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Environmental Impact Analysis in the Cement Industry with Life Cycle Assessment Approach

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Abstrak

Industri semen merupakan salah satu jenis industri yang berimplikasi pada timbulnya permasalahan pencemaran lingkungan dan penurunan kualitas lingkungan akibat polusi debu yang dihasilkan. Industri semen juga dapat meningkatkan suhu udara dan kebisingan dalam kegiatan operasional dengan menggunakan mesin. Selain itu, dampak industri semen adalah menurunnya kualitas kesuburan tanah akibat penambangan tanah liat. Dengan demikian, dibutuhkan sebuah kajian analisis yang dapat digunakan sebagai salah satu dasar kebijakan dalam proses operasional industri semen. Penelitian ini bertujuan untuk melakukan kajian analisis beban lingkungan pada setiap tahap dalam siklus hidup produk, pengambilan keputusan untuk mengidentifikasi beban lingkungan, dan mengevaluasi dampak lingkungan dari suatu produk yang memainkan peran penting dalam pembangunan berkelanjutan. Metode ini dikenal dengan *Life Cycle Assessment* (LCA). Pada penelitian ini sistem batasan yang digunakan adalah *cradle to gate* dengan pendekatan tiga skenario. Pertama menggunakan 100% bahan bakar batubara, yang kedua menggunakan 90% bahan bakar batubara, dan ketiga 10% biomassa sekam padi. Kemudian dilakukan analisis dengan menggunakan *software* OpenLCA. Hasil analisis diperoleh beban emisi yang paling signifikan adalah karbon dioksida sebesar 1229,31 kg CO2eq. Skenario ketiga menghasilkan beban emisi karbon dioksida terendah dibandingkan dengan metode lainnya sebesar 849,1 kg.

Kata kunci: semen, LCA, dampak, aspek, OpenLCA

Abstract

The cement industry is one type of industry that has implications for the emergence of environmental pollution problems and a decrease in environmental quality due to dust pollution. The cement industry can also increase air temperature and noise in operational activities by using machines. In addition, the impact of the cement industry is the decline in the quality of soil fertility due to clay mining. Thus, an analytical study is needed that can be used as one of the policy bases in the operational process of the cement industry. This study aims to conduct an analysis of environmental loads at each stage in the product life cycle, make decisions to identify environmental loads, and evaluate the environmental impact of a product that plays an important role in sustainable development. This method is known as Life Cycle Assessment (LCA). In this study, the boundary system used is cradle to gate with a three-scenario approach. The first uses 100% coal fuel, the second uses 90% coal fuel, and the third uses 10% rice husk biomass. Then the analysis was carried out using the OpenLCA software. The results of the analysis showed that the most significant emission load was carbon dioxide of 1229.31 kg CO2eq. The third scenario produces the lowest carbon dioxide emission load compared to other methods of 849.1 kg.

Keywords: *cement, LCA, Impact, Aspect, OpenLCA.*

I. INTRODUCTION

The cement industry is an important industrial sector for development in Indonesia, which can stimulate economic growth. The materials used as energy sources are fossil fuels such as coal and petroleum. Cement production can contribute about 4% to global CO_2 emissions and 7% industrial fuel use [1]. The cement industry also produces other emissions such as NOx, SO_2, PM, CO, VOC, and heavy metals [2]-[4]. To support sustainable

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development, it is necessary to approach all development sectors by paying attention to conversion issues and environmental capacity's carrying capacity. Sustainable cement production can improve energy efficiency, reduce pollutants, reuse wasted heat and use alternative raw materials and fuels that can be evaluated using the Life Cycle Assessment (LCA) [5].

LCA is a tool or method used to analyze environmental loads at each stage in the product life cycle. LCA is also used as a decision-making tool to identify environmental loads and evaluate the environmental impact of a product, process, or service in its life cycle and plays an essential role in sustainable development. Each step of the LCA is described in International Standards (ISO 14040, ISO 14041). This step is recurring, with the level of detail and effort depending on the research. These steps define objectives and scope, inventory analysis, impact analysis, and interpretation [6].

