Environmental Impact Studied using Life Cycle Assessment on Cement Industry

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Abstract. The rapid development in Indonesia has caused cement production to be directly proportional to its needs. The cement industry produces commercial cement for domestic development needs. Cement is made by means of a series of exploitation and production processes that involve the main process and supporting processes in its activities. To be able to produce cement, it requires raw materials, fuel and chemical additives, and these activities produce emissions that have an impact of decreasing environmental quality. The gas emissions produced are CO₂, CH₄, NOₓ, SO₂, N₂O and particulate. These emissions have an impact of increasing global warming and decreasing ambient air quality which has an impact on human health and the environment. This study identifies the impact of the main process based on the cradle-to-gate approach, starting from the process of exploitation of raw materials to the production process that produces cement as the main product. Impact identification was done using the Life Cycle Assessment (LCA) method with the SimaPro 8.5.2 application. The Life Cycle Impact Assessment (LCIA) categories include global warming potential for 100 years, acidification, and carcinogens. The method used was TRACI, a midpoint approach. Results after normalization show that the highest impacts generated were global warming from kiln process (353,473); acidification from kiln process (95,273), and carcinogens from raw mill process (4,837,721).

Keywords: LCA, cement, SimaPro

1. Introduction
Cement demand in Indonesia had increased by 63% in the past 10 years. It was recorded that cement consumption in 2010 amounted to 40.78 million tonnes, while cement demand until the end of 2017 reached 107.4 million tonnes [1]. Cement is one of the main ingredients in building construction. High cement production has an impact of the high consumption of energy and raw materials needed so that it has a serious impact on the environment [2]. Along with the rapid development of cement, several types of cement emerged, including Ordinary Portland Cement (OPC), White Cement, and Portland Composite Cement (PCC). The main source of fuel used in making cement is coal, specifically in the combustion process in kilns.
In 2017, the production of cement was 29.6 million tonnes, while its total energy consumption was 53,559,270 GJ per year [3]. Materials used in making cement are limestone, clay, silica sand, copper slag, iron sand, gypsum, trass, fly ash, and return dust. The main type of cement produced by the studied cement industry was portland type II-V (non-OPC) cement [3]. Sources of energy used were coal, biomass, IDO (Industrial Diesel Oil), and electricity.

The process of burning coal from the main process of the cement industry produces CO\(_2\), NO\(_x\), SO\(_2\) and particulate emissions. The emissions of exhaust gases produced are dominated by CO\(_2\) gas. 0.5 tonnes of CO\(_2\) are produced per tonne of cement in the decarbonisation process of limestone when the raw material is burned. Then 0.75 tons of CO\(_2\) are produced from burning fuel to operate the kiln. So the total CO\(_2\) emissions generated from the cement production process are 162 tons. Pollutant gases can cause health problems in humans, such as damage to the composition of hemoglobin, Acute Respiratory Infection (ARI), throat irritation, pneumocinosis, cardiovascular disease, and cancer [4].

Based on existing conditions, it was necessary to make alternative strategies to reduce the burden of emissions generated from the production and exploitation processes. To analyze the environmental impacts caused by the production process, one of the methods that can be used is the Life Cycle Assessment (LCA) method. One of the advantages of the LCA method is that one can analyze the potential impacts that can occur in the environment comprehensively. Through the LCA method, environmental impacts, i.e. any changes that occur in the environment, can be investigated whether they are harmful or beneficial, entirely or partly due to environmental aspects [5].

The application chosen to run the LCA method is SimaPro because it can effectively help implement LCA expertise, help strong decision making, and change the product life cycle to be better. The approach used to run SimaPro in this study is the midpoint approach, which focuses on one environmental problem. The midpoint approach used is TRACI [6]. This study aims to identify the impacts caused in a series of exploitation and production processes of the cement industry using the LCA method.

2. Methods

This study focuses on fuels, raw materials, products, and emissions generated from the activities of the process of exploitation and production of cement at a cement company. The activities analyzed included the main processes and processes in the supporting units that are the source of stationary emissions in the cement industry. The exploitation process involves mining of raw materials in the quarry unit. The production process includes a crusher unit, raw mill, pre-heater, kiln, cooler, coal mill, finish mill, packer and supporting unit facilities.

