Analysis of the eco-efficiency level in the dining table production process using life cycle assessment method to increase industry sustainability

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Abstract. This study aims to measure the environmental costs (eco-cost) and the level of eco-efficiency of the production of the dining table in the Jepara furniture industry and formulates recommendations to improve eco-efficiency. The measurement of eco-efficiency was performed using life cycle assessment (LCA) with the eco-cost method. The furniture manufacturer produces waste of 30% and the product reject 15%. The result of the data processing shows that the eco-costs of IDR 134,000 per unit product and net value IDR 208,000. The eco-efficiency index or EEI is 1.55 which means that the products categorized as affordable and sustainable. The eco-efficiency level is 35% means that the environmental performance is low and the furniture production needs improvements in the production process. Strategy to improve the eco-efficiency of production is increasing the utilization of wood waste and increasing the capability of technicians and operators to reduce the product defect.

1. Introduction
The industry's development has brought many changes to environmental damage. The environmental impacts occur throughout the life cycle of a product, starting from the extraction of natural resources as raw materials, the production process, the use and reuse of products and finally to the disposal stage [1]. To create a sustainable industry and product, the use of renewable natural resources must be combined with a large reduction in environmental impacts such as greenhouse gases. Sustainable Development tries to give a new discourse about the importance of preserving the natural environment for the future. Jepara is a furniture industrial cluster located at Jepara, Central Java province. The furniture industries in this area already used the wood legality verification system certification. The regulation requires companies to use only the legal wood in their production process.

Dining table production per month reaches 246 units with a finished product volume of 15.8 m³. LCA considers materials taken from nature as production inputs and materials released into nature as output from the production process. The use of wood as an input material according to LCA contributes to climate change because trees are producing oxygen and absorbing carbon dioxide. The industries also produce waste in the form of small pieces of wood, sawdust and wood chips. The production process used electrical machinery, LCA takes into account coal burning that occurs to produce electricity as CO2 production and has an impact on climate change. The use of chemical materials for the finishing process contribute to human toxicity in certain amount define by LCA characterization. The interview with the industry management said that they have not planned how to handle the waste to reduce the impact of it to the environment. Therefore, measurement of eco-efficiency of the production process is needed to determine the level of the environmental impact of the production process.

Eco-efficiency is a strategy that combines the concepts of economic and ecological efficiency in the use of natural resources. Eco-efficiency is defined as a production process that minimizes the use of production resources such as raw materials and energy to reduce the environmental impact per unit of product. The eco-efficiency indicators for the industry are based on the World Business Council for
Sustainable Development (WBCSD) in the form of economic indicators and environmental indicators. WBCSD defines eco-efficiency as “increasing the production of goods and services with lower resource use, waste, and pollution” [3]. WBCSD describes the eco-efficiency as a concept of reducing resource consumption, reduce environmental impact, and increase the value of products and services. Adoption of the principles of eco-efficiency in production patterns in public policymaking will increase the technological capabilities [4]. Environmental Accounting since 1990 has been focusing on publishing The Greening of Accountancy by the Chartered Association of Certified Accountants (ACCA). Based on US Environmental Protection Agency (US EPA), Green Environmental Accounting has defined a function that environmental costs should be considered by the responsible party to reduce or avoid costs and improve environmental quality [5]. According to ESCAPE, eco-efficiency is a comparison between the economic value of the product indicated by the net value and the environmental cost to produce the product [6].

Nowadays, the eco-efficiency measurement is using the life cycle assessment (LCA) method which has indicators to measure the environmental impact category of a product. LCA is a compilation and evaluation of inputs, outputs and the potential environmental impact of a product or service based on the life cycle [7]. This research aims to measure the environmental impact of the production process as the eco cost of the product resulted, identify the most significant environmental impact category, measure the environmental efficiency performance of the production process and formulate recommendations to improve the efficiency performance of the production process. Method of Life Cycle Assessment is conducted to evaluate the environmental impact and provide an alternative improvement to reduce environmental impact [8].

