Volume 3, No. 2 February 2024 - (291-300)
p-ISSN 2980-4868 | e-ISSN 2980-4841
https://ajesh.ph/index.php/gp

SUSTAINABILITY ASSESSMENT OF CARBON DIOXIDE EMISSION REDUCTION FROM ENERGY USE IN CEMENT PRODUCTION VIA LIFE CYCLE ASSESSMENT AND AHP

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ABSTRACT:
The cement industry in supporting sustainable development is faced with the challenge of reducing energy consumption, natural resources and emissions generated from its production activities. PT X is one of the cement industries in Indonesia that has a production design capacity of 2.6 million tons/year. PT X's cement production activities use several fossil fuel energy sources and alternative fuels that can produce carbon dioxide emissions that are wasted into the environment. This study aims to identify process units that produce significant impacts to determine alternative environmental improvement scenarios. The method used is Life Cycle Assessment (LCA) as a tool for calculating potential environmental impacts, and AHP as an alternative selection of environmental improvement program scenarios. The scope of the LCA study carried out with the scope of "Cradle to Gate" includes the stages of the raw material extraction process, the production process to the distribution of cement. The resulting potential environmental impact is a total Global Warming Potential (GWP) of 0.20543 tons CO2 eq/ton. The largest potential impact comes from the kiln unit of 0.20221 tons CO2 eq/ton or an impact contribution of 98.43%. Based on the environmental impacts generated, there are 4 alternative programs that can be used to reduce the environmental impacts generated. The selection of alternative program scenarios is based on 3 criteria based on 3 types of respondents. Alternative programs that have the highest priority value are alternative program 1 with 35.5%, 38.1%, and 23.4%.

Keywords: Environmental Impact, Cement Industry, Carbon Dioxide, LCA, AHP

INTRODUCTION

Energy consumption has increased in line with economic growth, population, and policies set by the government (Raihan, 2023);(Elavarasan et al., 2023). The average growth of energy demand is estimated at 4.7% per year during 2030, the increase in energy demand is directly proportional to the addition of greenhouse gases. Greenhouse gases consisting of CO_2, CH_4, N_2O, HCFC, CFC and water vapor (H_2O) are the main sources of global warming (Minallah et al., 2017; Ratna, 2022). The presence of these pollutants in the air causes acid rain, global warming, health problems, decreased crop yields, and decreased biodiversity. Therefore, WHO has emphasized reducing the emission of pollutant substances by using efficient air treatment (Zhu et al., 2022).

The development of the mineral processing industry in value-added activities creates an increase in energy demand (Jawadand & Randive, 2021; Tampubolon et al., 2020). For example, energy consumption in the cement industry reaches 2% of the world's total primary energy consumption or equivalent to 5% of the energy consumption of the world's industrial sector. The source of emissions from cement production is generated through two processes, the first process is the decarbonation process of limestone when the raw material is burned which can produce nearly 0.5 tons of CO2/ton of cement. The second source comes from burning large amounts of fuel above 2000oC. Total carbon emissions from global cement production amount to 162 tons or 2.6% of the total carbon from fossil fuel oxidation. The highest CO2 gas emissions in cement plants result from the combustion of coal used in kilns for cement production and from the decomposition of limestone. Cement plants are a type of industry that contributes considerable CO2 emissions from the use of fuel electricity, and by-products from the production process (Minallah et al., 2017).

PT X has carried out various initiatives in product/service innovation of sustainable solutions, management of carbon dioxide emissions and air pollutants, responsible use of energy, use of alternative fuels and materials, waste utilization, biodiversity and water management, and other programs related to social and environmental responsibility towards society (Sustainability Report, 2021);(Hawrysz & Foltys, 2015; Żelazna et al., 2020). Therefore, a study of carbon dioxide reduction from energy use in the cement industry (case study of PT X) was prepared using forecasting or estimation methods to determine the critical points that cause environmental impacts from carbon emissions generated from the production process and products. Then an evaluation of environmental, social, and economic impacts is carried out by integrating LCA and AHP to get alternative environmental programs that are right on target (Torkayesh et al., 2022).

LCA is one of several environmental management techniques (e.g. risk assessment, environmental performance evaluation, environmental audit, and environmental impact assessment) that addresses environmental aspects and partial environmental impacts along the entire product life cycle from raw material acquisition, production, milling, final processing, and final disposal (i.e. cradle-to-grave) (Abele et al., 2005; Brilianty et al., 2022).

According to (Putra et al., 2020) analytic hierarchy process (AHP) is a multicriteria decision-making tool introduced by Saaty (1979). This method is used to find a ranking or priority order of various alternatives in solving a problem. AHP has been adopted as a selection tool for various applications (Chakraborty et al., 2023; Moslem, 2024). Holistic evaluation of environmental, social, and economic impacts can be done by integrating LCA and AHP to select the most favorable technology (Purnomo, 2013; Torkayesh et al., 2022).

