Life cycle assessment (LCA) of portland composite cement (PCC) 50 kg papercraft bag at PT. Semen Padang

T Panggabean*, R Aziz¹, Y Dewilda¹

¹ Department of Environmental Engineering, Faculty of Engineering, Universitas Andalas, Limau Manis, Padang, West Sumatera 25163, Indonesia

Abstract. PT. Semen Padang produces several cement types, including PCC, with a total production of up to 6,568,354 tons in 2018. PCC production reached 54% of the total, where the size of 50 kg bag dominates the production with 93%, and the use of papercraft bags as the cement packaging is 78.39%. This research aims to analyze the environmental impacts of the production of 1 ton of PCC 50 kg paper craft bag using the LCA method. The gate-to-gate approach applies as the boundary, ranging from raw mill till packing unit. The impact assessment method uses IMPACT 2002+ to assess the environmental impact of the production. The result shows that the highest environmental impacts are global warming, non-renewable energy, and respiratory inorganics, with the value amounted to 0.10884252 Pt. The process of calcination and coal used in the kiln, packaging transport by diesel-powered trucks, and electricity use is the main contributor to the impact value. In order to improve the PCC production, it is recommended to have an alternative fuel on the kiln unit using rice husks or Miscanthus giganteus.

1. Introduction

Infrastructure development is a means to improve human welfare. Indonesia, one of many developing countries, is currently aggressively repairing old infrastructure and building new infrastructure, which desperately needs cement. The cement industry generally uses coal as fuel where the greatest energy consumption and CO₂ emissions occur in the kiln process due to the burning process of limestone and fuel in the kiln [1]. The burning of coal can emit CO₂ which harms the environment in the form of global warming, depletion of the ozone layer, and a decrease in human health [2,3].

Through the Ministry of Environment and Forestry (KLHK), the Indonesian government has a Company Performance Rating Program (PROPER) that aims to encourage companies to comply with laws and regulations and carry out environmental management activities. In line with global developments and strengthening PROPER performance, the Ministry of Environment and Forestry's PROPER secretariat has begun to apply the LCA method as a prerequisite for the assessment [4]. The LCA method's application aims to calculate and identify the use of natural resources and disposal (emissions/waste) into the environment. The identification and calculation results were evaluated for further use as a reference in environmental improvement [5].

PT. Semen Padang is the first cement industry established in Indonesia and Southeast Asia. The company has five cement processing plants (Indarung II-VI) located in West Sumatra, Padang. PT. Semen Padang Indarung Factory in 2018 produced Type I, PPC, and PCC cement [6].
Traditionally, factors that are generally considered in product design include function, quality, cost, ergonomics, and safety. At the same time, there is no special consideration of a product's environmental aspects throughout its entire life cycle. The conventional "end of pipe" system only focuses on emissions from the manufacturing process. However, adverse impacts on the environment occur in the entire product life cycle. If the entire product life cycle is not studied and analyzed, the environmental problems that occur cannot be handled optimally. Due to this, a new paradigm was born, namely sustainable consumption and production. This paradigm has been accepted as the primary goal to be achieved in society [7]. Based on research conducted by Garcia-Gusano (2014), the cement industry is advised to replace fossil fuels with alternative fuels to reduce the negative impact of coal use [8].

LCA is a transparent analysis of the environmental impact of a product, system, or service, including the acquisition of raw materials, production, use, and end of life. Identifying the potential impacts of the product or service life cycle can further reduce environmental impacts and save production costs. The LCA study framework includes defining objectives and scope, inventory analysis, impact assessment, and interpretation [9]. There are four main options for determining the system boundaries used in an LCA study based on ISO 14044 standards, including gate-to-gate, cradle-to-gate, gate-to-grave, and cradle-to-grave [10].

Consider the further evaluation of PCC's production and its impact on the environment; this study aims to assess the environmental impact of cement production by applying the LCA and seeking recommendations for improving the system to make it more environmentally friendly.

2. Methodology
This research was conducted at PT. Semen Padang Indarung V factory is located in the city of Padang, West Sumatra. Observation and data collection were carried out at locations that supported obtaining information on this research data. Data were collected from August 2019 to January 2020 and continued with report writing from February 2020 to March 2020.

2.1. Research goals and scope definition
1. Research goals
   a. Knowing the product life cycle of 1 ton of PCC at PT. Semen Padang;
   b. Analyze the inventory in the form of types and quantities of raw materials, materials, energy, products, and emissions resulting from the production of 1 ton of PCC;
   c. Analyze the environmental impacts resulting from the 1 ton PCC life cycle;
   d. Recommend improvements needed in the cement life cycle of 1 ton PCC to make the production process more environmentally sound.
2. Scope and system boundary
Inventory data collected consists of the foreground system and background system. Foreground systems are processes that can be measured directly or obtained from PT. Semen Padang (primary data), background systems are processes that cannot be measured directly and are not data from PT. Semen Padang (secondary data). The limitations of the 1 ton PCC production system and the categories of inventory data collected can be seen in figure 1 below.