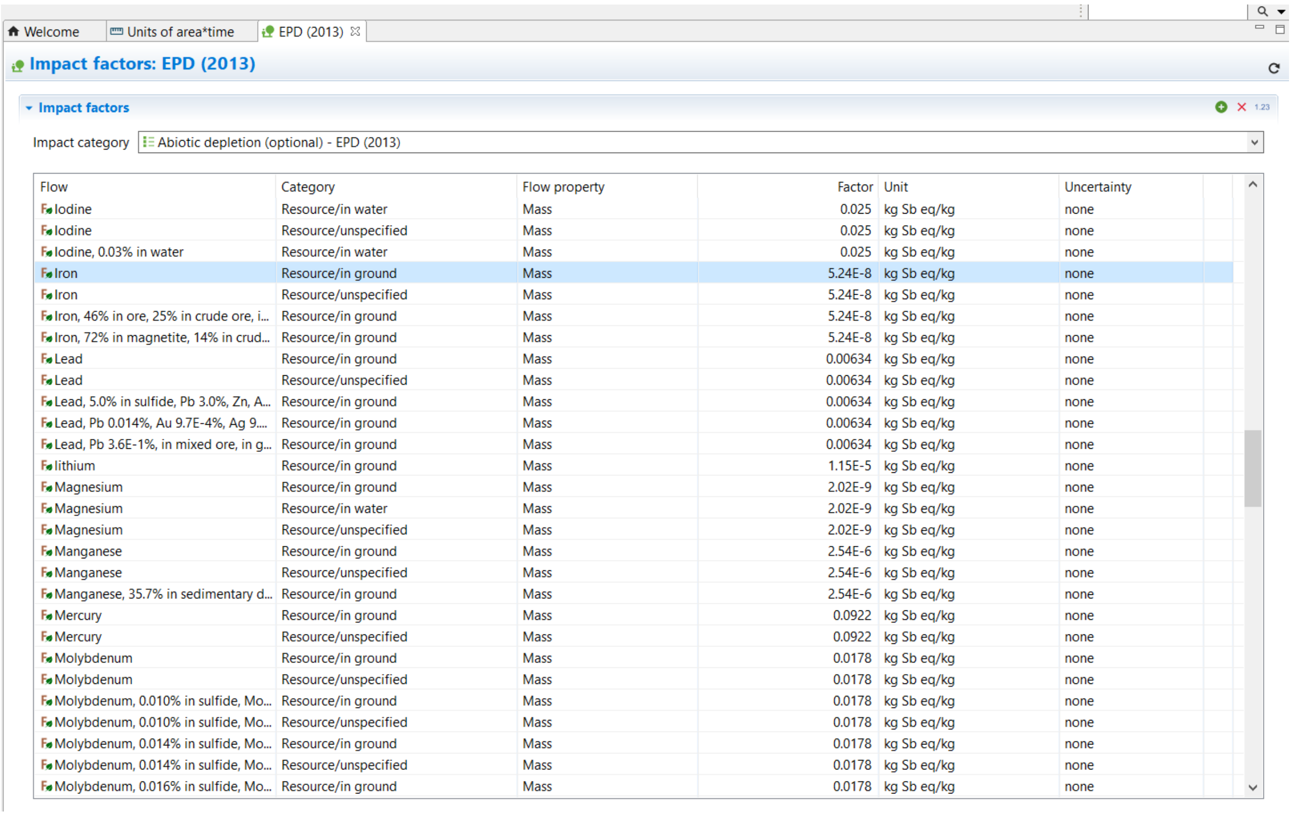
This study was conducted to evaluate the environmental impact of the cement industry process from cradle to gate. In addition, this study conducted three scenarios related to techniques that have different environmental impacts. The LCA scenario for the cement production process can also be helpful for industrial considerations in determining a more environmentally friendly strategy.

II. Research Method

LCA analyses the entire cycle from the production process to waste treatment. LCA is used to determine the amount of energy, costs, and environmental impacts caused by the product life cycle stages, starting from taking raw materials to the product being used by consumers [7]. These steps are (1) defining objectives and scope, (2) inventory analysis, (3) impact analysis/assessment, and (4) interpretation.

