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Eco-efficiency Modeling in the Production of Alcohol Based on Data Envelopment Analysis

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ABSTRACT
Economic growth can be assessed through industrial development. However, problems arise regarding the discharge of waste into lakes or rivers, leading to biodiversity loss and endangering human health. A study conducted in the UK stated that small and medium enterprises (SMEs) were the largest contributor to waste and pollution. This was because they ignored the regulations governing environmental management. As happened in the Bekonang alcohol industry center, the waste from the alcohol production process polluted the Bengawan Solo tributary as the Water Supply Corporation (WSC). In order to overcome these problems, we need a measurement that can increase production efficiency. Eco-efficiency is a concept that combines efficiency and economy based on efficiency principles. The different models are proposed to measure the eco-efficiency of production, namely with a weighting system that aggregates environmental results. The Data Envelopment Analysis (DEA) enables aggregation without the need for subjective or normative judgments about weights. Although DEA does not require subjective or normative judgments, weight restrictions can be incorporated into the framework. The purpose of this study was to determine the eco-efficiency of the Bekonang alcohol production process using the economic results of the production process and the environmental impact assessed through a life cycle assessment (LCA). There were three products, namely 30% alcohol for consumption, 90% alcohol for medical purposes, and hand sanitizer. The environmental impact was assessed from a life cycle assessment, while the economic assessment was determined by calculating the net profit for each product at a capacity of 100 liters/day. Economic assessment can be divided into two perspectives, namely the Social Perspective (SP) and Company Perspective (CP). From the modeling results, the most eco-efficient production process was hand sanitizer with an eco-efficiency value of 1.

Keywords: eco-efficiency, DEA, alcohol, economic value-added, environmental impact

ABSTRAK
Pertumbuhan ekonomi dapat dinilai melalui perkembangan industri, tetapi masalah muncul terkait pembuangan limbah ke danau atau sungai yang menyebabkan hilangnya keanekaragaman hayati yang membahayakan kesehatan manusia. Penelitian yang dilakukan di Inggris menyatakan, jika penyumbang limbah dan polusi terbesar adalah dari usaha kecil menengah (UKM), karena mereka mengabaikan peraturan yang mengatur tentang pengelolaan lingkungan. Seperti yang terjadi di sentra industri alkohol Bekonang, limbah hasil proses produksi alkohol mencemari anak sungai Bengawan Solo sebagai suplai air PDAM. Untuk mengatasi masalah tersebut diperlukan suatu pengukuran yang dapat meningkatkan efisiensi produksi. Eko-efisiensi merupakan konsep yang menggabungkan efisiensi dan ekonomi berdasarkan prinsip efisiensi. Model yang berbeda diusulkan untuk mengukur eko-efisiensi pada suatu produksi, yaitu dengan sistem pembobotan yang mengagregasi hasil lingkungan. Analisis data envelopment analysis (DEA) memungkinkan agregasi tanpa membutuhkan penilaian subjektif atau normatif pada bobot. Meskipun DEA tidak memerlukan penilaian subjektif atau normatif, pembatasan bobot dapat dimasukkan ke dalam kerangka kerja. Tujuan dari penelitian ini adalah untuk mengetahui nilai eko-efisiensi proses produksi alkohol Bekonang, menggunakan hasil ekonomi dari proses produksi dan dampak lingkungan, yang dinilai melalui life cycle assessment (LCA). Terdapat tiga produk yang dianalisi, alkohol 30% untuk konsumsi; alkohol 90% untuk keperluan medis; dan hand sanitizer. Dari hasil pemodelan yang telah dilakukan, proses produksi yang paling eko-efisien adalah hand sanitizer dengan nilai eko-efisiensi adalah 1.

Kata kunci: eco-efisiensi, DEA, alkohol, nilai tambah ekonomi, dampak lingkungan

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1. Introduction

Industrial development is considered an important aspect of economic growth. However, new problems arise as the industry grows rapidly. Many industries produce various types of hazardous waste, and it becomes an important issue when industrial discharge is carried out into lakes or rivers, causing loss of

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biodiversity and endangering human health. The types of hazardous waste produced by industry include heavy metals, cyanide, pesticides, paints, colored substances, oils, solvents, and other hazardous chemicals (Kurniawan, 2019).

According to Hillary (2000), the largest contributor to waste and pollution is Small and Medium Enterprises (SMEs). The environmental impact of SMEs is largely unknown but has a significant impact. A UK study showed that SMEs account for 70% of all pollution and waste. Government environmental agencies ignore most SMEs, so they are not aware of the laws governing environmental impact management and are indifferent to the rules made by the government that can actually help them improve environmental performance. In addition, SMEs are also difficult to reach, mobilize, or be involved in any improvements related to the environment (Hillary, 2000).

