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The Environmental Impact Assessment of Furniture Production Process Using the Life Cycle Assessment

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Abstract. The aim of this study is to evaluate the environmental impact of the wood table production process using the Life Cycle Assessment. Case studies are carried out in a wood furniture SME in Indonesia. Each activity is modelled using primary data, related to the input and output of the process. The production process includes four phases: sawing process, construction process, assembly process, and finishing process. The system boundary includes all activities that occur within the woodworking plant including material and energy consumption, transportation, and additional products used. The study concluded that the most affected categories were climate change, human toxicity, and metal depletion. While the most contributing production processes are finishing.

1. Introduction

The furniture industry has a significant contribution to Indonesian economic growth. Based on data Indonesian Ministry of Industry (2015), the export value of wood furniture has increased in recent years. The furniture industry was able to contribute to GDP by 0.26% in 2012 and increased to 0.27% in 2015. Although the furniture industry contributes to economic growth, it is also one industry that has a direct impact on the environment. Data from the Indonesian Ministry of Environment and Forestry in 2015 stated that timber production for furniture needs amounted to 35.3 million hectares of forest. The furniture industry also produces waste consisting of wood waste and liquid waste from the finishing and waste gas stages in the form of emissions from machines used for the production process. However, the wood products industry is generally regarded as one of the most sustainable. Wood has many advantages over other materials, one of which is because wood is a renewable material [1-2]. In Indonesia, wood-based industries produce various products, such as furniture, sawn timber, wood-based panels, handicrafts, and others. Hence, a proper evaluation of furniture industry sector to improve the environmental is of paramount relevance.

Life cycle assessment (LCA) has been identified as a reliable methodology for analyzing environmental impacts [3-4]. Mostly, the use of LCA for analyzing wood products focuses on panel and board production [5-6] and on a comparison of the sustainable performance of wood furniture that applies environmental design principles [7]. Michelsen & Fet []**Error! Reference source not found.** provide a tool to improve the environmental performance of SMEs active in the furniture sector. González-García et al. [9] study the environmental profile of set wood furniture to determine the most effective criteria for the eco design. In this study, LCA will be used to analyze the environmental impact of wood products. The research will evaluate processes and waste that contribute the most to the environment.

2. The Environmental Impact of Furniture Product

Eco-design strategies are very important for reducing the environmental impact of a product [10]. Some aspects are considered in eco-design for furniture products. The main focus is related to proper wood use, optimization of resources and recovery of wood chips, minimization of energy consumption, reasonable use of chemicals, and reduction of packaging [11]. The key problems in realizing environmentally friendly furniture are as follows: the use of solid wood, certified wood; reduction in the amount of glue and paint or substitution with water-based ones; reduction of plastic and metal used, privileges the use of steel; and dematerialization and mono-materiality. The environmental impact of furniture products can be reduced by minimizing the use of paint and glue. This material contains organic chemicals (VOC) and formaldehyde emissions [5];[12-13]

Michelsen et al [14] analyzed the environmental impact of two types of chairs (Chair A and Chair B) used in meeting rooms, waiting rooms and cafeterias. For Chair A, five different models were analyzed (I, II, III, IV, and V). Each has a different need for steel and wood. The selected variant is as close as possible. It is assumed that all models have the same function and durability. The LCA results state that seat A-IV has the largest CO2 emissions. Whereas heavy metal emissions are owned by seat A-V [8] proposed methods for improving environmental performance in the supply chain for small and medium enterprises (SMEs) furniture in Norway. This case shows the potential for process improvement under the direct control of the final producer. The method shows that SMEs with limited resources and supply chain strengths can identify key actors in the supply chain to make further improvements, based on the potential for improving environmental performance [15] developed eco-innovation strategies for minimizing environmental impacts. The object of the research was carried out on the assessment of the environmental impact of certified wood products wood and integrating eco-design criteria in their conceptions. The LCA method has been applied in case studies related to the wood furniture sector in the northern mountainous region of Italy. Each activity is modeled using primary data, related to the input and output of the process, which is provided directly by wood designers and companies. The results show that the largest environmental load is found in the production of solid wood panels and processing of iron parts. Conclusion This study proves that eco-design can improve environmental performance product.

Rinawati et al [16] asses an environmental impact of chair product. Climate Changed has the greatest environmental impact value 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. Climate change measured in the production process is equivalent to 9,014 Kg of CO2 (carbon dioxide). Carbon dioxide arose from logging trees as a raw material for production because trees play a role in converting carbon dioxide gas to oxygen through photosynthesis.