A. Goal and Scope

The LCA aims to compile and evaluate the environmental consequences of options proposed to fulfill a particular function or meet quality standards. In determining the LCA's objectives, some supporting questions such as, what environmental problems can a specific product be associated with? What is the share of a particular product in the world's environmental issues? As well as other questions that are thought to help us in determining the objectives of the LCA. LCA studies' application can be used for various applications such as marketing, product development, product enhancement, etc.



Flow	Category	Flow property	Factor	Unit	Uncertainty
Iodine	Resource/in water	Mass	0.025	kg Sb eq/kg	none
Iodine	Resource/unspecified	Mass	0.025	kg Sb eq/kg	none
Iodine, 0.03% in water	Resource/in water	Mass	0.025	kg Sb eq/kg	none
Iron	Resource/in ground	Mass	5.24E-8	kg Sb eq/kg	none
Iron	Resource/unspecified	Mass	5.24E-8	kg Sb eq/kg	none
Iron, 46% in ore, 25% in crude ore, i...	Resource/in ground	Mass	5.24E-8	kg Sb eq/kg	none
Iron, 72% in magnetite, 14% in crud...	Resource/in ground	Mass	5.24E-8	kg Sb eq/kg	none
Lead	Resource/in ground	Mass	0.00634	kg Sb eq/kg	none
Lead	Resource/unspecified	Mass	0.00634	kg Sb eq/kg	none
Lead, 5.0% in sulfide, Pb 3.0%, Zn, A...	Resource/in ground	Mass	0.00634	kg Sb eq/kg	none
Lead, Pb 0.014%, Au 9.7E-4%, Ag 9....	Resource/in ground	Mass	0.00634	kg Sb eq/kg	none
Lead, Pb 3.6E-1%, in mixed ore, in g...	Resource/in ground	Mass	0.00634	kg Sb eq/kg	none
lithium	Resource/in ground	Mass	1.15E-5	kg Sb eq/kg	none
Magnesium	Resource/in ground	Mass	2.02E-9	kg Sb eq/kg	none
Magnesium	Resource/in water	Mass	2.02E-9	kg Sb eq/kg	none
Magnesium	Resource/unspecified	Mass	2.02E-9	kg Sb eq/kg	none
Manganese	Resource/in ground	Mass	2.54E-6	kg Sb eq/kg	none
Manganese	Resource/unspecified	Mass	2.54E-6	kg Sb eq/kg	none
Manganese, 35.7% in sedimentary d...	Resource/in ground	Mass	2.54E-6	kg Sb eq/kg	none
Mercury	Resource/in ground	Mass	0.0922	kg Sb eq/kg	none
Mercury	Resource/unspecified	Mass	0.0922	kg Sb eq/kg	none
Molybdenum	Resource/in ground	Mass	0.0178	kg Sb eq/kg	none
Molybdenum	Resource/unspecified	Mass	0.0178	kg Sb eq/kg	none
Molybdenum, 0.010% in sulfide, Mo...	Resource/in ground	Mass	0.0178	kg Sb eq/kg	none
Molybdenum, 0.010% in sulfide, Mo...	Resource/unspecified	Mass	0.0178	kg Sb eq/kg	none
Molybdenum, 0.014% in sulfide, Mo...	Resource/in ground	Mass	0.0178	kg Sb eq/kg	none
Molybdenum, 0.014% in sulfide, Mo...	Resource/unspecified	Mass	0.0178	kg Sb eq/kg	none
Molybdenum, 0.016% in sulfide, Mo...	Resource/in ground	Mass	0.0178	kg Sb eq/kg	none

Figure 1. Example of using the EPD 2013 impact factor database on Open LCA 1.9

B. Life Cycle Inventory (LCI)

The primary cement production process consists of several stages: raw material mining, burning raw mix/slurry into clinker, grinding clinker, and gypsum into cement and packaging cement products [7]. This study's inventory study refers to the previous literature, which has been back in a narrative review and updates related to the latest research. LCA identifies and quantifies the flow material input and emissions as output [8].

D. Interpretation

Interpretation is a technique used to identify, qualify, check, and systematically evaluate information from the LCI and LCIA results to answer the LCA objectives and LCA coverage that have been set and determine recommendations for appropriate waste reduction based on the emission load.

