Indonesian Interdisciplinary Journal of Sharia Economics (IIJSE) Vol. 8. No. 2 (2025)
e-ISSN: 2621-606X Page: 6294-6316

ANALYSIS OF EMISSIONS AND ENVIRONMENTAL IMPACTS OF THE PRODUCTION AND DISTRIBUTION PROCESS OF TWO ASPECT TRAFFIC LIGHTS USING THE LIFE CYCLE ASSESSMENT METHOD

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Abstract

In Indonesia, carbon emissions declarations are still voluntary and their implementation by the business world is still rare. This study analyzes the potential environmental impacts and large emissions resulting from the supply chain traffic light (production and distribution) of traffic lights in two aspects at company in Sidoarjo. This study is relevant to the urgency of the Sustainable Development Goals (SDGs) number 13, Climate Action. Which emphasizes climate change mitigation and environmentally friendly industrial innovation. Traffic light production and distribution were chosen because of their significant contribution to the company's operations, long production cycles, and high energy consumption. Life Cycle Assessment (LCA) was applied to evaluate carbon dioxide emissions and environmental impacts at each process stage. The results showed that the processing and maintenance sub-production had the highest environmental impact, so process optimization was needed. The largest impact in the production cycle was human toxicity water with a value of 4.51. To reduce environmental effects, it is recommended to apply environmentally friendly technologies and optimize raw materials, such as the use of aluminum scrap and water recovery systems. These findings are expected to contribute to emission mitigation strategies and the formulation of sustainable policies for the traffic light manufacturing industry.

Keywords: Life Cycle Assessment, Environmental Impact, Supply Chain, Traffic Light Ord

INTRODUCTION

Since the Industrial Revolution, the world has experienced a significant spike in greenhouse gas emissions, driven by rapidly growing industrial activities. Indonesia is one of the countries with rapid industrial growth. According to data from the World Resources Institute (WRI) updated data for 2024, Indonesia is the country of 6th-largest emitter in the world. Of this amount, around 37% of emissions come from the manufacturing industry sector. This is because the manufacturing industry is energy-intensive as its production process requires a lot of energy to run machines, process raw materials, and run support systems such as lighting and temperature control.

The declaration of carbon emissions in Indonesia is still voluntary, and its implementation by businesses is still rare (Dwinanda and Kawedar, 2019). This is an important concern in efforts to reduce carbon dioxide emissions. To support environmental management, Law No. 32/2009 encourages the use of environmental economic instruments, such as green public procurement (GPP), ecolabels, and environmental financing to improve transparency and better environmental management. In this context, the application of Life Cycle Assessment becomes relevant as a method that can measure and evaluate the environmental impact of a product holistically throughout its life cycle. LCA has been internationally recognized and regulated in the ISO 14040 and 14044 standards, which guide in conducting environmental impact assessment systematically. LCA is important to carry out in assessing the environmental impact of the manufacturing industry because it has a large contribution to industrial movement, as it requires a long process and a lot of energy. Therefore, this is important to disclose the emissions and environmental impacts of industries with the largest contribution from various sectors. One of the manufacturing industries is located in Sidoarjo, East Java, is a manufacturer of various traffic equipment, and has obtained ISO 9001 and ISO 14001 certifications. The complexity of production processes makes the use of electricity high in this industry. The waste generated by this company is divided into two types, namely solid waste, including aluminum material waste, and liquid waste, including washing water from production and paint residue from the powder coating process. This company has not disclosed the environmental impact of the production and distribution cycle. The application of Life Cycle Assessment is suitable. LCA is a method that helps in knowing the environmental impact of a product from the extraction of raw materials to disposal or recycling (Vauche et al., 2024). According to research conducted by Parameswari et al. (2019), the LCA method has been proven to provide a comprehensive picture of the environmental impact of a product throughout its life cycle. LCA itself is a method for assessing the environmental impact of a product at each stage of its life cycle, from raw material processing to final disposal (ISO 14040:2006), by systematically analyzing inputs and outputs (Ciambrone, 1997).