RESEARCH METHODS

The research was conducted in one of the cement industries located in Cilacap Regency, West Java. The steps were (1) obtaining data for the main processes in LCA (2) implementing AHP to determine preference weights, and finally (3) integrating the data obtained in LCA with AHP to determine the priority of alternative programs.

Step 1- Life Cycle Assessment

Using the LCA framework by identifying functional units, process and technology alternatives, material and energy flows, and environmental emissions. The cradle to gate system boundary starts from dredging raw material production to packing activities. The functional units of this study are focused according to Figure 1 system boundary for cement production. The main environmental pollutant released from the cement industry is carbon dioxide. Based on this pollutant, the LCA assessment focuses on assessing the impact of global warming potential (GWP).

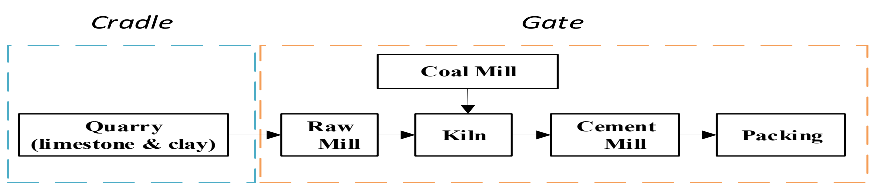

Figure 1. System boundaries for cement production

As a result of the environmental impact analysis, the process units that generate the greatest environmental impact can be identified. Based on the resulting environmental impacts, 4 alternative improvement scenarios were prioritized using AHP analysis.

Step 2 - Analytical Hierarchy Process

This stage is carried out by creating a hierarchy of criteria to be achieved and calculating the weight of each level of alternative selection of improvement programs. The AHP network is developed based on the criteria and sub-criteria that have been identified. The criteria and sub-criteria consist of four levels as illustrated in Figure 2. The objective of this study is to determine alternative program scenarios that can be implemented based on 3 criteria from each of the proposed criteria according to the criteria of the 3 types of respondents.

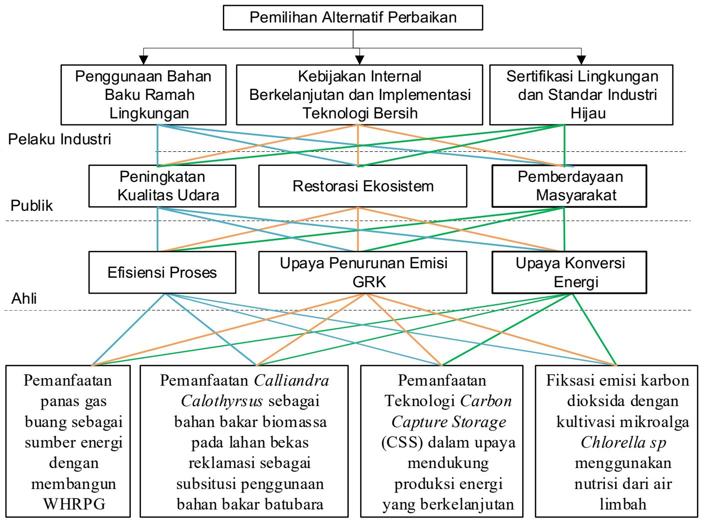

Figure 2. AHP hierarchy process

The priority weights for each of the main criteria or main sub-criteria or sub-criteria at the respective level are determined using pairwise comparison assessment. The pairwise comparison assessment process is based on the impact value of each of the compared criteria elements. Based on the eigenvector calculation, each alternative has a priority weight value. The alternative with the highest priority weight value is determined as a possible alternative program that can be implemented by the cement industry to reduce carbon dioxide emissions resulting from the cement production process.

RESULTS AND DISCUSSION

Inventory Analysis

PT X cradle data comes from the Raw Material Extraction & Raw Meal Preparation process, in the process there is a Quarry unit (limestone and clay) The limestone mining process is carried out through several stages, namely drilling, blasting, dredging, and material collection. Raw materials from the stockpile are fed into the raw mill and added with iron sand and silica sand to be ground and dried into raw meal. Raw materials from the stockpile are fed into the raw mill unit and added with belsi sand and silica sand to be ground and dried into raw meal. Then enter the coal mill unit Raw Meal will undergo several stages of the process before finally becoming clinker then through the cooling system and through transportation equipment to be stored in the clinker silo. The combustion process uses coal fuel that has been ground and dried through a coal mill. Clinker is then processed to be processed into bulk cement in the kiln unit. This cement grinding process is the stage of obtaining cement as it is in the market. These materials are jointly fed to the cement mill and then undergo a grinding process and the product is cement. After obtaining quality cement, the cement is stored through the cement silo and then transported to the cement bin through air slides, belt conveyors, and vibrating screens. Furthermore, cement products are packed into bags in the Packing unit.