In Central Java, precisely in Sukoharjo Regency, Bekonang, Mojolaban, there is an alcohol industry center consisting of 50 SMEs and capable of producing 1000-1500 liters of alcohol/day (Nurcahyani and Utami, 2015). Alcohol SMEs in Bekonang has existed since 1961 and are a hereditary business. In addition, this industry has received a permit from the Indonesian trade office in 1987. Alcohol production in Bekonang has a positive impact; from an economic aspect, the total investment of alcohol production SMEs in Bekonang reaches 1 billion, with a total production of 708,035 liters/year. From a social perspective, this industry is able to absorb labor for the surrounding community. In 2019, the total number of workers consisting of men and women was 83 people (Department of Industry and Manpower of Sukoharjo, 2019). The raw materials for alcohol production do not have to be imported and obtained from sugar factories around Java. The products produced by alcohol SMEs in Bekonang are 30% alcohol for consumption, 90% alcohol for medical purposes, and hand sanitizers.

However, some time ago, the Bekonang alcohol waste polluted the Bengawan Solo river as a water supply for the Regional Drinking Water Company. It was estimated that liquid waste discharged into the Bengawan Solo river reached 114.6 m^3 per day, while the number of SMEs with a waste disposal permit was only 21%. Actually, liquid waste disposal can be channeled and processed at the Waste Water Treatment Plant (WWTP), but alcohol SMEs threw it into the river due to lack of processing capacity. The solution from the local government had actually been planned, but because the technology designed was not optimal to filter the waste, the project was finally delayed.

Therefore, we need a solution that can increase production efficiency, limited by strict environmental regulations. Eco-efficiency is a measurement of environmental performance by combining economic performance. Eco-efficiency analysis links the two pillars of sustainability, the economic and environmental pillars, and links economic and environmental efficiency (Cramer, 2000; Huppes and Ishikawa, 2005; Schmidheiny & Stigson, 2000; Suh et al., 2005).

Eco-efficiency is the ratio of economic value-added to environmental impact or the ratio between environmental value-added and economic costs. Eco-efficiency has been widely applied in environmental research combined with other measurement methods, such as Data Environment Analysis (DEA) (Kuosmanen and Kortelainen, 2005; Liu et al., 2010). Combining the DEA and eco-efficiency models makes it possible to integrate unwanted outputs in measuring the productive technical efficiency of DEA, which is a nonparametric methodology for assessing the relative eco-efficiency of a Decision-Making Unit (DMU) with multiple inputs and outputs (Charnes et al., 1978).

DEA has been proposed to combine impact categories to construct an eco-efficiency index. The first proposal for aggregation using DEA is to measure eco-efficiency by definition (economic value-added/environmental damage) from Kuosmanen and Kortelainen (2005). In their paper, Kuosmanen and Kortelainen (2005) argued that the DEA could provide methods such as using a specific weight model based on evaluation or subjective assessment. DEA identifies the weight that maximizes the efficiency score of the units of activity being evaluated compared to groups of formally similar units.

In this study, DEA modeling would evaluate eco-efficiency in Bekonang alcohol SMEs at a capacity of 100 liters/day for each product. The model from Sanjuan et al., (2011), which adopted the model from Kuosmanen and Kortelainen (2005), was used in this study. The model integrated the economic output of the production process and its environmental impact in an eco-efficiency index. The purpose of this study was to determine the eco-efficiency value of Bekonang alcohol SMEs using the economic results of the production process and the resulting environmental impacts using a Life Cycle Assessment (LCA). Both types of measurement were integrated with the eco-efficiency ratio through a weight estimation model based on DEA.

2. Conseptual Framework

Based on the literature review of the study that has been done, the definition of eco-efficiency can be denoted as the ratio of economic value-added/environmental damage (Schmidheiny and Zorraquin 1996; Helminen 2000). In a study conducted by Kuosmanen and Kortelainen (2005), value-added is defined as total income minus intermediate input costs. Meanwhile, labor costs and capital inputs are not included in intermediate input costs because these costs are incurred by the company and are income for the community, which implies a social point of view. Meanwhile, according to Sanjuan et al. (2011), value-added is net income in the company's production process, including considering labor costs and capital inputs concerned with profit (See Figure 1).

