E3S Web of Conferences **31**, 08005 (2018) https://doi.org/10.1051/e3sconf/20183108005
ICENIS 2017

Eco-efficiency Analysis of Furniture Product Using Life Cycle Assessment

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Abstract. Furniture is one of Indonesia's main commodities strategically role in economic growth and employment in Indonesia. In their production process there many wastes resulted, such as such as sawdust, cuttings - pieces of wood, components that do not conform to specifications and the edges of wood from a log. Contrast with requirement of timber for furniture industries, availability of raw material sources decrease because of limited forest areas. Beside that, using electricity and chemical material in furniture production process have impact to environment. This study aim to assess the eco-cost and eco-efficiency ratio of the product so strategic recommendations to improve the eco-efficiency of products can be designed. The results of data processing showed the environmental costs of the furniture production process amount Rp 30.887.84. Eco-efficiency index of furniture products studied was 4,79 with the eco-efficiency ratio of 79,12%. This result means that the measured furniture products already profitable and sustainable, as well as its production process is already fairly efficient. However, improved performance of the production process can still be done to improve the eco-efficiency by minimizing the use of raw materials.

1 Background

Furniture industry has strategic role and significant contribution to economic growth for Indonesia. Based on data from the Ministry of Industry Indonesian, wood furniture export value continued to increase in recent years. In 2012 the export value of wooden furniture Indonesia reached US $ 1.6 billion, later increased to US $ 1.7 billion in 2013 and then in 2014 increased to USD 1.9 billion. However the industry strategically and contribute to the economic development, it also contributed to the pollution of the environment and ecosystems. Based on a report from the United Nations Development Program (UNDP) in 2008 stated that in the forestry sector, carbon emissions released as a result of deforestation reached 80 percent, while 20 percent are caused by degradation. This triggered destruction of forests and environmental damage to the ecosystem [1].

The furniture industry that used wood raw material produces several types of Non-Product Output (NPO) or waste. Waste generated from each stage in the form of solid waste such as sawdust, wood chips, small wood pieces, and waste water which causes water pollution such as residual solvent finishing, resin particles and adhesive residual. Wastes in form of sawdust, wood chips and small wood pieces almost reached 30% in Jepara SME's [2]. This waste will have a serious impact on the environment, health and safety in the absence of a strong commitment to make change for sustainable development, clean production and waste reduction [3].
Measuring of sustainability has been developed by [4] known as the eco-efficiency index (EEI) that finding the ratio between profit and production costs added by environmental impact. Eco-efficiency is a strategy that combines the concepts of economic and ecological efficiency in the use of natural resources. Simply put eco-efficiency can be understood as a strategy to produce a product with better performance, using less energy and natural resources. Eco-efficiency can be regarded as a business strategy that has more value because of less use of natural resources and reducing the amount of waste and environmental pollution [5]

Appraisal of product eco-efficiency based on production and environmental costs (eco-cost). Production cost is obtained from the cost of goods manufactured data, while the environmental costs previously obtained by measuring the environmental impact of the production process. Impact measurements of the use of wooden material can be done by using the Life Cycle Assessment (LCA). LCA measurement is intended to calculate the cost of the environment (eco-cost) of the use of material making up the product and then calculated the eco-efficiency level of products and propose recommendations to improve the eco-efficiency of products [5].

In order to reach sustainable production in the furniture industry, it is needed a measurement of the eco-efficiency index as a baseline for making improvement. This study aim to measure the environmental impact and value of environmental costs or eco-costs of the furniture production process and analyze eco-efficiency index and eco-efficiency ratio of furniture products.

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2 Research methodology

Research methodology of this study consist of Life Cycle Assessment (LCA) and eco-efficiency measurement.