3. The environmental impact assessment using life cycle assessment

Life cycle assessment (LCA) has been identified as one of the most reliable methodologies for evidencing and analyzing the environmental impacts along the life cycle of a product and should be part of the decision-making process towards more environmentally friendly products [3-4]. The LCA framework includes the determination of objectives and scope, life cycle inventory (LCI), life cycle impact assessment (LCIA) and interpretation.

3.1. The Goal and scope definition

The goal of this study is to identify the impact and determine the environmental costs arising from the production process of a table. The system to be evaluated in the Life Cycle Assessment is a cross leg table production system that includes roughing, construction, assembly, and finishing. The inputs to be analysed are material consumption, energy and waste produced. The calculation uses SimaPro v.8.4 software with the Eco-cost 2017 version 1.1 method. The output of the SimaPro software in the form of impacts produced from production systems that are converted into environmental costs (eco-costs).

3.2. Life cycle Inventory

Life cycle inventory phase involves the compilation and quantification of inputs and outputs of the system considered (ISO 14040 2006). The inventory and data collected, plus a final discussion about data quality and assumptions, are detailed in this section.

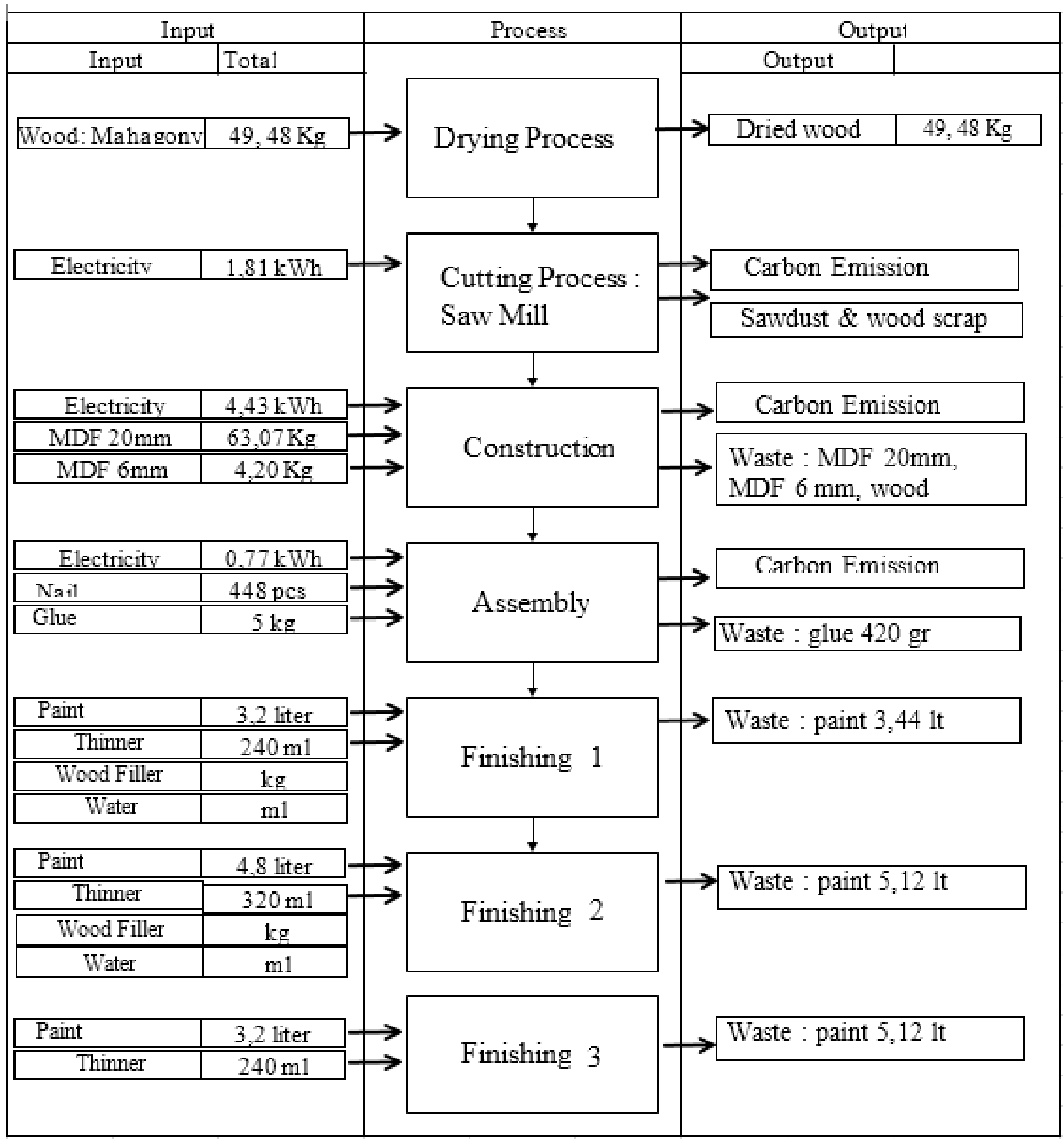

Figure 1. Input-output diagram

Figure 1 is an input-output diagram of the table production process. Electricity consumption is calculated by multiplying the time with the power of the production machine. The time of the production process is obtained using a stopwatch time study.