2.2. Inventory analysis
Inventory analysis includes materials and raw materials, energy, and natural resources shown in inventory tables. All data inputted into the SimaPro software for impact analysis.

2.3. Impact assessment
This stage was carried out using the IMPACT 2002+ method. This method was chosen because it contains an assessment of global warming's impact, which is the highest impact on the cement industry. The impact assessment stages include impact classification, impact characteristics, normalization, and a single score.
Figure 1. The system boundary of 1 ton PCC production.

2.4. Interpretation
This stage includes comparative analysis and contribution analysis.

3. Result and discussion

3.1. Inventory analysis
Table 1 below shows the collected inventory data of 1 ton PCC production in PT. Semen Padang.

| No. | Process                              | Parameter                  | Amount  | Unit |
|-----|--------------------------------------|----------------------------|---------|------|
| 1.  | Raw Mill                             | Input: Limestone (CaCO₃)   | 1.03    | ton  |
|     |                                       | Silicon (SiO₂)             | 0.15    | ton  |
|     |                                       | Clay (Al₂O₃)               | 0.065   | ton  |
|     |                                       | Copper Slag                | 0.016   | ton  |
|     |                                       | Oil Lubricant              | 0.048   | l    |
|     |                                       | Grease Lubricant           | 0.035   | g    |
|     |                                       | Electricity                | 32.37   | kWh  |
|     | Output:                               | Raw Mix                    | 1.23    | ton  |
|     |                                       | Particulate (SPM)          | 64.82   | g    |
| 2.  | Kiln System (Preheating-Kiln-Cooling)| Input: Raw Mix             | 1.23    | Ton  |
|     |                                       | Oil Lubricant              | 0.06    | L    |
|     |                                       | Fine Coal                  | 179.2   | Kg   |
|     |                                       | Electricity                | 38      | kWh  |
|     | Output:                               | Clinker                    | 0.76    | Ton  |
|     |                                       | Nitrogen dioxide (NO₂)     | 0.62    | Kg   |
|     |                                       | Sulfur dioxide (SO₂)       | 0.1     | Kg   |
3.2. Impact assessment

Based on table 2 below, the process that contributes to the most dominant environmental impact is the kiln system. It is the major contributor to carcinogens' effects, non-carcinogens, respiratory inorganic, aquatic ecotoxicity, terrestrial ecotoxicity, terrestrial acid/nutri, aquatic acidification, global warming, and non-renewable energy. Meanwhile, the main contributor to the impact of respiratory organics is the packing process.

| Impact category                | Impact Value             | Percentage (%) |
|-------------------------------|--------------------------|----------------|
| Carcinogens                   | 2.99E-05                 | 0.027471       |
| Non-carcinogens               | 0.000313627              | 0.288147       |
| Respiratory inorganics        | 0.009561724              | 8.784916       |
| Respiratory organics          | 9.72E-10                 |                |
| Aquatic ecotoxicity           | 2.61E-07                 |                |
| Terrestrial ecotoxicity       | 0.000154123              |                |
| Terrestrial acid/nutri        | 0.000289996              |                |
| Global warming                | 0.073468941              |                |
| Non-renewable energy          | 0.025023933              |                |

The single score below shows that the impact category with the highest value is global warming, with an amount of 0.073468941 Pt and dominates the overall impact with a percentage of 67.50%. The impact category with the lowest score was respiratory organics with a 9.72E-10 Pt score and a percentage of 0.000001%. The total impact value from the production of 1 ton of PCC is 0.10884252 Pt.

| Impact category                | Unit   | Impact Value   | Percentage (%) |
|-------------------------------|--------|----------------|----------------|
| Carcinogens                   | Pt     | 2.99E-05       | 0.027471       |
| Non-carcinogens               | Pt     | 0.000313627    | 0.288147       |
| Respiratory inorganics        | Pt     | 0.009561724    | 8.784916       |
### Table 4. Environmental impact characterization of 1 ton PCC production.