1.1 Stage of Life Cycle Assessment (LCA)

Life Cycle Assessment (LCA) evaluates holistically the environmental consequences of a product system or activity, by quantifying the energy and materials used, the wastes released to the environment, and assessing the environmental impacts of those energy, materials and wastes [6]. Stages of LCA consist of four phases, first, it is goal and scope phase, then followed by life cycle inventory, the third is life cycle impact assessment and interpretation phase is the final stage.

Life Cycle Inventory (LCI) is second stage in LCA and consists of activities related to the search, collection and interpretation of the data requirements for the measurement of environmental impacts. Gate-to-gate LCI information being used in this study. Chair product has been observed because this product are the highest volume of export product. This product exported in form of unfinishing condition. Detailed of LCI given in Fig. 1. It can be seen that process production of the observed product conducted in three areas, there were Rough Mill, Smooth Mill and Sanding.

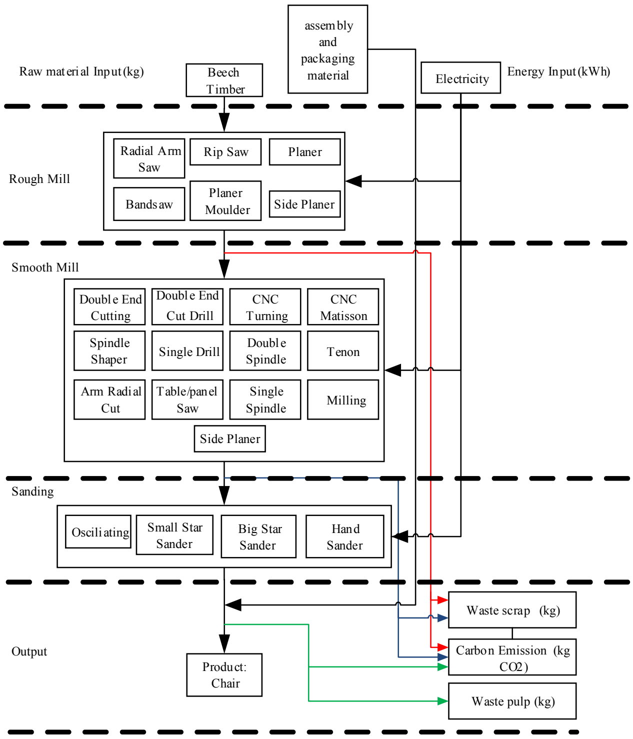

Fig.1. Life cycle inventory of chair product

Assembly, disassembly and packing were assumed include in Sanding Department because no physically product changing. Upholstery and finishing processes were not conducted in the observed product. Input of chair product was Beech timber, assembly and material packaging and electricity. Output of the process consists of product output and non product output (NPO). NPO consist of sawdust, wood chips and carbon emission. Measurement of energy consumption is done by logging all the machines used in producing bye product in the boundary of production system under study. Then the power on each machine (kw) is identified and multiplied by the time of the product (hour) by the machine so that the machine energy consumption is obtained to produce the product in kwh.

In Life Cycle Impact Assessment (LCIA), types and amounts of environmental impact calculated using software Simapro Ecoinvent database v 7.1 and 2.0 as well as the impact assessment method Eco costs 2012 v 3.03. In the Eco costs method, LCIA calculation consists of several stages, among others, characterization, normalization and a single score from the resulting environmental impacts. The results of this indicator category is obtained by assigning the results of the Life Cycle Inventory for emissions to soil, water and air of the substances that are used to group representing environmental issues so-called impact category. Normalization step in the Eco costs 2012 method is calculation in the preventive marginal cost of each impact category obtained by multiplying the result by a normalization factor indicator category which is the value of eco cost of each unit of emissions. For single stage score, based on the marginal cost of preventive obtained from normalization stage then summed from each category to a total eco-impact cost. Eco-cost given in Euro that the exchange rate assumed as Rp 14.036,93/euro based on rate in 22 December 2016.

Life cycle interpretation is the last phase of the LCA process. Life cycle interpretation is systematic techniques to identify, measure, examine, and evaluate information from LCI and LCIA results.