Sanjuan et al., (2011) also mentioned that the economic assessment of value-added can be seen from two perspectives, the Company Perspective (CP) as carried out in his study and the Social Perspective (SP), which refers to the study of Kousmanen and Kortelainen (2005). Therefore, in this study, economic value-added can be seen as CP and SP to determine the effect of economic factors on the assessment of the eco-efficiency of the alcohol industry in Bekonang. This is also in line with the definition of eco-efficiency according to the WBCSD (2000), where the numerator of the eco-efficiency ratio, namely economic value-added, is a broad concept, so it needs to be interpreted differently. Based on Figure 1, economic value-added as an independent variable that affects the dependent variable is eco-efficiency.

3. Method

3.1. Goal and Scope

This step helped the consistency of the LCA research, which included a definition of the study objectives, a description of the alcohol production process, and the definition of functional units and system boundaries. In this study, the approach used was cradle-to-gate, which assessed the partial product life cycle from resource extraction (cradle) to gate (before it reached the consumer). This study aimed to measure the value of eco-efficiency in the alcohol production process in Bekonang.

3.2. Economic Assessment

The economic assessment was obtained from the variables of income and production costs to estimate the value-added of the economy as net profit in one production because there was no special bookkeeping related to sales data for a certain period. Revenue came from product sales, namely: 30% alcohol, 90% alcohol, and hand sanitizer.

The economic assessment was divided into two perspectives based on the conceptual framework, the social perspective (SP) and the corporate perspective (CP). SP was the total revenue minus intermediate input costs, where according to the Indonesian Central Bureau of Statistics, intermediate input costs were costs incurred related to the manufacturing industry production process in the form of raw and supporting materials, energy, other costs, excluding labor costs, which would produce output. In contrast, CP was the net income that implied profit for the company. In contrast to PS, the net income variables in PP included labor costs and company capital. However, the measurement of capital at the level of small and medium enterprises was very difficult and made the study ignored.

Production costs consisted of capital, labor, energy, furnace usage depreciation, and the price of material inputs. These costs were explained as follows:

- Labor costs were determined by considering the number of workers and hours worked, which were obtained from the owner of the alcohol business house.
- Energy costs came from electricity, used for water consumption as a material for the production process. The cost was calculated based on electricity consumption each month. In addition, other energy costs were firewood for the distillation process, namely purifying the alcohol after the fermentation process. The data was obtained from the owner of the alcohol business house.
- Furnace usage depreciation cost was determined from the value of the new equipment price and depreciation model, where the value decreased every year. Information on the value of new equipment and the length of its life was obtained from the owner of the alcohol business.
- The cost of raw materials used in producing alcohol were molasses, yeast, residual distillate water, NaOH, and water. The molasses were obtained from a sugar factory in East Java at IDR 3,000/kg. Meanwhile, 90% alcohol was added with other raw materials such as sorbitol, CMC, glycerin, and fragrance to make hand sanitizer. The data was obtained from the owner of the alcohol business house.

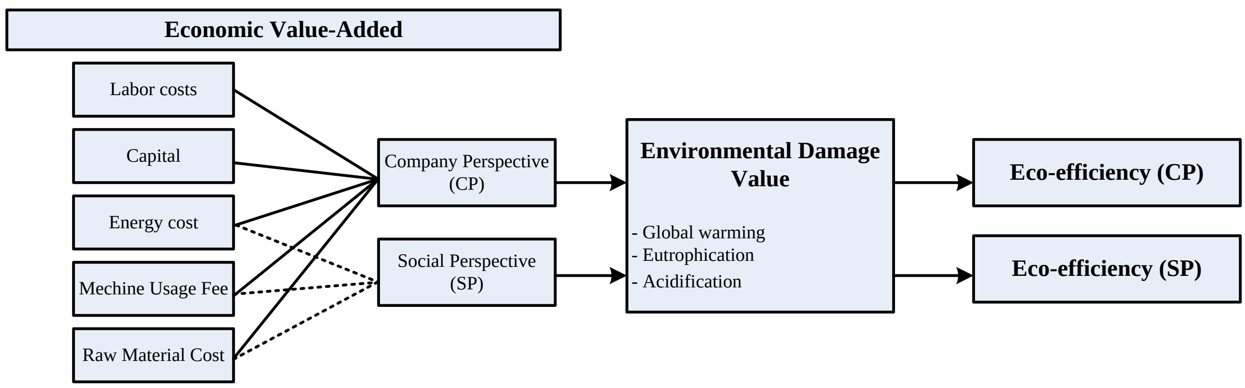

Figure 1 Conseptual Framework

3.3. Environmental Impact Assessment

This step aimed to measure the environmental impact of the alcohol production process in Bekonang using LCA. Then, collecting Life Cycle Inventory (LCI) data such as types of raw materials used, machine usage, energy use, product specifications, and waste generated. Inventory data was used for environmental assessment of the alcohol production process in Bekonang and obtained from home business owners.