Table 1. shows the results of the inventory analysis of the cradle to gate life cycle of cement products.

Input Material/Energy	Unit	Quantity	Output/Emission Materials	Unit	Quantity
explosives	Ton/ton	0,00026	*Limestone*	Ton/ton	0,851
Limestone	Ton/ton	1,1457	Used Packaging of B3 Waste	Ton/ton	0,0000012
Clay	Ton/ton	0,094	Used Batteries	Ton/ton	0,0000003
Iron Sand	Ton/ton	0,002	Used Oil Filter	Ton/ton	0,0000011
Silican Sand	Ton/ton	0,105	*Raw Meal*	Ton/ton	1,013
Alternative raw materials	Ton/ton	0,0983	Contaminated Mats	Ton/ton	0,0000011
Coal	Ton/ton	0,13154	Used Belt	Ton/ton	0,00001
Raw meal	Ton/ton	1,01	*Fine coal*	Ton/ton	0,095
Fine coal	Ton/ton	1.789,84	Klinker	Ton/ton	0,629
IDO	Mj/ton	19,13	Used Refractories	Ton/ton	0,000181
Bahan bakar alternative	Mj/ton	285,50	Used Oil	Ton/ton	0,000015
Klinker	Ton/ton	0,629	Used Filter Bag	Ton/ton	0,0000017
Raw meal	Ton/ton	0,03393	Used Cement Paper	Ton/ton	0,00000001
Gypsum	Ton/ton	0,0355	Used Pallets	Ton/ton	0,0000017
Fly ash	Ton/ton	0,0353	Emissions CO_2	Ton/ton	0,205430
Heavy Equipment Fuel	Lt/ton	1,0961	Particulates	Ton/ton	0,00004735
Paper bag	Ton/ton	0,0025	NOx	Ton/ton	0,00099
Water	m^3/ton	0,03012	CO	Ton/ton	0,001063
Electricity	kWh/ton	83,49	SO_2	Ton/ton	0,000097
Products	**Unit**	**Quantity**			
Semen	Ton/ton	1			

Impact Analysis

In this study, carbon dioxide emissions are limited to those from the use of heat energy (fuel combustion) and electricity. Particularly for the use of electricity is categorized as indirect emissions because the electricity production process is not generated directly from the cement plant. The fuel data used is as per table 2.

Table 2. Fuel Usage

Fuel Type	Unit	Year 2022
Diesel Oil	Liter	3.805.518,39
Coal Fuel	Ton	315.192
Altelrnative Fuel	Ton	86.509

The assessment of the environmental impacts of the resources and emissions generated is grouped and quantified into specific impact categories which are then weighted according to their level of contribution. In this research, this stage is processed using SimaPro software and produces an output of impact categories and their characterization values according to the inventory data. The impact analyzed is the Global Warming Potential (GWP) impact. In analyzing the impact category, the analysis process is carried out using the impact assessment model, namely, CML-IA Basellinel V3.05.

Based on the impact assessment process, the resulting value of each impact category in the cement production process in each unit, the results can be seen in Table 3. In this study focuses on the environmental impact resulting from carbon dioxide emissions from all process units at the Cradle-Gate stage. The presentation of the value in each impact category has been adjusted to the unit function per 1 ton of cement.

Table 3. shows the results of the impact assessment analysis of cement products

Year	Impact Category	Unit	Methods	Total	Quarry	Raw Mill	Kiln	Coal Mill	Cement Mill	Packing
2022	*Global warming (GWP)*	ton CO2 /ton	CML-IA basellinel V3.07	0,20543	0,002712	0,000039	0,20221	0,000027	0,000189	0,000257
2022	*Global warming (GWP)*	%	CML-IA basellinel V3.07	100	1,3202	0,0189	98,4304	0,0131	0,0921	0,1253

The impact category relevant to carbon dioxide emissions is Global warming (GWP100a). The impact assessment is derived from total carbon dioxide emissions multiplied by the Global warming characterization factor (GWP100a) according to the CML-IA Baseline method of 1 kg CO2/kg or equal to the emission factor according to the IPCC Guidelines for National Greenhouse Gas Inventories 2006. Calculation of greenhouse gas mass is done with modification by the GWP equivalence factor. The GWP equivalence factor is an estimate of the atmospheric lifetime and radiative forcing that can contribute to global climate change compared to greenhouse gas emissions from carbon dioxide emissions. GWP is therefore in units equivalent to carbon dioxide.