| Impact Category   | Unit                | Total   | Raw Mill | Kiln System | Cement Mill | Packing |
|-------------------|---------------------|---------|----------|-------------|-------------|---------|
| Carcinogens       | kg C₆H₇Cl eq        | 0.075779 | 0.022160 | 0.026015    | 0.020538    | 0.007065 |
|                   | %                   | 100     | 29.2438  | 27.1027     | 21.5302     | 9.3233  |
| Non-carcinogens   | kg C₆H₇Cl eq        | 0.794395 | 0.232311 | 0.272717    | 0.215302    | 0.074023 |
|                   | %                   | 100     | 29.2438  | 27.1027     | 21.5302     | 9.3233  |
| Respiratory       | kg PM₂,₅ eq         | 0.096877 | 0.020963 | 0.090196    | 0.020538    | 0.007065 |
| inorganics        | %                   | 100     | 29.2438  | 27.1027     | 21.5302     | 9.3233  |
| Respiratory       | kg C₆H₆ eq          | 3.24E-06| 2.69E-07 | 3.16E-07    | 2.49E-07    | 2.40E-06|
| organics          | %                   | 100     | 8.3081   | 7.6990      | 7.4233     |
| Aquatic           | kg TEG water        | 71.1176 | 20.7957  | 24.4148     | 19.2748     | 6.6305  |
| ecotoxicity       | %                   | 100     | 29.2438  | 27.1027     | 21.5302     | 9.3233  |
| Terrestrial       | kg TEG soil         | 266.9125| 78.0554  | 91.6313     | 72.3405     | 24.8851 |
| ecotoxicity       | %                   | 100     | 29.2438  | 27.1027     | 21.5302     | 9.3233  |
| Terrestrial       | kg SO₂ eq           | 3.819761| 0.092509 | 3.611155    | 0.085737    | 0.030597 |
| acid/nutri        | %                   | 100     | 2.421875 | 2.455528    | 0.794807    |
| Aquatic           | kg SO₃ eq           | 0.619158| 0.024875 | 0.563197    | 0.023050    | 0.008039 |
| acidification     | %                   | 100     | 4.016975 | 2.245552    | 0.794807    |
| Global warming    | kg CO₂ eq           | 727.4152| 12.6927  | 69.8900     | 11.7635     | 4.05864 |
| Non-renewable     | MJ primary          | 3803.0293| 0        | 3803.0293   | 3803.0293   |
| energy            | %                   | 100     | 0        | 100         | 0           |

Explanation: The highest impact value

### 3.3. Interpretation

#### 3.3.1. Comparative analysis

Comparative analysis was carried out to determine each process stage's comparison in each category of environmental impacts assessed in the IMPACT 2002+ method. Figure 2 shows that the kiln system impact's percentage value dominates almost all impact categories, except respiratory organics.

![Figure 2. Comparison of the environmental impact on each unit process.](image-url)
3.3.2. **Contribution analysis.** Contribution analysis is used to identify the process that has the most dominant contribution to the impact assessment results. The processes and substances that affect the value of each impact category are shown in table 5 below.

| Impact category          | Contributor (Process) | Value (Pt) | Contributor (Substance) | Value (Pt) |
|--------------------------|-----------------------|------------|-------------------------|------------|
| Carcinogens              | Electricity           | 29,917921  | Arsenic                 | 2,99E-05   |
|                          | Electricity           | 0,0003136  | Ammonia                 | 8,83E-10   |
|                          | Transport, truck, diesel-powered | 5,85E-12 | Antimony               | 4,01E-06   |
|                          |                       |            | Arsenic                 | 0,000300195|
|                          |                       |            | Hydrogen sulfide        | 5,48E-09   |
|                          |                       |            | Mercury                 | 9,42E-06   |
| Non-carcinogens          | Kiln system           | 0,008559   | Ammonia                 | 5,25E-07   |
|                          | Electricity           | 1,00E-03   | Carbon monoxide         | 3,75E-07   |
|                          | Transport, truck, diesel-powered | 2,55E-06 | Nitrogen dioxide        | 0,007789204|
|                          |                       |            | Nitrogen monoxide       | 1,10E-06   |
|                          |                       |            | Nitrogen oxides         | 0,000606405|
|                          |                       |            | Particulates, < 10 µm   | 2,27E-07   |
|                          |                       |            | Particulates, < 2,5 µm  | 3,46E-07   |
|                          |                       |            | Sulfur dioxide          | 0,001163546|
| Respiratory inorganics   | Kiln system           | 0,0001541  | Ammonia                 | 6,27E-13   |
|                          | Electricity           | 2,76E-10   | Methane                 | 2,77E-10   |
|                          | Transport, truck, diesel-powered | 6,96E-10 | VOC, volatile organic compounds, unspecified origin | 6,95E-10 |
| Respiratory organics     | Electricity           | 2,61E-07   | Ammonia                 | 6,27E-13   |
|                          | Transport, truck, diesel-powered | 4,15E-15 | Antimony               | 6,82E-08   |
|                          |                       |            | Arsenic                 | 1,22E-08   |
|                          |                       |            | Mercury                 | 1,80E-07   |
| Aquatic ecotoxicity      | Electricity           | 0,0001541  | Ammonia                 | 2,48E-10   |
|                          | Transport, truck, diesel-powered | 1,64E-12 | Antimony               | 7,30E-07   |
|                          |                       |            | Arsenic                 | 1,47E-05   |
|                          |                       |            | Mercury                 | 0,000138671|
| Terrestrial ecotoxicity  | Kiln system           | 0,0002659  | Ammonia                 | 4,98E-08   |
|                          | Electricity           | 2,40E-05   | Nitrogen dioxide        | 0,000258325|
|                          | Transport, truck, diesel-powered | 6,58E-08 | Nitrogen monoxide       | 3,64E-08   |
|                          |                       |            | Nitrogen oxides         | 2,01E-05   |
|                          |                       |            | Sulfur dioxide          | 1,15E-05   |
| Terrestrial acid/nutri   | Kiln system           | 0,069084   | Carbon dioxide          | 0,073467032|
|                          | Electricity           | 0,0043837  | Carbon dioxide, fossil  | 1,21E-06   |
|                          | Transport, truck, diesel-powered | 1,21E-06 | Carbon monoxide        | 5,77E-07   |
|                          |                       |            | Carbon monoxide, fossil | 4,83E-09   |
|                          |                       |            | Dinitrogen monoxide     | 5,43E-10   |
| Global warming           | Kiln system           | 0,0250239  | Coal, hard             | 0,025023933|
|                          | Electricity           | 0,10884252 | Coal, hard             | 0,10884252 |