After all data had been collected, the next step was LCA analysis using SimaPro v.7.1.8 software to evaluate environmental impacts. After being evaluated, the last step was interpreting the results of the Life Cycle Inventory Analysis (LCIA).

In a study conducted by Kuosmanen and Kortelainen (2005), the term in the LCIA analysis is environmental pressure, not measuring the final impact, because it is very complex and difficult to predict. Meanwhile, a study by Sanjuan et al., (2011) referred to the same concept, but the term used is the category of environmental impacts, as in the terminology of ISO 14042 (ISO, 2000). The impact category can be defined as a class representing environmental problems resulting from a predetermined life cycle inventory.

The environmental impact category analysis method used the Environmental Design of Industrial Products (EDIP) 2003 method. The EDIP 2003 was an update from the previous EDIP'97. The EDIP 2003 method focused on industrial activities, particularly on the category of impacts to the air. In the 2003 EDIP database, there were seven impact categories, with each having another impact sub-category, but only three impact categories were analyzed on the alcohol production process, namely global warming (kg CO_2 eq), eutrophication (kg P eq), and water ecotoxicity (acute) (m^3). Other impact categories were not analyzed because the production process depended on energy consumption, such as global warming and the effect of liquid waste generated.

3.4. DEA Modeling

The DEA modeling in this study was used to integrate the results so that an index was obtained that served as a basis for comparing products or processes both from an environmental and economic perspective. The key point in the integration of outcomes was the multiple categories of impacts expressed with different units of measurement. To overcome this complexity, a weighting method was needed. The weight assigned to the impact category was very important in the final score obtained.

The DEA was usually used to estimate technical efficiency measures. As previously mentioned, the model developed by Kuosmanen and Kortelainen (2005) was the first study to use DEA to measure eco-efficiency by definition. The definition of efficiency in DEA was based on the engineering concept of total factor productivity, which was determined as the ratio of the number of weighted outputs to the number of weighted inputs of production units (Allen et al., 1997). The numerator ratio was the output, which is the value of the production process as economic value-added. For the denominator, it is defined as an input, a linear function of environmental damage, which is denoted as follows:

$$D(Z) = w_1 Z_1 + w_2 Z_2 + \cdots + w_m Z_m \qquad (1)$$

with a weight in determining environmental problems (w) from various environmental impacts (Z) categories. The variable Z stands for the environmental impact category, not the unwanted output measure in the technical efficiency measure. In contrast to economic inputs and outputs, the environmental impact category has no other price or weight.

The DEA eco-efficiency value of the alcohol production process in Bekonang for product n can be calculated by the following equation.

$$\max EE_n = \frac{Vn}{D(Z)}$$
$$\max EE_n = \frac{V_n}{w_1 Z_{1n} + w_2 Z_{2n} + w_3 Z_{3n}}$$

Limitation

$$\frac{V_1}{w_1 Z_{11} + w_2 Z_{21} + w_3 Z_{31}} \leq 1$$
$$\frac{V_2}{w_1 Z_{12} + w_2 Z_{22} + w_3 Z_{32}} \leq 1$$
$$\frac{V_3}{w_1 Z_{13} + w_2 Z_{23} + w_3 Z_{33}} \leq 1$$
$$w_1, w_2, \ldots, w_n \geq 0 \qquad (2)$$

Where:

n : each product n
V_n : net income for each product
$w_{1,2,3}$: weight of environmental impact category
$Z_{1,2,3}$: impact category value

The environmental impact category had the same value for both perspectives. According to Sanjuan et al., (2011), the implemented model does not consider the economic dimension, so it is possible to warn against an object being analyzed only considering environmental impacts.

The mathematical modeling of the above equation shows that the unknown weights w_1, w_2, and w_3 can be solved using a standard linear program with Lingo 18 software. Meanwhile, the eco-efficiency value can be obtained from the inverse or inverse of eco-efficiency.

3.5. Interpretation Result

The optimal solution of eco-efficiency modeling with DEA in the Bekonang alcohol industry center was to identify w_1, w_2, and w_3 weights for each impact category as unknown model variables to maximize the eco-efficiency ratio of each product. According to Kuosmanen and Kortelainen (2005), the eco-efficiency ratio of DEA is analogous to the engineering definition of efficiency, where the maximum value of the eco-efficiency score is one (or 100%). Thus, the eco-efficiency ratio of each product should not exceed one at any weight. Since the weights were constrained to be non-negative, the eco-efficiency ratio was always between 0 and 1, where a high value indicated good performance. Meanwhile, the eco-efficiency score was considered eco-efficiency if it was equal to one (eco-efficiency = 1); if it was less than one (eco-efficiency <1), then it was considered not eco-efficiency.