1.2 Eco-efficiency measurement

Eco-efficiency measurement consist of four phases. There are cost-benefit analysis, eco-efficiency Index (EEI), eco-cost value Ratio (EVR) and eco-efficiency ratio (EER) Rate calculation.
Cost-benefit analysis was conducted to determine the value of the net value of the product. Net value is obtained by reducing the benefits the company obtains in the form of product selling price with production cost represented by cost of goods manufactured. Costs calculated in the determination of cost of goods manufactured include material costs that include raw materials in the form of wood and supporting materials in the form of material assembly and packaging, labor costs either directly or indirectly, the cost of electrical energy, and the cost of overhead companies. Price of the product were US$40 or Rp 538.319 (based on exchange rate in 22 December 2016, Rp 13.457,99/US$). Cost of good manufacture was Rp 393.929, so net value of the product were Rp 144.390.
The calculation of the eco-efficiency index (EEI) is conducted to assess the feasibility of a product, whether

the product is economically efficient (profitable) and ecologically efficient (sustainable). Formula for measuring EEI is net value divided by eco-cost [7]. If EEI more than 1, so it called profitable and sustainable. If EEI are in range 0-1, it called profitable but unsustainable. While EEI less than 0, it is unprofitable and not sustainable.
The calculation of eco-cost per value ratio is obtained by comparing the amount of eco-cost incurred by the value of the furniture product. The output of the EVR calculation is the ratio of the two values to the inputs in this calculation.
EER Rate is the final calculation of the eco-efficiency measurement of the production process of furniture products. The EER Rate calculation is obtained by reducing the product's net value with the eco-cost of the production process and then the reduction result is subdivided by the net value of the product.

3 Results

Based on data processing, the results are described in tables 1., table 2 and table 3. Table 1. give information about input and output of life cycle inventory for the product being studied.

Table 1. Input & Output of Product Life Cycle Inventory

Type	Classification	Volume	Unit	
Input	Material	37.225	Kg	Timber
	Energy	10.20	kWh	electricity
Output	Product Output	21.036	Kg	Chair
	Non Product Output	16.189	Kg	Waste
		Output of LCIA		Emission

Table 2. Characterization of Output of Chair Product

Impact category	Unit	Rough Mill	Smooth Mill	Sanding
climate change	kg CO2 eq	5.007862	3,146243	0.,859937
Acidification	kg SO2 eq	0.027109	0.,009499	0.,000981
Eutrophication	kg PO4-- eq	0.004970	0.001863	0.,000239
photochemical oxidant formation	kg C2H4 eq	0.001534	0.,000455	0.000015
fine dust	kg PM2.5 eq	0.005243	0.,001531	0.000041
Human toxicity	CTUh	0.000000263	0.000000077	0.000000002
Ecotoxicity	CTUe	3.955764	1.,155359	0.030606
Metals Depletion	Euro	0	0	0
Oil&Gas Depletion excl energy	kg oil equ	0	0	0
Waste	MJ	0	0	0
land-use	Euro	0	0	0
Water Stress Ind	WSI factor	0.,036176	0.,010566	0.000280

Table 3. Eco-cost of Chair Product (in Euro)

Impact category	Rough Mill	Smooth Mill	Sanding	Total
climate change	0,676061	0,424743	0,116092	1,216896
Acidification	0,223650	0,078365	0,008093	0,310108
Eutrophication	0,019383	0,007264	0,000932	0,027579
photochemical oxidant formation	0,014877	0,004416	0,000150	0,019443
fine dust	0,178268	0,052067	0,001379	0,231714
Human toxicity	0,270554	0,079021	0,002093	0,351669
Ecotoxicity	0,005637	0,001646	0,000044	0,007327
Metals Depletion	0	0	0	0,000000
Oil-Gas Depletion excl energy	0	0	0	0,000000
Waste	0	0	0	0,000000
land-use	0	0	0	0,000000
Water Stress Indicator	0,027493	0,008030	0,000213	0,035736
Sum				**2,200472**