Broadly speaking, it can be seen that the kiln process unit has emissions consisting of various parameters, both GHG and conventional emissions. The resulting emissions can cause several categories of impacts. However, in this study, the emissions studied are only related to carbon dioxide emissions. Based on Table 4.1, the results of the impact derived from inventory data which is the substance that causes the impact with the highest value coming from the 2022 data kiln unit with an input carbon dioxide emission value of 0.202206 tons CO2/ton, resulting in an impact value of 0.202206 tons CO2/ton, the impact comes from the use of fuel in the kiln unit in the form of diesel oil, alternative fuels and coal.

Potential GWP impacts resulting from the cement production process, the largest contribution comes from the clinkerization process (kiln unit) based on 2022 data has a percentage of 98.43% Based on the table above, the GWP impact contributor comes from emissions from fuel use of heavy equipment, alternative fuels and coal. Meanwhile, emissions from the use of electricity include indirect emissions that are not discussed in this study.

Analytic Hierarchy Process

Based on the results of the impact analysis using LCA, it is known that the relevant environmental impact of carbon dioxide emissions in the cement production process results in environmental impacts derived from the use of fuel in production units. The alternatives used are obtained from the results of the analysis carried out by analyzing the literature obtained in journals and analyzing the reports of companies in the field of cement production in the country.

The results of the calculation of the final weight of each improvement alternative can be seen in Table 4-Table 6.

Tabel 4. The results of the calculation of the final weight of each improvement alternative

Kode	K1	K2	K3	Total	Priority	%
A1	0,147	0,145	0,063	0,354	1	35,4%
A2	0,179	0,116	0,050	0,346	2	34,6%
A3	0,094	0,033	0,030	0,157	3	15,7%
A4	0,083	0,045	0,015	0,143	4	14,3%

Tabel 5. The results of the calculation of the final weight of each improvement alternative

Kode	K4	K5	K6	Total	Priority	%
A1	0,144	0,207	0,030	0,381	1	38,1%
A2	0,078	0,173	0,068	0,318	2	31,8%
A3	0,043	0,074	0,056	0,173	3	17,3%
A4	0,043	0,060	0,026	0,129	4	12,9%

Tabel 6. The results of the calculation of the final weight of each improvement alternative

Kode	K7	K8	K9	Total	Priority	%
A1	0,037	0,148	0,049	0,234	2	23,4%
A2	0,118	0,179	0,056	0,353	1	35,3%
A3	0,081	0,109	0,030	0,219	3	21,9%
A4	0,054	0,111	0,029	0,193	4	19,3%

The results of consistency between criteria can be seen in Table 7.

Tabel 7. consistency between Alternative criteria

Kode	A1	A2	A3	A4	Weight	Consistency
A1	1,000	1,636	1,040	1,101	0,292	4,061
A2	0,611	1,000	3,271	2,237	0,356	4,562
A3	0,961	0,306	1,000	1,170	0,187	4,601
A4	0,909	0,261	0,855	1,000	0,166	3,651
Total	3,481	3,203	6,166	5,508	1	
					Eigen Value	4,219

Kode	A1	A2	A3	A4	Weight	Consistency
					CI	0,073
					CR	0,013

The analysis of alternative improvements in this study is the selection criteria for alternative improvements that have the highest priority value, namely alternatives with code A1, namely the utilization of Calliandra Calothyrsus as a biomass fuel on reclaimed belkas land as a sulbsitulsion for the use of coal fuel based on the types of respondents 1 and 3 respectively by 35.5%, 38.1% and second priority based on the type of respondent 2 by 23.4%. As for the alternative with code A2, namely the alternative of utilizing flue gas heat as an energy source by building WHRPG with a value based on the type of respondent 2 of 35.3%, and based on the types of respondents 1 and 3 of 34.6%, and 31.8%. The criteria and alternative improvements were chosen by the respondents with a percentage value of the validation level using consistency ratio testing is ≤ 0.10, which means that the respondents' preferences are consistent and the calculation results can be declared correct.

CONCLUSION

The biggest impact is generated by the kiln unit with the amount of global warming potential (GWP) impact resulting from the substance of carbon dioxide emissions of 0.202206 tons of CO2 eq/ton resulting from the use of energy from the use of heavy equipment, alternative fuels and coal. This impact can be minimized by reducing CO2 emissions by using alternative program scenarios generated from AHP analysis. The resulting 2 priority programs resulting from AHP analysis are the use of Calliandra Calothyrsus as biomass fuel on former reclaimed land as a substitute for the use of coal fuel with a percentage of 35.5%, 38.1% based on the types of respondents 1 and 3 and the second priority based on the type of respondent 2 of 23.4%. As for the alternative utilization of flue gas heat as an energy source by building WHRPG with a value based on the type of respondent 2 of 35.3%, and based on the types of respondents 1 and 3 of 34.6%, and 31.8%.

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First publication right:
Asian Journal of Engineering, Social and Health (AJESH)