4. Result and Discussion

4.1. Economic Assessment

The economic assessment was obtained variables related to production costs and selling prices to estimate net income from both perspectives, namely Social Perspective (SP) and Company Perspective (CP), at a capacity of 100 liters/day for each product. Revenue came from sales of roducts, with the quality of the raw materials assumed to be the same because they were not included in the study. The production costs came from capital, labor, energy, material inputs, and machine depreciation costs. The capital was not included in the calculation of income because it was very difficult to measure it. Additionally, this business was hereditary. Labor costs assumed in one month are 25 days, with the specified wage being daily.

The main cost came from material input, namely molasses as the main material input; other input materials such as distillate residual water and yeast did not incur costs because the distillate residual water was obtained from the rest of the previous process. Meanwhile, yeast was obtained from the previous production that has been bred. The selling price for 30% alcohol was IDR 20,000/liter, and 90% alcohol was IDR 35,000/liter. In the hand sanitizer production process, the main ingredient used was 90% alcohol by mixing other supporting ingredients such as glycerin, sorbitol, CMC, and fragrance. For every two liters of 90% alcohol, 10 bottles of hand sanitizer would be produced with a volume of 250 ml and sold for IDR 25,000/bottle.

Energy costs came from the use of electricity for water consumption and firewood for heating in the distillation process. Electricity costs were determined based on electricity tariffs and fixed costs. Fixed costs were determined by the amount of power used by the water pump.

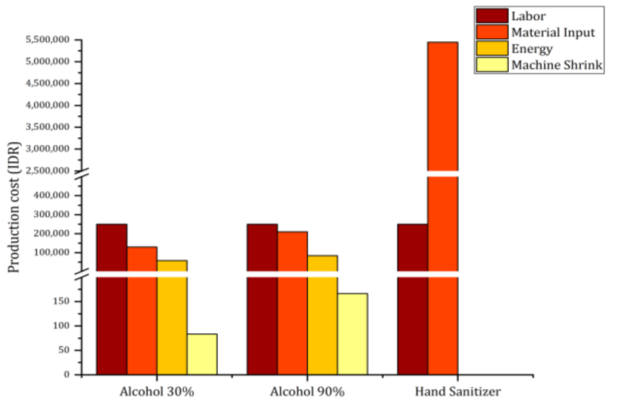

Figure 2 Cost of production

The need for firewood for each furnace was 122,772 kJ. The depreciation cost of the machine, namely the furnace used for heating in the distillation process, has decreased costs by 5% per year, with the life of the furnace being 5 years. Figure 2 shows the distribution of production costs for each product; as already mentioned, material input costs are the largest costs of other costs.

4.2. Environmental Impact Assessment

The data collection results obtained at the LCI stage were analyzed using SimaPro v.7.1.8 software and the Environmental Design of Industrial Products (EDIP) 2003 analysis method. The LCI data for each product is presented in Table 1. The next stage was to interpret the results of data processing, commonly called LCIA, which aimed to understand and evaluate the magnitude of the environmental impact of each product throughout the product life cycle. The environmental category impacted generated by the 2003 EDIP method were seven impact categories. However, this study focused on the impacts that affected energy consumption, such as global warming, in addition to the presence of liquid waste pollution in the Bengawan Solo river. Therefore, an ecotoxicity analysis was needed to determine how much liquid waste was generated in each production.

Global warming was the emission of greenhouse gases associated with climate change. A measure of how much energy was absorbed by the emission of 1 tonne of gas in a given period of time, relative to the emission of 1 tonne of CO_2 gas. The higher the global warming, the more gases that warm the earth due to CO_2 trapped in the atmosphere. The global warming potential factor was expressed in different timescales of the year, but the most common was 100 years (GWP_{100}), measured in kg CO_2 equivalent reference units.

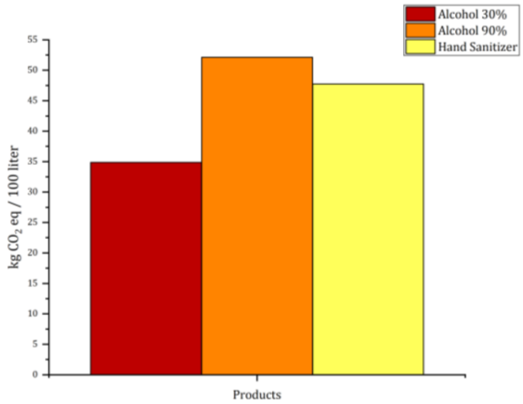

Figure 3 Results of global warming analysis

Figure 3 shows that the 90% alcohol production process is the one that produces the highest global warming, followed by hand sanitizer and 30% alcohol. In the production of alcohol, the distillation process was traditionally carried out using firewood, which caused carbon emissions. Besides being relatively cheap and easy to obtain, firewood was an energy source that was not environmentally friendly.