III. Result and Discussion

A. Goal and Scope

This study used a cradle-to-gate approach, starting from the raw material extraction process (cradle) to the distribution stage to the distributor's warehouse (gate). Therefore, the extraction of additional raw materials, explosives, and electricity generation are not included in this study. The industrial process diagram and scope of this study can be seen in Figure 2.

The purpose of this study is to compare control methods based on possible scenarios. Design and develop air quality control devices in the industry to inform product designers about the development effort of ISO 14000 within the company in analyzing potential air pollution. Scope of LCA study follows:

1. The cement product is the raw material for limestone. Limestone mining, of course, directly and indirectly, impacts the environment and the surrounding community. One of the impacts that are felt is air pollution, namely in the mining of dust or PM with a micro or even nano flying, which can disturb health workers. Also, limestone mining causes air pollution in dust particles and carbon monoxide gas.
2. Cement production per year reaches 100 million tons with 3 (three) scenarios:
   - The fuel used is 100% coal.
   - The fuel used comes from 90% coal and 10% biomass from rice husks.
   - The fuel used comes from 50% coal and 50% biomass from rice husks.
3. System boundaries used are cradle to gate, considering that scenario conditions 1, 2, and 3 can be compared between performance and the environment due to differences in handling due to fuel use with different formulations.
4. Location and system expansion: allowance by mass and volume, and electricity.
5. Data Quality Requirements is an index of air control standards (ISPU).