Table 2. show characterization output of chair product and Table 3. Give information that the total of eco-cost are 2,200472 euro or equal to Rp 30.888. So, calculated EEI are 4,67. Because the score more than 1, the product are profitable and sustainable.

$$EEI = \frac{Rp\ 538.319 - Rp\ 393.929}{Rp\ 30.888} = 4{,}67 \quad (1)$$

Table 4. Comparison between cost, EVR and EER of The Product

Benefit (Rupiah)	Prod Cost (Rupiah)	Net value (Rupiah)	Eco-cost (Rupiah)	EVR	EER
538.319	393.929	144.390	30.888	0,21	78,6 %

Table 4. Show comparison between cost, EVR and EER. Eco-cost per value ratio (EVR) or eco-indicator is a comparative indicator that takes into account the economic and ecological aspects of the seat product. Ecological aspect factor is calculated as net value while ecological aspect is expressed in eco-cost. EVR value is obtained from eco-cost division as ecological value, while net value of product as economic value. The larger the net value of a product, the smaller the EVR value of the product where it indicates that the environmental costs that need to be removed from product production are only a small part of the net value of the product. The smaller EVR value of the product means better and worthy for product to be produced. The EER value represents the value obtained from net product value reduction with eco-cost of the product and then result of the deduction is divided by net value of the product itself. So far the company has not considered eco-cost as part of product cost. Through this measurement, net-value value reduced by eco-cost indicates that eco-cost is also a cost factor calculated in product value.

4 Discussion

Table 1 and Table 2 illustrate that highest waste and carbon emission resulted by Smooth Mill department. In Smooth Mill were processed formations of chair components into more detail so that the physical changes of product components are also getting bigger. The chair production process using Beech wood as raw materials and electricity generated from burning coal or crude oil that has an impact on the environment. Environmental measurement endpoints measured using Simapro Software are shown in eco-cost. Eco-cost is cost that is required to address the emerging environmental impacts, but the environmental costs are not mandatory for the company. Since there is no subjective factor in eco-cost measurement, the level of significance and urgency of the impact is seen from the value of the eco-cost impact.

Climate change measured in the production process is 9.014 Kg CO2 (carbon dioxide) equivalent, which means use of resources to produce 1 unit of seats in the form of 0,0517 m3 or 37,225 kg of wood and the use of electric power of 13.252 kWh contributes to the generation of 9.014 kg of carbon dioxide that affects climate change. Carbon dioxide in this study arises from the felling of trees as raw materials for production because the tree plays a role in converting carbon dioxide gas into oxygen through photosynthesis.

Acidification measured in the seat production process is 0.0376 Kg SO2 (sulfur dioxide) equivalent, which means the use of resources to produce 1 unit of seats in the form of 0.0517 m3 or 37.225 kg of wood and the use of electric power of 13.252 kWh contributes to the generation of 0, 0376 Kg of sulfur dioxide gas. This compound is a toxic gas with a pungent odor released by some industrial processing such as coal combustion and petroleum also contains sulfur compounds. Sulfur dioxide is produced from burning coal and petroleum in electricity production [8].

Eutrophication measured in a chair production process of 0.0071 Kg PO4 (phosphate) equivalent, which means the use of resources to produce 1 unit of Brant Chair chairs in the form of 0.0517 m3 or 37.225 kg of wood contributes to 0.0071 kg of phosphate. Phosphate is produced by the use of wood because the tree plays a role in binding phosphate substances.