![Diagram of cement production process](image)

**Figure 1.** System boundaries for cement production LCA
For an analysis of the impacts that occur from each activity analyzed, the LCA method is used. The analysis was carried out on data on fuels, raw materials, chemicals, products, and emissions produced in exploitation and production activities. In conducting an impact analysis with the LCA method, SimaPro software was used. The steps taken in analyzing the impact with the LCA method using SimaPro software are as follows:
1. Collect data on fuel, raw materials and chemicals used
2. Collect data on emissions produced
3. Convert the unit of data values of each processing unit into the same unit
4. Determine the boundary of analysis by selecting a database that will be used in the research on SimaPro 8.5.2.
5. Input data into the SimaPro: fuel, raw materials, chemicals, products, and emissions that have been converted into the same unit
6. Select the environmental impact assessment method used in the research on the SimaPro. In this study, the TRACI method was used.
7. Perform the characterization stage
8. Perform normalization stages
9. From the data entered in the SimaPro 8.5.2 software, the impact of each activity would be analyzed according to the chosen impact category.

3. Results and discussion

3.1 Life cycle inventory
Life cycle inventory (LCI) is a stage in the life cycle assessment (LCA), which describes the inventory of data inputs and outputs from the production process. Inventory is based on material input and output in the system. LCI results are classified into assessment categories, each having category indicators. The following is the LCI of each production process at the Cement Industry during 2018.

- Mining unit
Mining activities at the Cement Industry functioned as a raw material miner unit needed in making cement. Raw materials obtained from the mine are limestone and clay. The following is the input and output from exploitation unit:

| Table 1. Mining unit inventory |
|-------------------------------|
| **Input** | **Output** |
| **Energy** | **Quantity** | **Emissions** | **Quantity** |
| 1 | IDO | 12,512 kWh | 1 | CO₂ | 69,485 t |
| 2 | | | 2 | SO₂ | 270 t |
| 3 | | | 3 | NO₂ | 5,351 t |
| 4 | | | 4 | PM | 431 t |
| 5 | | | 5 | CO | 2,560 t |
| **Product** | **Quantity** |
| 1 | Limestone | 15,474,525 t |
| 2 | Clay | 3,516,160 t |
• Crusher unit

The crusher unit serves to crush large clay and limestone so that they are smaller when later processed in the raw mill. Clay and limestone are received from the exploitation unit.

Table 2. Crusher unit inventory

| Material   | Quantity       | Energy        | Quantity     | Emissions         | Quantity |
|------------|----------------|---------------|--------------|-------------------|----------|
| 1 Electricite | 278,683,246 kWh | 1 | CO₂ secondary | 202 t |
| 1 Limestone | 15,474,525 t   | 1 | Crushed limestone | 15,474,525 t |
| 2 Clay      | 3,516,160 t   | 2 | Crushed clay   | 3,516,160 t |

• Raw mill unit

Materials that have passed through automatic scales containing a mixture of limestone, clay, silica sand and iron sand is then carried out by grinding and drying in the raw mill until it reaches a certain degree of fineness.

Table 3. Raw mill unit inventory

| Material   | Quantity       | Emissions | Quantity |
|------------|----------------|-----------|----------|
| 1 Limestone | 15,474,525 t   | SO₂       | 2.73 t   |
| 2 Clay      | 3,516,160 t   | NO₂       | 22.32 t  |
| 3 Silica sand | 353,342 t | PM        | 0.41 t   |
| 4 Iron sand | 78,359 t      |           |          |
| 5 Copper slag | 230,261 t | Raw meal  | 19,668,427 t |
| 6 Iron ore  | 15,805 t      |           |          |

• Coal mill unit

The main function of the coal mill is to crush the coal that will be used for combustion.

Table 4. Coal mill unit inventory

| Material   | Quantity       | Energy        | Quantity     | Emissions         | Quantity |
|------------|----------------|---------------|--------------|-------------------|----------|
| 1 Coal mill | 2,396,587 t   | 1 | CO₂       | 457 t |
| 2 PM       | 2,156 t      | 1 | Crushed coal | 2,029,826 t |
• Kiln unit
The function of the kiln is to burn material into clinker slag.

