Environmental impact evaluation of crumb rubber industry production process by life cycle assessment (LCA) method (case study: PT FRP)

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Abstract. PT FRP produces crumb rubber SIR 20 with a total annual production of 42,000 tons. This study aims to analyze the environmental impact of 1-ton crumb rubber production using the Life Cycle Assessment (LCA) method to be further explored for recommendations for ecological improvement. LCA was carried by a gate-to-gate scope using SimaPro software with the eco-indicator 99 method. The steps for completing this research refer to ISO 14040:2016. Characterization step results from the category of fossil fuels impact have the highest value (931 MJ surplus). The total value of the single score generated is 369 Pt, with the highest impact value is respiratory inorganics. The dryer drying process, the usage of electricity, and the generator and boiler are four production processes that significantly impact the environment. Improvement recommendations given to reduce the effects of the four processes are using an economizer in the boiler, the combination of fuel used by the boiler, and substitution of diesel fuel with Pertamina Dex as generator's fuel.

1. Introduction
Natural rubber is the second-largest export commodity in Indonesia after palm oil. The value of the rubber trade reached USD 3.349 billion in 2013-2017 [1]. PT FRP is one of the crumb rubber industries that produces crumb rubber of the Standard Indonesia Rubber (SIR 20) type with an installed production capacity of 42,000 tons per year. The product is semi-finished rubber. PT FRP is also faced with environmental problems in potential contamination of water and air. The potential for environmental contamination due to the production process requires special attention because PT FRP is near residential areas and on the banks of rivers. Crumb rubber production processes such as breaking, washing, and creeping cause potential water contamination containing BOD5, COD, TSS, ammonia, and total nitrogen. The drying process with a dryer causes the potential for air pollution, which contains SO2, NO2, HCl, NH3, and other harmful emissions.

The Regulation of the Minister of Environment and Forestry Number concerning the Company Performance Rating Program in Environmental Management [2] added new criteria in the Company Performance Rating Program (PROPER) assessment. One of the assessment criteria developed by the Ministry of Environment and Forestry for aspects beyond obedience is applying the Life Cycle Assessment (LCA). PT FRP previously achieved a blue rating on PROPER. One way to maintain or improve the rating is to conduct an environmental impact assessment using the LCA method. This LCA
aims to identify the flow of inputs and outputs of the system and their disposal to the environment and implement possible environmental improvements. The LCA assessment follows the perspective framework of SNI ISO 14004:2016 [3] and SNI ISO 14044:2017 [4].

Research using the LCA method with a gate to gate approach can evaluate the input, process, output, and environmental impacts of crumb rubber processing. The environmental impact can be calculated based on the number of pollutants discharged into the environment and other needs during the production process. Therefore, the LCA method with a gate-to-gate approach can analyze the life cycle at PT FRP to maintain or increase the blue rating on PROPER. The results obtained from this study are expected to be used as a source of information to minimize pollution and improve the environmental management performance of the company.

2. Methodology
The LCA study steps refer to SNI ISO 14044:2016. There are defining objectives and scope, inventory analysis (life cycle inventory), impact assessment, and interpretation.

2.1 Goal and scope definition
The objectives contain the output generated from the research and a description of the system limits. This study aims to analyze the life cycle of crumb rubber products produced by PT FRP and its assessment of environmental impacts to provide recommendations for improvements to the company to make it more environmentally friendly. Crumb rubber production activities at PT FRP consist of transportation, breaking and washing, creeping, pre-drying, shredding, drying, weighing and press, packing and marking, boiler, generator, wastewater treatment plant (WWTP), and electricity. A complete flow chart of the production process can be seen in Figure 1.

The functional unit used is 1-ton of crumb rubber produced. The impact assessment method used is the eco-indicator 99 method, with the midpoint impact category is being analyzed. The impact category consists of carcinogens, respiratory organics, respiratory inorganics, climate change, radiation, ozone layer, ecotoxicity, acidification, land use, minerals, and fossil fuels.

The cut-off system in this study is odor, noise, and hazardous waste. This study did not study hazardous waste because there was no data about hazardous waste. Noise and odor were not examined in this study because damage to human health due to allergic reactions, noise, and odors cannot be modeled [5].