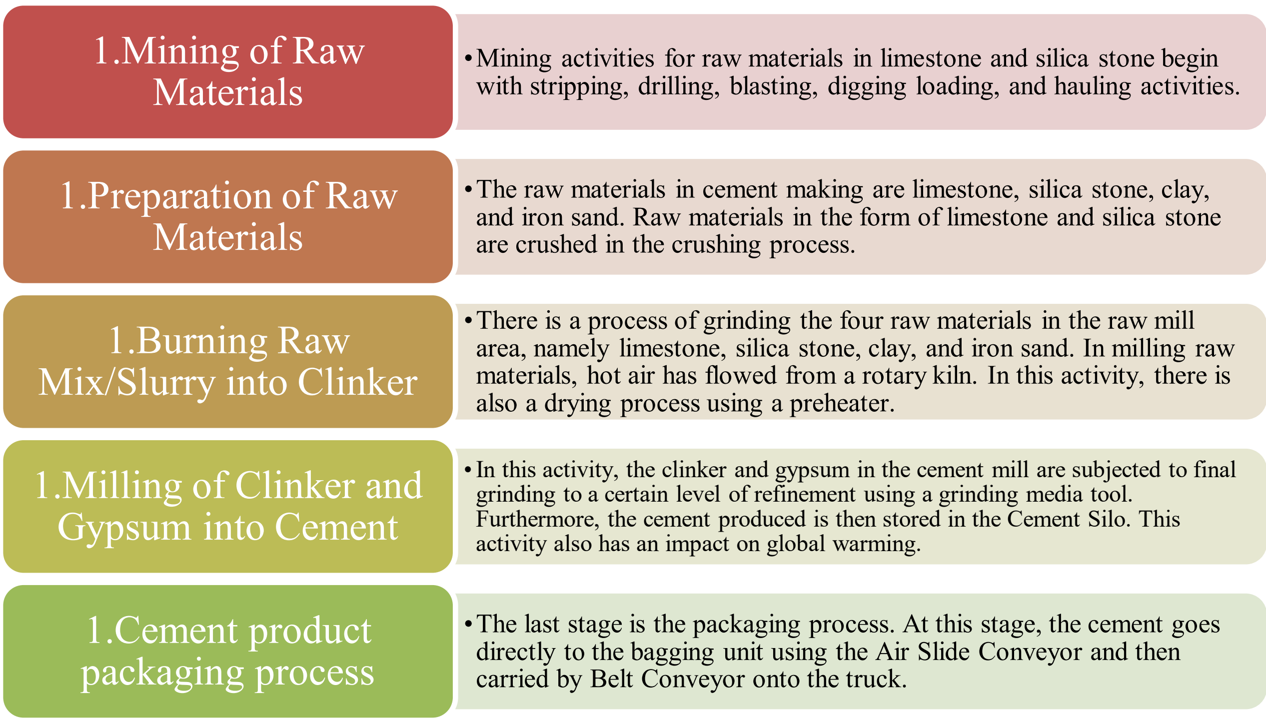


Figure 2. Scope of the cradle to gate study of LCA in the cement industry

B. Life Cycle Inventory (LCI)

Inventory is done based on input and material output in the system. Input data consists of the needs of raw materials, energy or electricity needs, water needs. Output data in the form of cement products and emissions released into the environment for each process. Table 1 shows the inventory of emissions to produce 1000 kg of cement products. The raw materials used to produce cement are limestone and clay. In Table 1 in planning is used approach with three scenarios. The first scenario is the cement production process using coal as a power source and the clinker ratio factor of 0.95. The second scenario is fuel derived from 90% coal, 10% with rice husk biomass, and a clinker ratio factor of 0.75. The third scenario uses fuel derived from a mixture of 50% coal, 50% biomass miscanthus giganteus, and a clinker ratio of 0.75.

C. Life Cycle Impact Assessment (LCIA)

Impact analysis on this research using OpenLCA software through input and output data obtained from inventory analysis. Impact analysis is performed for each scenario, seen in Table 2, Table 3, and Table 4. Based on these tables, several units determine the amount caused by impact damage. For example, kg of CO_2eq is used as a unit for the category of characterization of the impacts of global warming, and the effect is climate change globally. Table 6 is the result of impact analysis using the Simapro Version 7 application quoted from literature. The resulting impact can be presented into several categories of damage. The types of impact in question include human health, ecosystem quality, climate change, and resources. However, our findings are that global warming is the highest impact resulting from the three scenarios created. This result is supported by research [13] which also shows the most dominating global warming effect. Other studies mention that manufacturing and using cement in concrete is a significant responsibility for GHG emissions and climate change [14], [15]. However, the essential measured impact of GHG is in the use of kilns; this is usually due to the coal combustion process, IDO (Industrial Diesel Oil), and several alternative fuel elements CO_2 and other gases into the atmosphere [16].

Table 1. LCI for 1000 kg of cement production [7]

Component	Scenario 1	Scenario 2	Scenario 3
Carbon dioxide	1229.31 kg	979.7 kg	849.1 kg
Carbon monoxide	1.47 kg	1.99 kg	1.86 kg
Nitrogen dioxide	5.15 kg	5.16 kg	3.45 kg
Particulates	1.22 kg	0.88 kg	0.88 kg
Sulfur dioxide	1.7 kg	0.24 kg	0.25 kg
Methane	1.28 kg	1 kg	0.52 kg
COD	2.81 kg	2.41 g	2.21 g
SS	100.69 kg	87.07 g	83.93 g
BOD	384.35 kg	331.72 mg	316.77 mg
Cd	152 ug	620 ug	560 ug
Pb	4.56 mg	4.66 mg	2.7 mg
Hg	76 ug	80 ug	50 ug

Table 2. Results of environmental impact value Scenario 1 with OpenLCA 1.9

Input	Output	Result
Silica	Abiotic depletion	0.00313 kg Sb eq
Iron	Abiotic depletion	8.38400×10^{-7} kg Sb eq
Nitrogen dioxide	Acidification	5.30500 kg SO_2eq
	Eutrophication	0.66950 kg PO_4eq
	Photochemical oxidation	0.14420 kg C_2H_4eq
Sulfur dioxide	Acidification	1.70000 kg SO_2eq
	Photochemical oxidation	0.08160 kg C_2H_4eq
Carbon dioxide	Global warming	1229.31000 kg CO_2eq
Methane	Photochemical oxidation	0.00768 kg C_2H_4eq
	Global warming	35.84000 kg CO_2eq
Carbon monoxide	Photochemical oxidation	0.03969 kg C_2H_4eq
COD	Eutrophication	4.00594×10^{-6} kg PO_4