| Table 5. Kiln unit inventory |
|-----------------------------|
| **Material** | **Input** | **Quantity** | **Output** | **Quantity** |
| Raw meal | 19,668,427 t | CO₂ primary | 9,286,647 t |
| Energy | Quantity | CO₂ secondary | 275 t |
| Electricity | 379,893,019 kWh | CH₄ | 145 t |
| IDO | 1,207 t | N₂O | 70 t |
| Crushed coal | 2,029,826 t | PM | 2,259 t |
| Rice husk | 41,009 t | | |
| Cocopeat | 12,564 t | Clinker | 9,978,633 t |
| Tobacco aval | 5,127 t | |
| Resin | 861 t | |
| Refused derive fuel | 2,700 t | |

• Finish mill unit
Finish mill is a cement making unit in the final stage. At this stage there will be mixing, grinding and refining process. Besides, at this stage, there will be the addition of a third material to determine the type of cement to be processed.

| Table 6. Finish mill unit inventory |
|-----------------------------|
| **Material** | **Input** | **Quantity** | **Output** | **Quantity** |
| Clinker | 9,978,633 t | CO₂ secondary | 295 t |
| Gypsum | 467,067 t | PM | 20 t |
| Spent earth | 7,675 t | PM | 2 |
| Bottom ash | 156,439 t | Cement | 12,395,563 t |
| Fly ash | 127,745 t | |
| Limestone | 582,858 t | |
| Blast furnace slag | 304,793 t | |
| Energy | Quantity | CO₂ secondary | 295 t |
| Electricity | 407,183,164 kWh | |

• Packer unit
After going through the final processing stage at the finish mill, the cement from the cement silo will be transported by air slide conveyor towards the packer. The cement packing process uses a rotary packer machine.
Table 7. Packer unit inventory

| Input              | Material | Quantity     | Output       | Emissions   | Quantity |
|--------------------|----------|--------------|--------------|-------------|----------|
| 1 Cement           | Energy   | 12,395,563 t | 1 CO₂ secondary | 12.73 t    |          |
| 1 Electricity      | Energy   | 17,563,953 kWh | 2 PM          | 0.35 t     |          |
|                    | Product  | 1 Packing cement | 12,395,563 t |            |          |

3.2 Life cycle impact assessment (LCIA)
Impact estimates were calculated based on the input and output at each activity. The method used in the process of determining impact is TRACI 2.1. The type of approach used is the midpoint approach, where it refers to the impact assessment results that are specific per impact category. Some of the impact categories that can be analyzed using the TRACI 2.1 approach include ecotoxicity, global warming, smog formation, acidification, eutrophication, carcinogens, non-carcinogens, respiratory effects, ozone depletion, and fossil fuel depletion [6]. LCIA does the handling of impacts on the environment, where all the impacts of the resources and emissions produced are grouped and quantified into a certain number of impact categories which are then weighed according to their level of importance. The stages in LCIA for the midpoint approach consist of characterization and normalization.

Characterization is the stage where the SimaPro application will display the contribution relative to the environmental impact. This stage measures the contribution of the impact of the product or activity on each impact indicator. In its calculation, characterization factors are used to convert the LCI results into the shape of each impact. Normalization is a comparison of the selected impact indicators. This stage normalizes the indicator results by dividing them by the selected reference value. Following are the normalization factor values:

Table 8. Normalization factor

| Impact Category      | Normalization Factor $[\text{M}]$ |
|----------------------|-----------------------------------|
| Ecotoxicity          | $7.6 \times 10^1$                 |
| Carcinogens          | $5.5 \times 10^6$                 |
| Non-Carcinogens      | $3.7 \times 10^3$                 |
| Global Warming       | $2.4 \times 10^4$                 |
| Ozone Depletion      | $1.6 \times 10^1$                 |
| Acidification        | $9.1 \times 10^1$                 |
| Eutrophication       | $2.2 \times 10^4$                 |
| Smog                 | $1.4 \times 10^1$                 |
| Respiratory Effects  | $2.4 \times 10^1$                 |
| Fossil Fuel Depletion| $1.7 \times 10^4$                 |

The main function of impact assessment is to identify how much a process contributes to the environmental impact of a process. Of the overall activities in the cement production, each process contributes to the impact on the environment. At the characterization stage, each impact value appears automatically after being calculated by the SimaPro application based on material inputs, fuel, energy, and emissions. Below is the result of characterization life cycle impact assessment:
Table 9. Characterization of life cycle impact assessment

| Processing unit | Global Warming (kg CO₂ eq) | Acidification (kg SO₂ eq) | Carcinogens (CTUh) |
|-----------------|-----------------------------|---------------------------|-------------------|
| Exploitation    | 8,852,690.40                | 4,081,792.33              | 0.22              |
| Crusher         | 212,727,667.60              | 1,020,055.33              | 11.18             |
| Raw mill        | 636,922,752.00              | 4,196,228.04              | 2,550.40          |
| Coal mill       | 789,852,260.00              | 3,050,863.70              | 239.09            |
| Kiln            | 8,562,424,630.00            | 8,653,629.00              | 17.51             |
| Finish mill     | 2,205,661,000.00            | 2,304,978.60              | 231.64            |
| Packer          | 13,396,000.00               | 59,083.00                 | 0.70              |