Reporting to wood-energy.extension.org, the combustion reaction would produce heat and emissions in water, organic steam, gases, and other particles. The most produced emissions were carbon monoxide (CO), carbon dioxide (CO_2), sulfur oxides (SO_x), and nitrogen oxides (NO_x). Other components formed were mercury and HCl but in very small amounts. The composition and amount of emission depended on the combustion temperature; if the temperature were high, the combustion would occur completely and produce cleaner emissions (up to 1300°C). At low-temperature combustion, emissions can include volatile organic compounds with a relatively high CO content (a product of incomplete combustion) and produce other particulates.

Eutrophication was the build up of chemical nutrient concentrations in an ecosystem that led to abnormal productivity. This leads to the overgrowth of plants such as water hyacinth in rivers, decreasing water quality and animal populations. Emissions of ammonia, nitrate, nitrogen oxides, and phosphorus into air or water all impacted eutrophication (Acero et al, 2016).

Figure 4 shows that the category with the greatest eutrophication impact results from the 90% alcohol production process because the input material used is more than 30% alcohol production. In addition, the energy consumed is also greater than 30% alcohol because, in the production process, 90% of alcohol goes through a two-time distillation process. For the hand sanitizer production process, the impact categories that result in eutrophication are CMC, glycerin, and bottles, with a total value of 5.5788×10^{-5} kg P eq.

Table 1. The LCI data on the analysis of the alcohol production process in Bekonang

Cost	Unit	Product (100 liter/day)		
		Alcohol 30%	Alcohol 90%	Hand Sanitizer
Labor	People	2	2	2
Cane drops	kg	40	60	0
Distillate Residual Water	kg	53.33	80	0
Yeast	kg	46.67	70	0
Water	kg	33.33	50	0
NaOH	kg	0.67	2	0
Sorbitol	kg	0	0	0.0745
CMC	kg	0	0	0.01
Glycerin	kg	0	0	0.252
perfume	liter	0	0	0.08
Bottle	pcs	0	0	400
Alcohol 90%	liter	0	0	80
Firewood	kWh	122.772	122.772	0
Electricity	kWh	0.0444	0.0667	0
Machine shrinkage	per day (Rp)	83.33	166.67	0

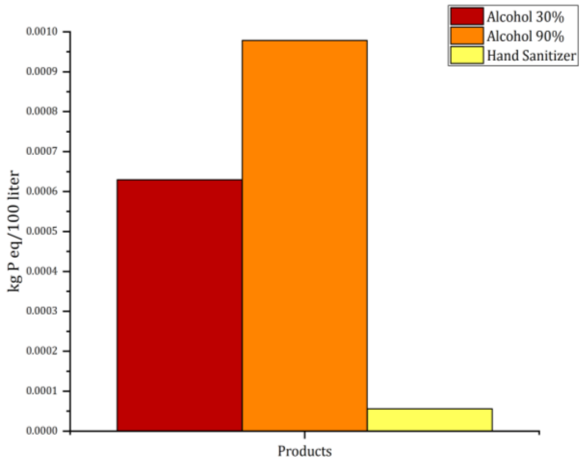

Figure 4 Results of eutrophication analysis

Environmental toxicity was measured in three different impact categories, namely fresh water, marine and soil. The emission of some substances, such as heavy metals, can impact the ecosystem, and this assessment was based on the maximum tolerable concentration in the water for the ecosystem. In the EDIP 2003 analysis method, ecotoxicity was based on the chemical screening method, which looked at toxicity, persistence, and bioconcentration. The distribution of the substance to the environment was also taken into account. Ecotoxicity potential was calculated for acute and chronic ecotoxicity to water, but this study only discussed acute ecotoxicity, which had a significant value compared to chronic level measurements.

Figure 5 shows that the ecotoxicity of water for the 90% alcohol production process is the highest, followed by 30% alcohol, then hand sanitizer. This happened because of the large use of chemical input materials used during the process. The water ecotoxicity analysis aimed to monitor environmental conditions and assess the risk of chemicals on the quality of water used by humans and predict the impact of pollutants on the ecosystem.