2. Research Methodology
2.1. Life Cycle Assessment Method
Today, LCA began to be applied in government policy, marketing, strategic planning, process improvement, and product design and also used as the basis for eco-labeling and consumer education program [9]. The eco cost consists of four groups, eco cost of resource scarcity, eco cost of carbon footprint, eco cost of ecosystem and eco cost of human health. Each group consists of some impact categories [10]. The group of eco cost and their impact category describe in Figure 1.

![Figure 1. Eco cost category in life cycle assessment.](image)

The LCA method has three phases. The first phase is to define the purpose and scope to determine the direction of the research. LCA goals and scope aim to formulate and describe the objectives, the boundaries, and the assumptions related to impacts throughout the life cycle of the system being evaluated. The scope of the assessment of the dining table starts from the resources entry the
manufacture, the production process and ended in the finishing product package. We can say the scope is a gate to gate type. The second phase is the analysis of inventory (life cycle inventory assessment /LCIA) which identifies and collects data of the input and output of the production system and did some data processing through Classification, Characterization, Normalization, Weighting and define a Single Score. LCIA analyzes the type and magnitude of the value of each impact category. The third phase is the environmental impact statement which is intended to get the output of data processing in the form of a potential category to the damage of the environment. The output shows as Output of Impact Category Diagram. The diagram shows the environmental category impact of the production process [11].

2.2. Life Cycle Assessment Indicators
LCA has some indicators of the economic aspect and environmental aspect. First, we did the cost-benefit analysis to obtain the net value. The net value is the selling price reduced by the cost of production. Cost-benefit analysis can also determine whether the product is eligible to be sold or not.

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

Then, the net value used to obtain the Eco-efficiency index (EEI) which determines the feasibility of the product in terms of ecological efficiency (sustainability) as well as economic efficiency (profitable). Eco-efficiency index value obtained by dividing the net value to the eco-cost [4].

Eco-Efficiency Index (EEI) is used to categorize the product whether the product is affordable and sustainable or not. Products categorized as affordable and sustainable if the value of EEI is more than 1, while affordable but not sustainable if the value of EEI is between 0 – 1. The product categorizes as not affordable and not sustainable if the value of EEI is less than 1 [12],[13].

The EEI value used to calculate the EVR (Eco-Cost Value Ratio). EVR is an indicator that compares the eco cost to produce a product that represents the ecologic value to the net value of a product that represents the economic value.

\[
\text{EVR} = \frac{\text{Eco cost}}{\text{Net value}}
\]

The final calculation is the Eco-Efficiency Ratio Rate as the measurement of the eco-efficiency of production [14]. The formulation to calculate this indicator are state below. The EER defines how efficient the environmental performance of the production process in the form of a percentage.

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

2.3. The Input of the Life Cycle Assessment
Inventory flow includes the input of raw materials, auxiliary materials, natural resources, energy use and everything released to land, water, and air. To develop LCI, a system flow model is built using input and output data. We must input to SimaPro all of the materials used in the production process and the materials outputs resulted in process. The raw material for the production of Square Dining Table is Teak wood. The wood must go through a kiln-drying process to reduce the moisture content before processing. The process also used bolts to connect components one another, and other materials for assembly and packaging process. The product and the specification (size) is described in Figure 2. The input and output of the production process are shown in Table 1.