2.2 Life Cycle Inventory (LCI)
Inventory analysis is a phase of LCA that involves compiling and quantifying inputs and outputs for a particular product system throughout its life cycle or a single process. Inventory analysis includes data collection and compilation in the Life Cycle Inventory (LCI) table [6].

The data used in the study consist of the foreground system (primary data) and the background system (secondary data). Primary data were obtained from direct observation of production activities and informal interviews with PT FRP; observations are made by considering the entire production process, from breaking and washing to packing. Secondary data were obtained from previous research and data provided by PT FRP. The data obtained are adjusted to the actual conditions in this study. The secondary data obtained is adapted to the previously determined functional unit, 1 ton of crumb rubber produced. FRP data is obtained from UKL-UPL [7] and Company Profile [8]. The previous research data used in this study are data on diesel energy needs and electrical energy in the crumb rubber production process by Utomo and Suroso [9]. This data is used because it discusses the energy requirements needed for crumb rubber SIR 3 and SIR 20. PT FRP produces crumb rubber SIR 20. So that research data can be used as additional data in this study. More complete inventory table data can be seen in Table 1.
2.3 Life Cycle Impact Assessment (LCIA)

The impact assessment uses the eco-indicator 99 methods. The eco-indicator 99 method divides the impact categories into eleven midpoint impact categories. The endpoint impact category focuses on the impact that affects the end of the cause-and-effect chain so that it tends not to be overcome. At the same time, the midpoint is an impact category whose effects on the environment can still be minimized. The midpoint impact category was chosen so that the results obtained are easier to identify the cause. Through the knowledge possessed about possible impacts on the environment, the results of the midpoint impact categories can provide an opportunity to make well-founded decisions. Also, the midpoint impact category has lower statistical uncertainty. Each method of analysis will be described in the following discussion.

The impact assessment consists of three steps: classification, characterization, and a single score. Classification is the step to choose what impact categories will be analyzed. Characterization is the step to calculate the amount of each impact category that has been selected. Thus, a single score is a step that will compare all the impact categories and all the production processes.
2.4 Interpretation
The interpretation stage is the conclusion from the previous inventory analysis and impact assessment stages. The interpretation stage consists of comparison analysis and contribution analysis. The interpretation stage is carried out by looking at the comparison between the steps of the production system.

3. Results and discussions
3.1 LCI
Table 1 below shows the collected inventory data of 1-ton crumb rubber production in PT FRP.