The most dominant contributor to the impact of carcinogens is the use of electricity from PLN, which emits a carcinogen in the arsenic form. The effect of non-carcinogens is generated from the dominant emission of ammonia, antimony, arsenic, H₂S, and mercury caused by the use of electricity and a diesel-powered transport truck. Respiratory inorganics are generated from the emission of ammonia, CO, NO₂, NOₓ, and particulates <10 µm and <2.5 µm, which are predominantly caused by the use of fine coal as fuel in the kiln, use of electricity, and diesel-powered transport trucks. Respiratory
organics are generated from volatile organic carbon (VOC) and methane, predominantly from the use of electricity and diesel-powered transport trucks.

The dominant aquatic ecotoxicity and terrestrial ecotoxicity impacts are caused by electricity uses and the diesel-powered truck, which emits ammonia, antimony, arsenic, and mercury. The main contributors to the impact of terrestrial acid/nutrients are the use of fine coal as fuel in the kiln, electricity use, and a diesel-powered transport truck with emissions in the form of ammonia, CO, NO₂, NO₃, and SO₂. The impact value on the global warming category is generated using fine coal as fuel in the kiln, the use of electricity, and a diesel-powered transport truck with emissions in the form of ammonia, CO, CO₂, NOx, and methane. The impact of non-renewable energy using fine coal as fuel in the kiln.

Therefore, due to PCC production improvement, recommendations for improvements that can be given to fine coal as a fuel are gradually reducing its use and combining it with biomass. One of the conventional biomass that can be used as fuel is rice husk. PT Holcim Indonesia Tbk. since 2007 has carried out the use of rice husks as an alternative fuel to replace coal [11].

Apart from rice husks, another type of biomass that can be utilized is the Miscanthus giganteus (giant reed) plant that can be used as fuel to generate heat. The University of Illinois has carried out research and development on the use of this plant as biomass fuel since 2002, with an average production volume of 13.7 tonnes/acre. This plant can be developed with a short harvest period, which is four months at the first harvest, and after that, it can be harvested every two months, with a productive age of 6-8 years. This plant is easy to grow globally in various geographies, climates, and soil types. These plants can reach 8-12 ft in height [12].

The cultivation of the Miscanthus giganteus plant can help increase biomass fuel production by utilizing local resources. Another advantage of Miscanthus giganteus cultivation is that it is not a food crop, so the price will be stable because it does not compete with human food needs. Besides, the cultivation of these crops can provide new income streams for farmers and landowners. In Indonesia, this plant cultivation has been carried out by CV. Prima Indoargo Fortuna collaborates with the Faculty of Mathematics and Natural Sciences, Sebelas Maret University (UNS) [13].

4. Conclusion
This study assesses the product life cycle of 1 ton of PCC at PT. Semen Padang consists of a raw mill, kiln system (preheating-kiln-cooling), cement mill, and packing. PT. Semen Padang uses the raw material for making PCC consists of limestone, silicon, clay, copper slag, gypsum, fly ash, and additives (limestone and pozzolan). Additional materials in the production process are oil lubricant, grease lubricant, and cement bags. The energy used comes from burning fine coal and PLN electricity. The primary emissions produced are CO₂ and other emissions, namely NOx, SO₃, and particulate (SPM). Rated impact based on a single score is the product of the 1 ton of PCC is equal to 0.10884252 Pt, with the three highest categories of global warming impacts, non-renewable energy, and respiratory inorganics. Recommendations for improvement that can be given are combining coal fuel in the kiln with biomass with a combination option, namely with rice husks or Miscanthus giganteus.

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