3.3. Life cycle impact analysis

Life cycle impact analysis aims to evaluate the environmental impact of the table production process. This phase consists of several stages, namely characterization, normalization, weighting, and single score. Calculation of Life Cycle Impact Assessment uses SimaPro software with Eco-Indicator 99 and Eco-cost calculation methods in 2012. Characteristics are the stages to identify and classify production processes that cause environmental impacts in several categories based on the method used. Table 1 describes the result of characteristic stage using simapro.

Table 1. The result of characteristics stage

Impact Category	Unit	Sawing Process	Construction Process	Assembly Process	Finishing Process	Total
Climate Change	Kg CO2 eq	0.2740	1.0100	0.1190	1.1500	2.5530
Acidification	Kg SO2 eq	0.0015	0.0052	0.0001	0.0057	0.0124
Eutrophication	Kg PO4-- eq	0.0005	0.0022	2.E-05	0.0030	0.0057
Photochemical Oxidant Formation	Kg C2H4 eq	7.E-05	0.0003	3.E-06	0.0007	0.0011
Fine Dust	Kg PM 2,5 eq	0.0008	0.0014	0.0002	0.0010	0.0034
Human Toxity	Cases	1.63E-08	9.E-08	4.27E-10	5.01E-08	1.56E-07
Ecotoxicity (Freshwater)	PAF.m3.day	1,280	5,460	31.7	6,650	13,421.7
Metals Depletion	Euro	0.0009	0.0070	2.E-05	1.36	1.3679
Oil & Gas Depletion exd Energy	Kg Oil equ	0	0	0	0	0
Waste	MJ	-4.0600	-2.6000	0	1.8600	-4.8000
Land-Use	Bio Factor	0	0	0	0	0
Water Stress Indicator	WSI Factor	0.0005	0.0026	0.0000	0.0079	0,0110

Table 2. The result of normalization stage

Impact Category	Unit	Sawing Process	Construction Process	Assembly Process	Finishing Process	Total
Climate Change	Kg CO2 eq	0.031800	0.117000	0.0137000	0.13300	0.295500
Acidification	Kg SO2 eq	0.013200	0.045700	0.0007570	0.05000	0.109657
Eutrophication	Kg PO4-- eq	0.001910	0.009320	0.0000805	0.01230	0.023611
Photochemical Oxidant Formation	Kg C2H4 eq	0.000774	0.003290	0.0000309	0.00708	0.011175
Fine Dust	Kg PM 2,5 eq	0.027700	0.045900	0.0066800	0.03380	0.114080
Human Toxity	Cases	0.015000	0.081900	0.0003930	0.04610	0.061493
Ecotoxicity (Freshwater)	PAF.m3.day	0.007060	0.030300	0.0001760	0.03680	0.074336
Metals Depletion	Euro	0.000863	0.006980	0.0000212	1.36000	1.367864
Oil & Gas Depletion exd Energy	Kg Oil equ	0	0	0	0	0
Waste	MJ	-0.043900	-0.028100	0	0.02010	-0.051900
Land-Use	Bio Factor	0	0	0	0	0
Water Stress Indicator	WSI Factor	0.000519	0.002570	0.0000175	0.00785	0.010957

The normalization stage aims to assess the contribution of the production process to global and regional environmental impacts. Normalization value is the result of multiplication of characterization values with normalization factors so that all impact categories have used the same unit and can be compared. The weighting stage is the stage of giving weight to each category of environmental impact. Weighting factors have a variety of values depending on the method used and the level of importance of an impact category. At this stage, the impact is measured in units of currency so that the weighting is not necessary to avoid double-counting. Table 2 is the result of normalization. Single score aims to classify the value of impact categories based on activities or processes. From the single score, it can be seen activities that contribute to environmental impacts and the impact of the damage (Table 3). Figure 2 explains the environmental impact of production process.