Photochemical Oxidant Formation measured in the process of production of 0.002 Kg C2H4 (ethylene) equivalent, which means the use of resources to produce one unit of erupa seat 0.0517 m3 or 37.225 kg of wood and electric power consumption of 13.252 kWh contribute to the generation of 0.002 Kg of ethylene substances. Photochemical Oxidant Formation is a forming phenomenon through chemical reactions due to exposure to sunlight. Photochemical oxidants or more defined as smog are the result of reactions that occur due to volatile organic compounds (VOCs) exposed to UV radiation. One type of volatile organic compound is ethylene gas. The substance formed here is the ozone layer which at the right altitude of the atmosphere is the protector of the Earth from the sun's heat but ozone in this case is formed at low atmospheric levels making it harmful to living things [9]. The contribution of the production process to this environmental impact is due to the combustion process in the production of electricity and the use of wood as fuel because the tree plays a role in airborne toxic substances in the air.

Fine Dust in the process of production of wooden chair reaches 0.0068 Kg PM 2.5 equivalent, which means waste in the form of wood pulp contribute to 0.0088 kg of measured dust particles. Wood dust particles are very commonly released into the air because of their very micro size so often unhandled. These dust particles are air pollution because it is very disturbing breathing and can result in various respiratory problems.

Human Toxicity measured in a chair production process of 3.41 x 10-7 Kg Benzo (a) pyrene equivalent which means the use of resources to produce 1 unit of chair in the form of electricity power consumption of 13.252 kWh contributes to 3.41 x 10-7 Kg Benzo (a) pyrene. Benzo(a)pyrene is a compound resulting from incomplete combustion of coal and organic material. In this study the Benzo compounds (a) pyrene arise from the combustion process for electricity production as production energy [10]. Benzo(a)pyrene is a toxic compound that if exposed to living things for a long time can cause damage to the nervous system, decreased immune system, damage to the reproductive system and even potentially cause cancer cells [11].

Ecotoxicity measured by eco-cost method in a chair production process of 5.14 Kg Zn (Zinc) equivalent which means the use of resources to produce 1 unit of ch in the form of electric power consumption of 13.252 kWh gives an impact equivalent to 9.014 kg of zinc. Ecotoxicity is an environmental impact that refers to the potential of substances in polluting the aquatic ecosystem. The pollutant substance measured by Simapro Software with this eco-cost method is a zinc substance. The process of extracting natural oils generally leads to zinc content which is then released into the aquatic ecosystem. Zinc is a type of heavy metal that is very dangerous if it goes into the human metabolism system for example through the processing of water containing zinc into drinking water. Excessive zinc content in human metabolic system can lead to malfunction and maintenance of skin, pancreas and male reproductive organs. In addition, the zinc content can also lead to deficiency of other minerals in the body such as iron is very important in the process of blood formation [12].

Water-stress indicator measured in the production process Chair of 0.047 WSI factor which means the use of resources to produce 1 unit Chair of 0.0517 m3 or 37.225 kg of wood that comes from trees and the use of electric power of 13.252 kWh contribute to the increase in water saturation .

Climate Changed has the greatest environmental impact value that caused by the use of wood raw materials. In order to reduce the impact of Climate Change, it is recommended to decrease the use of wood as raw material for production. The difference in length of the coarse size and average final size for each component is 20 mm. One of the components of the arm post even has a gap size difference and the final size of 60 mm.

Reduction of wood material usage can be done by cutting the length of the crude component by 10 mm. If this is done then it can save the use of wood materials by 0.000421 m3. At a glance, the aforementioned savings value is small but this will be significant if it takes into account large-scale production. The size of the production lot of wooden chairs used as the measurement object of this research is 700 units. If the size reduction is done on this production lot, the saving of wood material can reach 0.2946 m3 where the savings value is equal to the wood material needed to produce 10 units of chair.

5 Conclusion

Based on the result of gate-to-gate life cycle inventory of wooden chair product, it can be conclude that the product was profitable and sustainable because the EEI is more than 1. However, the product has climate change impact that can be reduced by decrease the tolerance of crude component. This scope of the study can be enlarged to be gate-to-cradle or cradle-to-cradle approach and also for local market product, so it can describe the eco-efficiency of furniture industry more clearly.

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