Table 3. Results of environmental impact value Scenario 2 with OpenLCA 1.9

Input	Output	Result
Nickel	Abiotic depletion	0.00550 kg Sb eq
Iron	Abiotic depletion	0.00549 kg Sb eq
Nitrogen dioxide	Eutrophication	0.67080 kg PO_4 eq
	Acidification	3.61200 kg SO_2eq
	Photochemical oxidation	0.14448 kg C_2H_4eq
Sulfur dioxide	Acidification	0.24000 kg SO_2eq
	Photochemical oxidation	0.01152 kg C_2H_4eq
COD	Eutrophication	3.43570 X 10^{-6} kg PO_4
Carbon dioxide	Global warming	979.7000 kg CO_2eq
	Photochemical oxidation	0.05373 kg C_2H_4eq
Methane	Global warming	28.00000 kg CO_2eq
	Photochemical oxidation	0.006000 kg C_2H_4eq

Table 4. Results of environmental impact value Scenario 3 with OpenLCA 1.9

Input	Output	Result
Nickel	Abiotic depletion	0.00549 kg Sb eq
Nitrogen dioxide	Eutrophication	0.44850 kg PO_4 eq
	Acidification	2.41500 kg SO_2eq
	Photochemical oxidation	0.09660 kg C_2H_4eq
Sulfur dioxide	Acidification	0.25000 kg SO_2eq
	Photochemical oxidation	0.01200 kg C_2H_4eq
COD	Eutrophication	3.15058 x 10-6 kg PO_4 eq
Carbon dioxide	Global warming	849.10000 kg CO_2eq
	Photochemical oxidation	0.05022 kg C_2H_4eq
Methane	Global warming	14.56000 kg CO_2eq
	Photochemical oxidation	0.00312 kg C_2H_4eq

D. Interpretation

Interpretation is the last step in the LCA stage before decisions and action plans. In conducting interpretations to determine critical environmental issues, the analysis method can be done by the contribution analysis approach that aims to identify the data that has the most significant contribution to impact indicators' results. Furthermore, a method of analysis of the improvement of the products is carried out.

From the analysis of the estimated impact of contributions, carbon dioxide is into emissions in the air. The contribution of extra carbon dioxide depends on technical and management efficiency in conventional production processes in addition to plant performance, causing increased electricity consumption [17].

Several technologies are commonly used in air quality control, cyclone, electrolyte precipitator, wet scrubber, and humidifier with gravity system. In addition to air quality control technology, the use of fuel also affects the emissions produced. So, recommendations that can be given include controlling air quality. Technology is one recommendation that can reduce the resulting carbon dioxide emissions. In conducting cement production operations, the company is equipped with an air filter located in the factory chimney. Besides controlling the emission, fuel substitution with new and renewable energy needs to be studied further. Moumin also explained that the emission solar calciner in substitute for fossil fuels in the conventional calciner, the prizes in the Spanish cement industry ranged from 2%-7% [18].

In recent years, the Government of Indonesia has clarified favorable policies supporting the commercial development of waste to energy programs such as Refuse Derived Fuel (RDF) waste to energy facilities to reduce greenhouse gas emissions [19], [20]. One example of implementation is in The Central Java Provincial Government is committed to helping part of RDF operations. The Cilacap Regency Government is obliged to provide land and operational costs for transporting waste to RDF and maintaining RDF. PT. SBI will use RDF as a substitute for coal in cement kilns, although it still has to invest in the kiln in a feeding system [21]. PT. SBI is committed to collaborating on RDF waste management because it has hopes of efficiency and support for reducing gas emissions and waste to energy [21].

IV. Conclusion

It can be concluded that avoiding the environmental impact of cement industry activities required the LCA method to analyze environmental load at every stage. The life cycle of the product and decision-making to identify environmental burdens and evaluate the environmental impact plays an essential role in sustainable development. To approach the method used is cradle to gate using 3 scenarios. Firstly, using 100% coal fuel, the second uses 90% coal fuel and 10% rice husk biomass, and the latter use fuel derived from 50% coal and 50% rice husk biomass. After analysis using OpenLCA software, it was found that the most significant emission load is carbon dioxide. The third scenario has the lowest carbon dioxide emission burden compared to the other strategy of 849.1 kg. in addition to using fuel from a mixture of coal and biomass, the use of technology can also lower emissions. Air quality control technology that can be used includes a cyclone, electrostatic specific precipitator, wet scrubber, etc. Air quality control equipment is selected based on air quality resulting from production.

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