Table 3. The enviromental impacts of each process based on impact categories

Impact Category	Unit	Sawing Process	Construction Process	Assembly Process	Finishing Process	Total
Total	Euro	0.0549	0.3150	0.0219	1.7100	
Climate Change	Euro	0.0318	0.1170	0.0137	0.1330	0.2955
Acidification	Euro	0.0132	0.0457	0.0008	0.0500	0.1097
Eutrophication	Euro	0.0019	0.0093	0.0001	0.0123	0.0236
Photochemical Oxidant Formation	Euro	0.0008	0.0033	0.0000	0.0071	0.0112
Fine Dust	Euro	0.0277	0.0459	0.0067	0.0338	0.1141
Human Toxity	Euro	0.0150	0.0819	0.0004	0.0461	0.1434
Ecotoxicity (Freshwater)	Euro	0.0071	0.0303	0.0002	0.0368	0.0743
Metals Depletion	Euro	0.0009	0.0070	0.0000	1.3600	1.3679
Oil & Gas Depletion exd Energy	Euro	0	0	0	0	0
Waste	Euro	-0.0439	-0.0281	0.0000	0.0201	-0.0519
Land-Use	Euro	0	0	0	0	0
Water Stress Indicator	Euro	0.0005	0.0026	0.0000	0.0079	0.0110

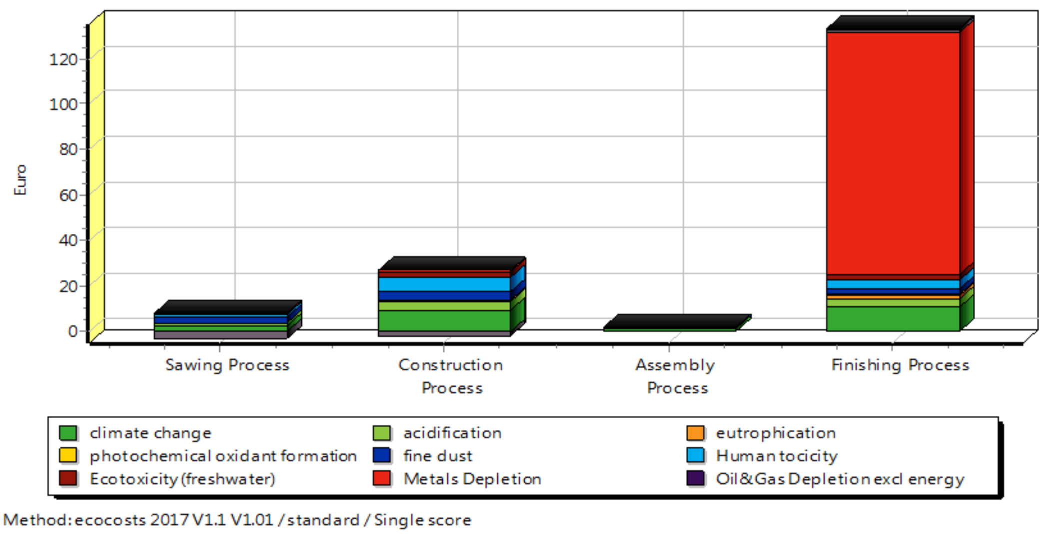

Figure 2. The single score diagram

4. Discussion

Calculation of environmental impact is carried out with the help of SimaPro software. The following is an analysis of the environmental impacts that arise due to the production process of cross-legs table:

- Climate Change

Climate change due to global warming is caused by carbon emissions in the troposphere. In general, CO2 is produced from fuel combustion, biomass combustion, respiration of living things, piles of garbage, volcanic eruptions, forest fires, draining of peatlands, factories that produce ammonia, cement, and ethanol, even from the plants themselves. In this case study, CO2 emissions are generated from the use of electricity generated from burning biomass. The value of the impact of the indicator of climate change arising from the production process of the table is 2,553 Kg CO2 equivalent. The value of climate change is the third largest environmental impact contribution. Climate change is indicated by the shifting of the wet and dry seasons, changes in rainfall and temperature changes for several 30-year periods [17].

- Acidification (acidification)

SO2 can cause acidification in the form of acid rain. A small portion of SO2 is produced from natural processes such as volcanoes. The process that produces the largest SO2 comes from fossil fuels to produce electricity, vehicles, manufacturing processes, oil refineries and other industries (Environmental Protection Agency US, 2017). Increased concentration of Sulfur dioxide will cause acidification of the water surface (sea, river etc.), damage forests and plants, building damage, acid rain, and human health problems. Health problems in humans include the occurrence of lung cancer, bronchitis, and asthma [18]. The environmental impact of the acidification category in the production process of cross leg tables is 0.01233 Kg SO2 equivalent. In this process, SO2 is generated from the use of electricity during the production process.