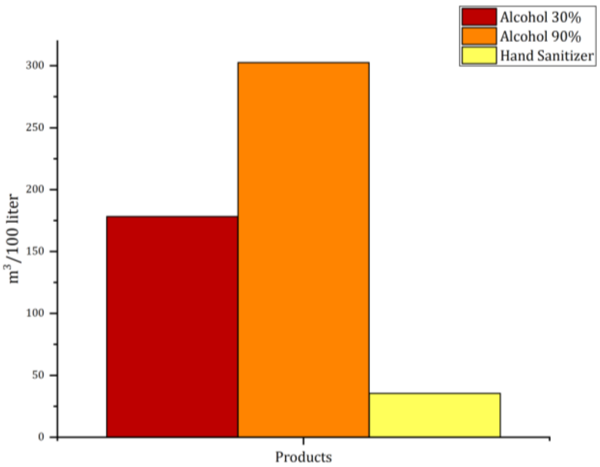

Figure 5 Results of ecotoxicity water analysis

4.3. Integration of DEA Results

The calculation of the DEA eco-efficiency value by solving the linear programming problem has been presented in the previous chapter. The model presented by Kousmanen and Kortelinen (2005) and adopted by Sanjuan et al., (2011) was applied to calculate the eco-efficiency of the three products in the Bekonang alcohol industry center. Two different measures of economic value-added were calculated for each product, resulting in two perspectives, a Social Perspective (SP) and a Company Perspective (CP), with economic value-added as the numerator of the eco-efficiency ratio. Meanwhile, the environmental impact category was the denominator of the eco-efficiency ratio for both perspectives of the DEA model.

Based on the value of eco-efficiency with DEA, it can be determined which DMU was eco-efficient and not eco-efficient. The eco-efficiency value always lied between 0 and 1, with the highest value indicating good performance. The eco-efficiency value was equal to 1 (eco-efficiency = 1). It means that the scenario was relatively eco-efficient, while the eco-efficiency value was less than 1 (eco-efficiency < 1), not eco-efficient (see Table 2).

The SP model obtained an average eco-efficiency ratio of 0.642, compared to an average eco-efficiency ratio of 0.709 for the CP model. The difference results were obtained for the SP and CP models because the numerator did not include labor costs in the PS model, which reduced the variability in economic results and therefore created a discrepancy. A study conducted by Sanjuan et al., (2011) analyzed eco-efficiency in the manufacture of the cheese industry. The eco-efficient process scenario and the value of certain environmental impact categories were high. Thus, the choice of several environmental impact categories in one case study would differ from one another to the environmental impact category, which can be added by using several scientifically reasonable conversion factors. However, in this study, if the value of the environmental impact category was high, the eco-efficiency value tended to be low.

The classical DEA model builds an efficient constraint with the efficient units analyzed. In this case, the eco-efficiency of the production process was the limit, so that the eco-efficiency ratio can be interpreted as the distance to that limit. Of the three products, hand sanitizer was the most eco-efficient for all perspective models. Meanwhile, all perspective models were not eco-efficient for 30% and 90% alcohol production processes.

Table 2. Eco-efficiency rasio

Products	CP	SP
30% alcohol	0.545	0.497
90% alcohol	0.381	0.629
Hand Sanitizer	1.000	1.000