![Figure 2. Square dining table.](image-url)
Input and Output of the production process are needed to build life cycle inventory. The input and output of the production process are shown in Table 1.

| Input          | Quantity | Unit |
|----------------|----------|------|
| Teak wood      | 24.2     | m³   |
| Energy         | 4910     | kwh  |

| Output         | Quantity | Unit |
|----------------|----------|------|
| Dining Table   | 15.8     | m³   |
| Wood scrap &   | 8.4      | m³   |

### Table 1. Input-output of the production process.

#### 3. Results and Discussion

The second phase of LCA is LCIA calculations which consist of (1) characterization, (2) normalization, (3) weighting and (4) define a single score of the environmental impact. LCA calculation use the 2012 eco-costs method. The result of the characterization phase and normalization phase are shown in Table 2 as an output of data processing using SimaPro software after input the value of material volume in Table 1. To change the environmental impact in characterization column to environmental cost in euro, the characterization value is multiplied by the normalization factors value. Normalization value is the price of environmental impact in euro for one unit of material that taken from and release to the environment. The calculation was done by characterization process on SimaPro. Continue by the weighting process, here the process is ignored by using the same weight for all impact factors because all factors assumed to have the same influence to environment and to human life. The result of characterization, normalization and weighting is shown in Table 2.

Table 2 shows that the highest value of the environmental impact category is climate change which reaches 45.9 kg CO₂ resulted from energy consumption and teak wood consumption. Life Cycle Assessment can be used to evaluate the environmental impact of the use of raw materials such as coal and biomass fuels which the removal of these can lead to a problem of how big the emissions and other impacts resulted from the use of biomass fuels [15].

We also see that the highest normalization factors are Fine Dust which reaches € 34 / kg. Fortunately, the fine dust output only has impact category value 0.0012 and the highest eco cost here is still climate change. There are 21 machines used in the production process and the total time of machinery processing is 2073 seconds or 34.5 minutes per unit and consumes 4.910 kwh electrical energy. The electrical energy consumed in the production process is calculated by SimaPro as a component that releases the CO₂ emission from the coal burn in generating power. While using 24.2 m³ of teak wood which exploited from the forest also gives an impact on climate change. The total of eco cost for production of one unit of dining table is 9,38 euro or IDR used the exchange rate IDR 14,285 per euro rounded off to 134,000.

The net value defines by selling price reduced by the production cost. The selling price of a product is IDR 700,000 and the production cost is IDR 492,000. The production cost consists of material cost, energy cost, labour cost, and overhead cost. The production cost and other value to obtain net value are given in Table 3.
Table 2. Recapitulation of SimaPro output.

| Impact Category                        | Unit     | Characterization | Normalization Factors | Normalization Result (Euro) |
|----------------------------------------|----------|------------------|-----------------------|-----------------------------|
| Climate Change                        | kg CO₂ eq | 45.9             | € 0.135 / kg CO₂ eq   | 6.2                         |
| Acidification                         | kg SO₂ eq | 0.408            | € 8.25 / kg SO₂ eq    | 3.36                        |
| Eutrophication                        | kg PO₄ eq | 0.0295           | € 3.9 / kg PO₄ eq     | 0.115                       |
| Photochemical Oxidant Formation       | kg C₂H₄ eq | 0.00581        | € 9.7 / kg C₂H₄ eq    | 0.0564                      |
| Fine Dust                             | kg Pm 2.5 eq | 0.0012       | € 34 / kg Pm 2.5 eq   | 0.0408                      |
| Human Toxicity                        | CTUh     | 1.22 x 10⁻⁶      | € 1.030.000 / CTUh    | 0.0125                      |
| Ecotoxicity (Freshwater)              | CTUe     | 12.6            | € 0.0014 / CTUe       | 0.018                       |
| Metals Depletion                      | euro     | 0               | € 1                   | 0                           |
| Oil & Gas Depletion Excl Energy       | kg oil eq | 0               | N/A                   | 0                           |
| Waste                                 | MJ       | -37.8           | € 0.012 / MJ          | -0.45                       |
| Land-Use                              | euro     | 0               | € 1                   | 0                           |
| Water Stress Indicator                | WSI factor | 0.0125       | € 0.76 / WSI factor   | 0.0949                      |

Table 3. The LCIA indicators for 1 batch or 250 products.