- Eutrophication

Organic waste produced from the production process of cross-legs tables produces substances containing phosphate (PO4). At the optimum concentration, this element is beneficial for the growth of phytoplankton as fish food so that it can increase fish production in the river. However, if the phosphate concentration in waste increases, it will encourage the growth of phytoplankton excessively (eutrophication) causing river pollution. If this situation drags on, then the river water quality will decrease: water turns cloudy, dissolved oxygen is low, other toxic gases emerge [19]. The table production process, in this case, produces a phosphate at 0.0057 Kg equivalent PO4. The resulting waste is dominated by the finishing process.

- Photochemical Oxidant Formation (POF)

The environmental impact in the Photochemical Oxidant Formation category, known as air pollution, is the second largest after Eco toxicity. Air pollution is the entry of substances into the air due to human activities so that ambient air quality decreases to a certain level so that it cannot be used according to its functions. Pollutant gases that can cause POF impacts include sulfur dioxide, ethane, tin, and carbon. The POF environmental impact of the table production process is equivalent to 69.5 Kg C2H4 equivalent. Most of it is caused by the sawing process.

- Fine Dust

Fine dust is pollution caused by fine dust produced from the production process. The fine dust environmental impact produces dust particles of varying sizes. These particles form a layer of dust that usually attaches to items. These dust particles can interfere with human health. Large dust particles tend to get trapped in the nose and mouth when you breathe them and can be easily inhaled or swallowed. Smaller or finer dust particles are not visible. Fine dust particles are more likely to penetrate deep into the lungs while ultrafine particles can be absorbed directly into the bloodstream. The environmental impact of fine dust in the table production process is equivalent to 0.0034 Kg PM 2.5 equivalent.

- Human Toxicity

Human toxicity reflects the potential hazards of a chemical unit released into the environment. In this study, the chemicals released into the environment came from glue, paint, thinner, and wood filler materials used for assembly and finishing. The use of these materials can harm the environment because of the chemical contained therein, for example, Titanium Dioxide contained in white paint material. The production process of cross-legs table generates the value of the human toxicity impact at 1,56E-07 CTUh. CTUh = a comparative toxic unit for human toxicity impact. Comparative toxic units for human toxicity impacts state estimates of increased morbidity (number of disease cases) in the total human population per unit mass of chemicals used [20].

- Eco toxicity (Freshwater)

Eco toxicity has an effect on damage to ecosystem quality due to emissions of eco toxic substances released into the air, water and soil. In this case, eco toxicity measurements are focused on pollution to water. The value of eco toxicity's environmental impact on the foot table production process is 13421.7 PAF.m3.day. This unit is an estimate of the fraction of potentially affected species (PAF) that are integrated over time and the volume of freshwater compartments, per mass unit of chemicals released into the environment. The value of eco toxicity (freshwater) is an impact that has the greatest value compared to other categories in this case. eco toxicity (freshwater) is caused by the use of wood, MDF, electricity, and chemical substances in finishing materials. Chemicals released into aquatic ecosystems also endanger the environment, because the content in them will endanger living creatures, whether human, animal or plant. Examples of dangerous chemicals, when released directly into the environment are Ethyl Acetate in thinner which can damage the liver and cause anemia.

- Metals Depletion

Metals depletion is included in the category of resource depletion or depletion of resources, especially in metal materials. Thinning of metal material is caused by metal exploitation which is then extracted into industrial material. The cross leg table production process resulted in the value of metals depletion of 1.36 Euros. Metals depletion, in this case, comes from the use of finishing materials such as paint, thinner, and wood filler. The material contains heavy metals with an eco-cost value of 1.36. Chemical substances with the highest metal content are found in Titanium Dioxide in white paint material.

- Water-stress indicator

Water stress occurs when water demand exceeds the amount available for a certain period or when poor quality limits its use. Water stress causes damage to the number of freshwater resources (over-exploitation aquifers, dry rivers, etc.) and quality (eutrophication, pollution of organic matter, seawater intrusion, etc.). In this case, the environmental impact of water-stress indicators is 0.0109 WSI Factor. This can cause increased saturation in water.

5. Conclusion

Based on the production process, the greatest environmental impact value comes from the finishing process. The biggest environmental impact based on the indicator is metal depletion, followed by the climate change category. Metal depletion is an impact category in the form of depletion of metal resources, due to industrial activities that use raw materials derived from metal extraction such as paint use. Whereas climate change is the depletion of the ozone layer caused by CO2 produced from the combustion process such as drying process, electricity consumption, and wood logging in the furniture industry. Reducing environmental impacts on furniture companies can be done by reducing the number of defective products, especially in the finishing process. Further research can be carried out to study the use of water-based paint for furniture products.

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