| No | Process | Parameter      | Amount   | Unit | Source |
|----|---------|----------------|----------|------|--------|
| 1  | Transportation | Input: Diesel energy | 23.05 | MJ   | [9]    |
| 2  | Breaking and washing process | Electrical energy | 50.43 | kWh  | [9]    |
|    |        | Oil            | 0.017    | kg   | [7]    |
|    |        | Surface water  | 613.44   | m³   | [7]    |
|    |        | Recycled water | 466.56   | m³   | [7]    |
|    | Output: | Surface water  | 613.44   | m³   | [7]    |
|    |        | Recycled water | 466.56   | m³   | [7]    |
| 3  | Creeping | Electrical energy | 4.79 | kWh  | [9]    |
|    |        | Oil            | 0.017    | kg   | [7]    |
|    |        | Surface water  | 346.48   | m³   | [7]    |
|    |        | Recycled water | 263.52   | m³   | [7]    |
|    | Output: | Surface water  | 346.48   | m³   | [7]    |
|    |        | Recycled water | 263.52   | m³   | [7]    |
| 4  | Pre-drying | Electrical energy | 2.45 | kWh  | [9]    |
| 5  | Shredding | Electrical energy | 12.33 | kWh  | [9]    |
|    |         | Oil            | 0.017    | kg   | [7]    |
|    |         | Surface water  | 408.96   | m³   | [7]    |
|    |         | Recycled water | 311.04   | m³   | [7]    |
|    | Output: | Surface water  | 408.96   | m³   | [7]    |
|    |         | Recycled water | 311.04   | m³   | [7]    |
| 6  | Dryer   | Electrical energy | 19.15 | kWh  | [9]    |
|    |         | Diesel energy  | 1,167.07 | MJ   | [9]    |
|    | Output: | Particulates   | 1,272.41 | mg  | [7]    |
|    |         | SO₂            | 354.27   | mg   | [7]    |
|    |         | NO₂            | 1,647.31 | mg   | [7]    |
|    |         | HCl            | 1.55     | mg   | [7]    |
|    |         | Cl₂            | 12.51    | mg   | [7]    |
|    |         | NH₃            | 0.050    | mg   | [7]    |
|    |         | HF             | 0.084    | mg   | [7]    |
|    |         | H₂S            | 0.87     | mg   | [7]    |
|    |         | Hg             | 0.033    | mg   | [7]    |
|    |         | As             | 0.084    | mg   | [7]    |
|    |         | Cd             | 0.0035   | mg   | [7]    |
### No | Process | Parameter | Amount | Unit | Source
--- | --- | --- | --- | --- | ---
5 | | Zn | 7.78 | mg | [7]
6 | | Pb | 0.19 | mg | [7]
7 | | Sb | 0.032 | mg | [7]
7 | Weighting and press | | | | 
8 | | Electrical energy | 13.96 | kWh | [9]
8 | Packing and marking | | | | 
9 | Boiler | Palm shells | 52.14 | kg | [7]
| | Oil | 0.084 | kg | [7]
| | Particulate | 1,107,977.14 | mg | [7]
| | SO2 | 355,605.88 | mg | [7]
| | NO2 | 20,050.12 | mg | [7]
| | HCl | 1.15 | mg | [7]
| | Cl2 | 20.88 | mg | [7]
| | NH3 | 0.019 | mg | [7]
| | HF | 0.042 | mg | [7]
10 | Generator set | Diesel energy | 1,603.43 | MJ | [7]
| | Particulates | 218,802.19 | mg | [7]
| | SO2 | 772,686.76 | mg | [7]
| | NO2 | 59,728.25 | mg | [7]
| | CO | 1,283,000.79 | mg | [7]
11 | WWTP | Water | 2,500 | m³ | [7]
| | BOD5 | 18.6 | gr | [7]
| | COD | 113.33 | gr | [7]
| | TSS | 44.58 | gr | [7]
| | Ammonia | 5.97 | gr | [7]
| | Total Nitrogen | 11.58 | gr | [7]
12 | Electricity | Electrical energy | 141.71 | kWh | [7]

#### 3.2 LCIA

The flow chart for the production process of 1-ton crumb rubber can be seen in Figure 2. The crumb rubber production process in PT FRP that studied consists of twelve steps: transportation, breaking and washing process, creeping, pre-drying, shredding, drying, weighing and press, packing and marking, boiler, generator wastewater treatment plant (WWTP), and electricity.

Eleven impacts are studied: carcinogens, respiratory organics, respiratory inorganics, climate change, radiation, ozone layer, ecotoxicity, acidification, land use, minerals, and fossil fuels. The point unit (Pt) is the unit used to equalize the impact value in the figure. The results of the impact characterization can be seen in Figure 2, and the single score results in Figure 3.

Based on Figure 3, the color is yellow due to respiratory inorganics impact, which produces the highest impact value. The single total score due to the 1-ton crumb rubber production process is 369 Pt, with the process with the highest impact value is electricity worth 105 Pt.
3.3 Interpretation and improvement recommendation

Interpretation is carried out with three further stages, comparison analysis, contribution analysis, and improvement analysis.

3.3.1 Comparison analysis. Comparative analysis was carried out on the impact values at the characterization stage in Figure 4. Based on Figure 4, it can be seen that the impact of carcinogens was caused by electricity at 31.6% (0.0000869 DALY). The next impacts are respiratory organics due to drying 38.9% (0.00000249 DALY), respiratory inorganics due to electricity 31.7% (0.00021 DALY), climate change due to boiler 38% (0.00000882 DALY), radiation due to generator 39.2% (0.00000196 DALY), ozone layer due to generator 39.6% (0.00000271 DALY), ecotoxicity due to electricity 30.9% (44.3 PAF*m²yr), acidification due to generator 44.2% (14.4 PDF*m²yr), land use due to boiler 97.4% (230 PAF*m²yr), minerals due to drying 36.3% (0.721 MJ surplus), and fossil fuels due to generator 31.9% (286 MJ surplus).