The data source is processed from software

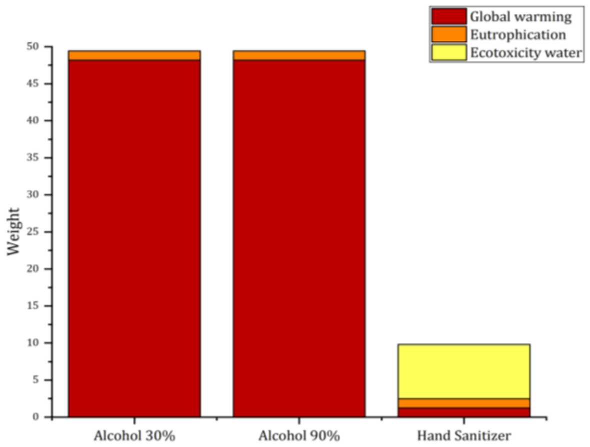

Figure 6 Weighting of impact category for CP

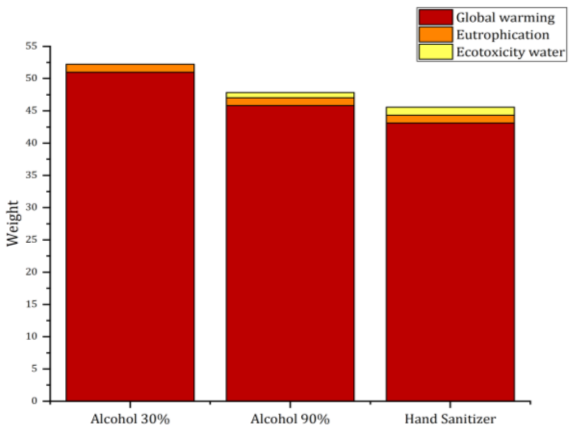

Figure 7 Weighting of impact category for SP

For the 30% alcohol production process, it can reduce all environmental impact categories by 50.27% = (1-0.497)×100% for CP and 45.47% for SP, and for 90% alcohol production process, it can reduce impact categories by 37.05% for CP and 61.93 % for SP. This showed that the opportunity in reducing the impact category with the current production process was still relatively lacking but can still maintain a net profit.

In addition to analyzing the results of the eco-efficiency of the three products, the weights based on impact categories can also be analyzed. According to Singgih and Chandra (2008), after calculating modeling in DEA, it is necessary to analyze variables that aim to determine the weight value generated by the model for each variable. The weights for each impact category in the two perspective models can be seen in the following below:

From Figures 5 and 6, it can be seen that the dominant weight for each product is global warming and shows that the distribution of weights is uneven. This happened because the value was the result of processing through a linear program for each impact category. Thus the weight of the impact category analyzed in this study was only used to estimate the eco-efficiency ratio for certain products. It was also confirmed by Kousmanen and Kortelinen (2005) in their research which analyzed the eco-efficiency of road transport in industrialized countries. It was difficult to explain some of the generally accepted weights that reflect the relative importance of the environmental impact categories. Because the environmental impact category measurement can be measured with one indicator, it can be aggregated based on the relative damage impact in other case studies. In contrast, aggregate stresses on different environmental themes require normative assessments of the severity of different types of damage to environmental impact categories.

In CP, the weight category for the impact of global warming for alcohol was 30% and 90%, the value was large, but the value was small for hand sanitizer. The weight of the environmental impact category on SP was also the same, where global warming was the largest for the three products. This means that the variable that got a large weight value had a large contribution or influence on the DMU's eco-efficiency. Meanwhile, the other impact categories, eutrophication and water ecotoxicity gave a small impact category for all products, even zero. This means that a product that produced a small weight value had a small effect on the DMU's eco-efficiency and a product that gave a zero value had no effect on the DMU's eco-efficiency. Although the interpretation of weights was highly specialized, it may be unrealistic or even politically acceptable, where it can be used to make decisions that represent an appropriate and profitable process.

According to Sanjuan et al., (2011), the use of weights in determining eco-efficiency can support a production process that performs well if the weight value is large, even though the same production process performs poorly on other impact categories. To avoid unbalanced weights, Wong and Beasly (1990) suggested limiting the flexibility of the weights by setting a minimum share of each impact category weight. Because the DEA modeling in this study did not estimate a common weight for a particular environmental impact, it was controversial because experts usually used a fixed set of weights. Although stakeholders easily understood the general weights in making policies, the general weights were often subjective. Therefore, limiting the weight of environmental impact categories by obtaining expert opinion can be done through several criteria decision-making techniques, such as the Analytical Hierarchy Process (AHP). With the AHP method, the new model would include the agreed limits, even though the model did not estimate the same weight, but the model had a fixed range. The new model would also consider stakeholder views in making better decisions because it would approach a set of agreed weights and remain objective.

5. Conclusion

With DEA modeling as a method for measuring eco-efficiency, it can accommodate various wanted and unwanted production effects into a single efficiency index. DEA does not require a priori weighting for various environmental impact categories, unlike other eco-efficiency methods. However, normative and subjective judgments of weights can be easily incorporated into the model framework.

From the LCA results, it can be concluded that the most eco-efficient production process is hand sanitizer, while for 30% and 90% alcohol, it is still necessary to reduce the environmental impact by more than 50%. The use of material and energy inputs has a major impact on the impacts.

According to the concept from WBCSD, the eco-efficiency ratio numerator is created based on the product's value. Product value is a broad concept and can be read in different ways. The use of economic value-added, taking into account the Social Perspective (SP) and the Company Perspective (CP) with a small difference in eco-efficiency results. Considering that eco-efficiency is the company's contribution to sustainability, the use of CP is more considered to analyze eco-efficiency with real results.

It is important to determine the need to develop and define methodologies for evaluating eco-efficiency in production processes. This methodology can be used to decide how to incorporate new techniques as economic and environmental perspectives are considered. In addition, it can also be used to consider other stages of the life cycle, such as waste treatment, which can increase the eco-efficiency of a production process.

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