Impacts resulting from the activities of the process of exploitation and production of cement were then converted into the same unit at normalization stage. The purpose of unit equivalence is so that the impact assessments produced in the running process of SimaPro can be compared with each other. In this normalization stage, the value that comes out is the result of the division between the value of the impact on the characterization and the normalization factor. The result of normalization of life cycle impact assessment are shown in Figure 2 to Figure 4.

Figure 2. Global warming impact on normalization stage
3.3 Interpretation
The impacts that arose from each process each had a different magnitude depending on material input, fuel, energy used, emissions released and the production process that occurred. Various types of impacts that arose needed to be analyzed more deeply to interpret the data on the SimaPro application with existing data and processes in the exploitation and production of cement. The purpose of this interpretation was to find out the hotspot with the greatest impact from a series of processes of cement exploitation and production. Impact hotspots are the biggest impact point in a process. Because the process between one unit and another is different, there will be differences in the value of the impact produced in each cement production process. The impact value is influenced by input data at the LCI stage. Input data are in the form of the type of raw material used, type of fuel, type of energy, and emissions produced along with the quantity. The value in the normalization stage is used as a
reference to find out the greatest impact, because at the characterization stage each impact has a different unit, so that the impacts cannot be compared between one another. In the normalization stage, equalization of all types of impacts is carried out. The value obtained from the normalization stage is the result of the value in the characterization stage divided by the normalization factor.

The hotspot point of the impact of global warming was found to be in the kiln unit with a potential impact of 353,473. This was influenced by the use of fuel in the form of coal, IDO, and several alternative fuels. The kiln unit produced the largest greenhouse gas emissions among other units. Besides, high-temperature heating is needed for burning fuel and coal in the process of forming calcination of limestone which releases large amounts of CO$_2$. Global warming is a form of ecosystem imbalance on earth caused by an increase in the average temperature of the earth's surface. For the past 100 years, the average temperature of the earth's surface had increased by 0.74°C. The main cause of this warming is the burning of fossil fuels which releases CO$_2$ and other gases into the atmosphere.

The hotspot point of the impact of acidification was found to be in the kiln unit with a potential impact of 95,273. Acidification is an environmental condition with a degree of acidity (pH) below 7. The cause of changing environmental conditions is at the acid level due to some chemical compounds being absorbed into the water/soil [8]. Air pollution is produced from combustion processes in industries and vehicles in the form of CO$_2$, SO$_2$, and NO$_2$. The compound will naturally experience a reaction with water, resulting in hydrogen ions which cause an increase in acidification. In the kiln unit a large amount of CO$_2$ was released through combustion and calcination processes.

The hotspot point of the impact of carcinogens was on the raw mill unit with a potential impact of 4,837,721. In the raw mill unit, there were grinding, smoothing, and mixing of raw materials. Some of the raw materials used were in the hazardous category. One of the hazardous materials was copper slag. Therefore, the potential impact of carcinogens on the cement production process was in the raw mill unit.

4. Conclusion
In this study, the cement production was analyzed using the life cycle assessment method. The results show that every process had different results on environmental category impact: global warming, acidification, and carcinogens. The environmental impact correlated with its input and output from each process in the cement production.

Global warming is influenced by greenhouse gases emission. The study results show that the highest damage of global warming was caused by kiln process with 8,562,424,630 kg CO$_2$-eq and 353,473 after normalization. Acidification is influenced by substances that can change environmental acidity to below 7. The study results show that the highest damage of acidification was caused by kiln process with 8,653,629 kg SO$_2$-eq and 95,273 after normalization. Carcinogens are influenced by substances that have potential toxicity to the environment. The study results show that the highest damage of carcinogens was caused by raw mill process with 2,550.40 CTUh and 4,837,721 after normalization. Between the 3 impact categories, carcinogens did the most damage after normalization, because it relates to human health.

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