Figure 2. Characterization midpoint impact category.
Figure 3. Single score.
3.3.2 Contribution analysis. Contribution analysis is carried out to find out what pollutants or substances are of high value due to the process and impacts. Arsenic emissions cause the effects of carcinogens most to water 18.5% and PM$_2.5$ to air 9.74% as results of electricity; respiratory organics due to NMVOC 37.2% and methane 0.154% as results of the drying process; respiratory inorganics due to PM$_2.5$ to air 29% as a result of electricity; climate change due to CO$_2$ to air 11.30% as a result of boiler process; radiation due to carbon-14 37.2% as results of generator set process; ozone layer due to methane 39.5% as a result of generator set process; ecotoxicity due to nickel 17.9% as a result of electricity; acidification due to NO$_x$ 40.9% and SO$_2$ 3.25% as a result of generator set process; land use due to annual harvest occupation and transformation 45% as a result of the drying process; minerals due to nickel 16.77% as a result of the drying process; and fossil fuels due to oil 30.7% as a result of generator set process.

3.3.3 Improvement analysis. Recommendations are given to the four processes that produce the highest impact value based on the comparative analysis. Four operations produce the highest impact value. Generators have the highest impact on radiation, the ozone layer, acidification, and fossil fuels. In contrast, electricity has the highest impact on carcinogens, respiratory inorganics, and ecotoxicity. Another impact is that boilers dominate climate change and land use, while the drying process impact is to respiratory organics and minerals is dominant.

1. Electricity and Drying

The use of heat exchangers will reduce electrical energy while reducing the impact (pollution) on the environment. A heat exchanger will reduce the heat required for the dryer, extend its service life, and increase efficiency [10]. A heat exchanger is a device that transfers energy from the wasted heat to the device. The energy obtained from this medium can be utilized directly or stored for further use. The type of heat exchanger chosen is an economizer because of the potential savings of up to 18% and can work at low or high temperatures (400F-800F) [11].

The boilers in PT FRP work at temperatures of 600F-700F with potential savings at that temperature of 9%-12%. This recommendation for improvement using a heat exchanger is an environmental audit recommendation for [10]. The company is also engaged in the crumb rubber industry.
2. Boiler
The recommendation given is to combine palm kernel shell fuel and palm fiber. Both of these fuels are sources of biomass energy that become residue from palm oil processing. The water content of oil palm fiber is lower than that of oil palm shells. The water content harms the calorific value, where the higher the water content, the more complex the initial ignition of the fuel and the smaller the heat produced [12]. The water content of oil palm fiber is 12.6% with a calorific value of 3,864 Kcal/kg, while the palm kernel shell is lower at 16% water content and a calorific value of 3,773 Kcal/kg [13].

Oil palm fiber's carbon content (C) is lower than oil palm fiber, 47.2 for palm fiber, while the shell is 52.4. The high content of C causes the need for oxygen (O₂) to be higher. The air requirement for burning oil palm shells is 6.66 kg/kg shell, while the fiber is 5.98 kg/kg [14].

CO₂ emissions resulting from burning palm shells ranged from 0.7% to 3.3%, while palm fiber from 0.75% to 3%. CO emissions from burning oil palm shells are 0.16%-0.46%, while palm fiber is lower at 0.08%-0.38%. Oil palm shells are more difficult to burn than palm fiber, although the energy produced is higher at 5.12 MJ/kg while oil palm fiber is 2.19 MJ/kg [15]. So, it can be concluded that the recommendation of combining these two fuels can improve the impact of using boilers on the environment because the emissions produced by palm fiber are lower than oil palm shells.

3. Generator set
It can be done by substituting diesel fuel with Pertamina dex. Pertamina Dex fuel is the most efficient fuel than the other two fuels. Pertamina Dex saves 57.1% more than Biosolar and 19% more than Dexlite [16]. The sulfur content of Pertamina Dex fuel is also low below 300 ppm, while Dexlite is a maximum of 1,200 ppm [17]. In addition, based on the results of the CO emission test, the results for diesel fuel are 900 ppm while Pertamina Dex fuel is only 600 ppm [18].