| No | Cost                  | Component                                                       | Total (IDR) |
|----|-----------------------|-----------------------------------------------------------------|-------------|
| 1  | Material              | Teak wood, bolts, and assembly components, packaging             | 48,400,000  |
| 2  | Direct labor          | Carpenter and machine operators                                 | 57,600,000  |
| 3  | Overhead              | supporting materials, electricity and administration             | 17,000,000  |
| 4  | Total Production cost | 1 + 2 + 3                                                       | 123,000,000 |
| 5  | Production cost/unit  | 123,000,000/250                                                 | 492,000     |
| 6  | Selling Price         | 50 USD, exchange rate IDR 14,000.                                | 700,000     |
| 7  | Net value             | 5 - 4                                                           | 208,000     |
| 8  | Eco cost from table 1 | 9.38 Euro x IDR 18,500 per unit product                         | 134,000     |
|    | EEI                   | Net value / Eco Cost                                            | 1.55        |
|    | EVR                   | Eco cost / Net value                                            | 0.644       |
|    | EER                   | (1 – EVR) 100 %                                                 | 35 %        |

We can define the net value as IDR 217,958. The net value used to obtain the eco-efficiency index (EEI) of a dining table from the result of the net value divide by the eco cost. The EEI is 1.55. The value of EEI is greater than 1 and said that the product is affordable and sustainable. This condition shows that dining table products are environmentally friendly and financially quite affordable. Dining table products are said to be sustainable means that products do not harm the environment, and said affordable because the value of eco-costs is smaller than the net value. The result of EEI, EVR and EER value are shown in Table 3.

The EVR value is obtained by dividing eco-costs with net value as the economic value of each product. From these calculations, it can be seen that the EVR of the dining table products is 0.64. The EVR value defines from the net value, the greater net value will result in the smaller EVR value. Small EVR value means better or more feasible for the product to be produced. EVR value is used as input to
determine the level of eco-efficiency of the product. The value of EER is 35% are categorized as less efficient.

3.1 Recommendations for Improvement

There are several problems faced by the wood furniture industry in Jepara with the environment, which are illegal logging and solid waste deposits [16]. Based on the data processing and analysis that has been done, the recommendations were formulated to improve the efficiency of the production process. The environmental impacts category which gives the highest contribution to eco cost is Climate Change and Acidification. Reducing the impact on climate change can be done by the reuse of wood waste. The industry can use wood blocks in the production process of products that require smaller sized parts. Also, wood waste can be used as valuable goods such as shoe racks. The wood scraps produce from the production process usually burned and impacts on air pollution. Workers health complaint are on eyes pain and respiratory organ which caused by air pollution from the smoke of burning wood scraps [17].

The second recommendation is replacing the material used in the finishing process to reduce health impacts on labor. Replace the use of water-based paint by wood paint will be much safer for the worker and reduce the impact on the environment. The substitution of dyes is often an alternative in efforts to reduce the impact on the environment and the health of workers. If possible, it would be better to use bio-degradable raw materials in which the disposal of raw material waste can be directly broken down by nature without causing negative effects on the environment [18].

4. Conclusion

Measurement of environmental impact categories with the eco-costs method finds out 9 categories of environmental impacts arising from the production of dining tables. The highest impact category is climate change with an eco-cost value of IDR 88,114 and the second is acidification with an eco-cost value of IDR 4,752. The eco cost to produce 1 unit product is IDR 134,000, while the product net value is IDR 208,000. Then, the EEI calculation result is 1.55 means that the dining table is categorized as an affordable and sustainable product. Affordable means that the products have an economic value where the selling price is greater than the cost of producing. Sustainable means that products do not harm the environment. The eco-efficiency ratio rate EER of the production process is 35% which means that the furniture production process is still categorized as less efficient and needs improvement. Recommendations given to the furniture industry to improve the environmental performance of production are to re-use wood waste to reduce the climate change cost and replacing paint of finishing materials with safer materials to reduce the acidification cost.

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