCO into liquid dish soap using kepok banana peel waste as an adsorbent and to measure the environmental impact of the process. The system studied includes recycling WCO into liquid dish soap, including the operation of depicting, purification, and soap making, Figure 1. The input is in the form of materials and energy used, while the output is soap products and the resulting waste. Calculations were carried out with the help of SimaPro 9.1.17 software using Ecoinvent 3.
2.1.2 Life cycle inventory (LCI). The LCI stage is the primary data collection and compilation activity, including input and output data. The data considered comes from the production system from the system determined at the goal and scope stage. The results of the LCI will be input to the LCIA. Table 1 is a Life Cycle Inventory table that shows the input and output of the WCO recycling process into liquid dish soap with kepok banana peel as adsorbent.

Table 1. The input and output of the WCO recycling process into liquid dish soap.

| Process          | Input          | Output          |
|------------------|----------------|-----------------|
|                  | Material       | Unit | Mass | Material | Unit | Mass |
| Despicing        | WCO            | g    | 112  | Residue  | g    | 12   |
|                  | WCO            | g    | 100  |          |      |      |
| Purification     | Banana peel    | g    | 100  | Banana peel waste | g | 127 |
| Soap making      | WCO            | g    | 100  | WCO      | g    | 73   |
| KOH 22.5 %       | g              | 73   | Liquid | g    | 360  |
| Aquadest         | g              | 77.5 + | Soap  |      |      |
| Food colouring   | g              | 2    | Soap waste | g | 17   |
| Fragrance        | g              | 2    |      |      |      |
| Electricity      | kWh            | 0.1488 | Emission | | |

2.1.3. Life cycle impact assessment (LCIA). The LCIA phase aims to estimate the effect of the product/process produced by the LCI phase and convert it into various impact categories. The LCIA method can be single-category or multi-category [12].

2.1.4. Interpretation. The interpretation phase analyzes and evaluates the results of the LCIA and draws some conclusions from the system under study.

2.2. Eco-efficiency

Eco-efficiency is one of the clean production strategies, where clean production is a preventive and integrated environmental management strategy that is continuously applied to the production process and product life cycle to reduce risks to humans and the environment [14]. The principle of eco-efficiency is the principle of material and energy efficiency to reduce environmental impacts.

Calculation of the eco-efficiency index (EEI) to determine the feasibility of the product/system based on ecological efficiency and economic efficiency. EEI is obtained by dividing the net value by eco-cost [17]. The product/system is said to be unaffordable when its value is less than 1. If the value ranges from 0-1, it is included in the affordable category. The product/system is included in the sustainable category if the value is more than one [13],[15],[16]. Eco-costs are "virtual" costs, i.e. costs of prevention and damage in free trade. The following is the equation used for eco-efficiency analysis [13], [18], [19].

\[\text{Net Value} = \text{Selling price} - \text{Production Cost}\]  

\[\text{EEI} = \frac{\text{Net Value}}{\text{Eco Cost}}\]  

The following parameter is the calculation of the eco-efficiency ratio (EER), which is the comparison between eco-costs and eco-indicators. The EVR calculation formula is described in equation 3.

\[\text{EVR} = \frac{\text{Eco cost}}{\text{Net value}}\]
Eco-efficiency ratio rate (EVR) is the final calculation of the eco-efficiency measurement. The EER calculation is obtained by subtracting the net value from the eco-cost value. The analysis of the EER rate is described in equation 4 [13].

\[
\text{EER rate} = (1 - \text{EVR}) \times 100\% \quad (2.4)
\]

3. Result and discussion

3.1. Life cycle assessment

The characterization of the impact category of the recycling process from WCO into dish soap with the adsorbent of kepok banana peel waste produced by Software Simapro is described in Table 2.

Table 2. The characterization of the WCO recycling process

| Impact Category                      | Unit          | Environment Impact |
|--------------------------------------|---------------|--------------------|
| Climate Change                       | kg CO₂ eq     | 3.19x10⁻¹          |
| Acidification                        | kg SO₂ eq     | 1.64x10⁻³          |
| Eutrophication                       | kg PO₄⁻⁻ eq   | 7.20x10⁻⁴          |
| Photochemical Oxidant Formation      | kg C₃H₄ eq    | 2.31x10⁻⁵          |
| Fine Dust                            | kg PM₂.₅ eq   | 9.07x10⁻⁵          |
| Human Toxicity                       | Cases         | 2.93x10⁻⁹          |
| Ecotoxicity (freshwater)             | PAF.M₃.day    | 9.89x10⁻¹          |
| Metals Scarcity                      | Euro          | 3.52x10⁻³          |
| Oil & Gas Depletion excl energy      | kg Oil eq     | 4.87x10⁻³          |
| Water Stress Indicator               | WSI factor    | 5.01x10⁻³          |

The normalization stage is a stage that aims to assess activities that contribute to environmental impacts. The results of normalization of impact categories from the WCO recycling process into liquid dish soap using kepok banana peel as an adsorbent produced from the output of Simapro Software are described in Table 3. The weighting stage has the same value as the normalization stage because the weighting factor is 1.