4. Conclusion
PT FRP's crumb rubber product life cycle consists of twelve processes, electricity, transportation, breaking and washing, creeping, pre-drying, shredding, drying, weighing and press, packing and marking, boiler, generator set, and WWTP. After analyzing the environmental impact assessment, a single score of 369 Pt was obtained, with the most influential impact category being respiratory inorganics. The process that produced the highest impact value was the use of electricity worth 105 Pt. Based on comparison contribution analysis, it can be concluded that arsenic emissions cause carcinogens most to water 18.5% and PM₂.₅ to air 9.74% as results of electricity; respiratory organics due to NMVOC 37.2% and methane 0.154% as results of the drying process; respiratory inorganics due to PM₂.₅ to air 29% as a result of electricity; climate change due to CO₂ to air 11.30% as a result of boiler process; radiation due to carbon-14 37.2% as results of generator set process; ozone layer due to methane 39.5% as a result of generator set process; ecotoxicity due to nickel 17.9% as a result of electricity; acidification due to NO₄ 40.9% and SO₂ 3.25% as a result of generator set process; land use due to annual harvest occupation and transformation 45% as a result of the drying process; minerals due to nickel 16.77% as a result of the drying process; and fossil fuels due to oil 30.7% as a result of generator set process. Improvement recommendations given to reduce the effects of the four operations are using an economizer in the boiler, the combination of fuel used by the boiler, and substitution of diesel fuel with Pertamina Dex as generator's fuel. In order to evaluate the environmental impact of the proposed improvement, further LCA study is needed through comparison with the initial impact to recommend the environmentally-friendly system.

References
[1] Kementerian Energi dan Sumber Daya Mineral 2019 Statistik Ketenagalistrikan Tahun 2018 Direktorat Jenderal Ketenagalistrikan Jakarta
[2] Regulation of the Minister of Environment and Forestry Number 1/BN2021/NO82 concerning the Company Performance Rating Program in Environmental Management.
[3] SNI ISO 14004 2016 Manajemen lingkungan-Penilaian daur hidup-Prinsip dan kerangka kerja. Badan Standardisasi Nasional
[4] SNI ISO 14044 2017 *Manajemen lingkungan-Penilaian daur hidup-Persyaratan dan Panduan. Badan Standardisasi Nasional*

[5] Goedkoop M J 2001 *The Eco-indicator 99 a damage oriented method for life cycle impact assessment methodology report. Pre Consultants*

[6] GaBi 2011 *Handbook For Life Cycle Assessment (LCA) Using The GaBi Education Software Package. PE International* (Germany: Leinfelden-Echterdingen)

[7] PT PFR 2019 *Environmental and Social Impact Assessment-Environmental Management and Monitoring Reports (UKL-UPL). Padang: PT PFR*

[8] PT PFR 2020 *Company Profile. Padang: PT PFR*

[9] Utomo T P, Hasanudin U and Suroso E 2010 *Comparative study of low and high-grade crumb rubber processing energy. In Proceedings of World Congress on Engineering*

[10] Ughwumiakpor V O, Obarnor A I and Aliu S A 2017 *International Journal of Scientific and Research Publications* 7(9) 318-334

[11] The New York State Energy Research and Development Authority (t.t) *A Guide To Heat Exchangers For Industrial Heat Recovery. New York*

[12] Setiawan Y 2016 *Jurnal Program Studi Teknik Mesin* 1(1)

[13] Siswanto J E 2020 *Journal of Electrical Power Control and Automation (JEPCA)* 3(1) 22-27

[14] Mahlia T M I, Abdulmuin M Z, Alamsyah T M I and Mukhlishien D 2001 *Energy conversion and management* 42(18) 2109-2118

[15] Mohamed W A N W and Abdullah N R 2008 *Combustion Characteristics of Palm Shells and Palm Fibers Using an Inclined Grate Combustor. Carbon NY* 57 48-94

[16] Kurniawan D 2018 *Analisis Perbandingan Jenis Bahan Bakar Pada Mesin Diesel Isuzu 4eci 1500cc Terhadap Opasitas Gas Buang* (Doctoral dissertation, Universitas Gadjah Mada)

[17] Pertamina 2020 *Kenali Jenis BBM yang Sesuai untuk Kendaraan Anda. Available from: https://www.pertamina.com/id/news-room/energia-news/kenali-jenis-bbm-yang-sesuai-untuk-kendaraan-anda.*

[18] Musa M I and Haruna H 2019 *Analisis Penggunaan Bahan Bakar Solar dan Pertamina Dex Terhadap Emisi Gas Buang Mesin Diesel. In Seminar Nasional LP2M UNM*