Table 3. The normalization of the WCO recycling process

| Impact Category                      | Normalization Factor |
|--------------------------------------|----------------------|
| Climate Change                       | 0.0370               |
| Acidification                        | 0.0144               |
| Eutrophication                       | 0.0030               |
| Photochemical Oxidant Formation      | 0.0002               |
| Fine Dust                            | 0.0027               |
| Human Toxicity                       | 0.0027               |
| Ecotoxicity (freshwater)             | 0.0006               |
| Metals Scarcity                      | 0.0035               |
| Oil & Gas Depletion excl energy      | 0.0039               |
| Water Stress Indicator               | 0.0050               |

The single score stage is a stage that aims to classify the value of the impact category of each process or activity. Based on the value of the single score, the processes or activities that most contribute to environmental impacts and damage can be seen. Table 4 is a single score for the impact category of the WCO recycling process into liquid dish soap using kepok banana peel adsorbent.
Table 4. Single score of the WCO recycling process into liquid dish soap.

| Impact Category                        | Single Score (Euro) | Single Score (IDR) |
|----------------------------------------|---------------------|--------------------|
| Climate Change                         | 0.0370              | 640                |
| Acidification                          | 0.0144              | 249                |
| Eutrophication                         | 0.0030              | 52                 |
| Photochemical Oxidant                  | 0.0002              | 4                  |
| Fine Dust                              | 0.0027              | 47                 |
| Human Toxicity                         | 0.0027              | 47                 |
| Ecotoxicity (freshwater)               | 0.0005              | 9                  |
| Metals Scarcity                        | 0.0035              | 61                 |
| Oil & Gas Depletion excl               | 0.0039              | 67                 |
| Water Stress Indicator                 | 0.0050              | 87                 |
| **Total**                              | **0.0730**          | **1,264**          |

The process of recycling WCO into liquid dish soap has an eco-cost value of IDR 1,264 for a 1-time process of 100 g of WCO into 360 g of liquid dish soap. This process has the most significant impact on the environment in the indicators of climate change and acidification. The use of electrical energy derived from fossil fuels affects the effect it causes.

3.2. Eco-efficiency index (EEI)

Analyzing eco-efficiency begins with determining the net value, which is determined by the product price and production costs. In this study, product prices and production costs are calculated for one product. The product's price is based on soap made from WCO with different adsorbents in the marketplace. The product price is 7500 IDR/unit. Production costs can be seen in Table 5. The recycling process can still get a profit of IDR 1,651. The calculation of production costs is carried out on a small scale with the assumption that it is carried out by the empowerment and family welfare group so that labour costs are assumed not to be incurred. The marketing strategy carried out is also still utilizing the marketplace, which does not require marketing costs. Referring to these assumptions, the WCO recycling process produces an eco-efficiency index of 1.31, which is included in the affordable and sustainable category. It means that it is feasible in economic and environmental aspects. The results of eco-efficiency are described in Table 6.

EEI increase can be done by increasing the net value or reducing production costs. The WCO recycling process using kepok banana peels produces an unattractive colour and odour. Thus, this research adds dyes and fragrances to produce dish soap that is more acceptable to consumers. The addition of materials causes additional production costs and environmental impact costs. To increase EEI, it is necessary to study the recycling of WCO by using adsorbents that produce dishwashing products with attractive colours and odours, such as coffee grounds.

When the recycling process is carried out on an industrial scale, professional workers are needed who must be paid. In addition, the right marketing strategy is required so that consumers can well receive the product. The recycling process carried out on an industrial scale will require equipment with a large capacity. It will affect the depreciation cost and the volume of products produced. Further research on the eco-efficiency of recycling WCO into liquid dish soap on an industrial scale is interesting in the following research.
Table 5. The production cost of liquid dishwashing soap.

| Item                        | Unit of Measure | Unit Cost (IDR) | Amount (unit) | Total Cost (IDR) |
|-----------------------------|-----------------|-----------------|---------------|------------------|
| A. Raw Material Cost        |                 |                 |               |                  |
| Oil filter paper            | Pcs             | 995             | 2             | 1,990            |
| Fragrance                   | mL              | 500             | 2             | 1,000            |
| Food colouring              | mL              | 133             | 2             | 267              |
| Potassium hydroxide         | kg              | 23,000          | 0.02          | 506              |
| Banana peel                 | kg              | 1,000           | 0.1           | 100              |
| Plastic packaging           | Pcs             | 1,000           | 1             | 1,000            |
| Waste cooking oil           | Litre           | 4,000           | 0.1           | 400              |
| Aquades                     | kg              | 900             | 0.35          | 315              |
| Subtotal                    |                 |                 |               | 5,578            |
| B. Equipment Cost           |                 |                 |               |                  |
| Hand blender                | Hour            | 18.06           | 1             | 18.06            |
| Scale                       | Hour            | 13.82           | 1             | 13.82            |
| Plastic container           | Hour            | 0.47            | 1             | 0.47             |
| SS spoon                    | Hour            | 0.11            | 1             | 0.11             |
| Syringe                     | Hour            | 1.50            | 2             | 3.00             |
| Gloves                      | Hour            | 1.20            | 2             | 2.40             |
| Subtotal                    |                 |                 |               | 38               |
| C. Labor Cost               | Hour            | 0               | 0             | 0                |
| D. Electricity              | kWh             | 1,352           | 0.17          | 234              |
| E. Marketing Cost           |                 |                 |               |                  |
| Total Cost (A+B+C+D+E)      |                 |                 |               | 5,849            |

Table 6. The result of eco-efficiency

| Price (IDR) | Production cost (IDR) | Net value | Eco cost | EEI | EVR | EER |
|-------------|-----------------------|-----------|----------|-----|-----|-----|
| 7,500       | 5,849                 | 1,651     | 1,264    | 1.31| 0.77| 23% |

4. Conclusion
The process of recycling WCO into liquid dish soap has the most significant impact on indicators of climate change and acidification. The eco-efficiency index has a value of 1.31 which means it is affordable and sustainable. This recycling process provides benefits that are greater than the costs of the environmental impact it causes. Future research is needed regarding the eco-efficient process of recycling WCO into liquid dish soap on an industrial scale. A study on the recycling of WCO using adsorbents from organic waste with an attractive aroma and colour is essential to increase eco-efficiency.

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