This study introduces the Integration of the Simplified Assessment System in LCA as a structured and systematic approach to assess environmental impacts during the production and distribution process. With this method, the study aims to identify critical areas that require improvement, so that environmental impact reduction strategies can be implemented more effectively and targeted. The focus of this study is to quantify the number of emissions as well as the environmental impact of two aspects in the traffic light manufacturing process, from production to distribution, and provide improvement recommendations to minimize negative impacts on the environment. The integration between the simplified scoring system and LCA can make it easier for researchers to identify which processes have the greatest environmental impact, which will help companies in choosing which processes to improve first.

REVIEW OF LITERATURE

Supply Chain Management

Supply Chain Management (SCM) is an essential element in a business, encompassing planning, design, implementation, and control of logistics activities. This includes procurement, storage, inventory management, production, distribution, and order fulfillment (Attaran, 2020). It has long been one of the fastest-growing research topics in management science (Martins and Pato, 2019). Supply Chain Management (SCM) is an integrated process that includes product development, procurement, planning, operations, and distribution. Each stage is interconnected to ensure quality products reach end consumers effectively and efficiently (Yusuf and Soediantono, 2022). A sustainable supply chain is a set of activities that aim to reduce negative impacts on the environment and society, while still achieving economic goals (Seuring and Muller, 2008). Sustainable supply chains are not just a trend, but a critical factor for companies' long-term success. By implementing them, companies can reduce their carbon footprint, improve their reputation, and strengthen their competitiveness. Collaboration, transparency, and technology play a key role in creating supply chains that support sustainability and a better future for future generations (Aminoff dan Kettunen, 2016). The integration of environmental considerations into SCM is commonly known as Green Supply Chain Management (GSCM) or Sustainable Supply Chain Management (SSCM) (Shekarian et al., 2022). Over time, the theory of Supply Chain Management (SCM) needs to be associated with the theory of sustainability, giving rise to the theory of SSCM (Hartanto, 2023). Based on the 2023 CNBC Indonesia Green Business Ratings Survey, one example of a company that has implemented sustainable supply chain management is PT Astra International Tbk. These companies have published sustainability reports covering their environmental, social, and governance impacts.

Waste

Air pollution is a never-ending problem, especially in Indonesia. Pollution continues to be a problem for Indonesians, and pollution levels are increasing every year (Maula, 2024). Peak carbon emissions have been analyzed using the Environmental Kuznets Curve (EKC) in most previous studies, which proposes an inverted U-shaped relationship between per capita income and environmental pollution. This suggests that while environmental degradation initially rises with increasing per capita gross domestic product (GDP), it eventually declines after reaching a peak (Chen et al., 2019). Waste is a by-product of a business or activity that contains hazardous or toxic materials, which, due to their nature, concentration, and amount, can pose a direct or indirect threat to the environment, human health, survival, and other living things (Waluyo, 2010). The method applied to assess and describe the environmental impact of products and systems is Life Cycle Assessment (LCA) (Ortmeier et al., 2021). The waste produced by this company is divided into two types, namely solid waste, including aluminum residue, and liquid waste, including washing water from production and paint residue from the powder coating process.

Life Cycle Assessment

Life Cycle Assessment is one of the methods developed as a form of effort to reduce the occurrence of environmental impacts that can arise from industry, and can protect the environment (Finkbeiner, 2013). LCA is a standard method for evaluating the environmental impact of a product or service by analyzing resource consumption and emissions at each stage of its life cycle, from raw material extraction to waste disposal (Fikri, 2021). Being able to provide a comprehensive assessment, LCA is considered a simple method, internationally recognized, and widely used by environmental experts around the world (Sirait, 2020). LCA helps companies present more credible environmental performance reports, an aspect that is increasingly in demand by consumers concerned about sustainability (Hoffman and Ross, 2020). Through in-depth analysis of the product life cycle, companies can improve resource efficiency, reduce greenhouse gas emissions, and minimize waste (Finnveden et al., 2009). LCA is a method commonly used to determine and assess the environmental impact of a product or activity throughout its life cycle, from raw materials, production, and use to waste management (Curran, 1996). The Life Cycle Assessment (LCA) methodology with a dynamic and network-based approach has proven to be an effective tool for measuring efficiency scores and establishing supply chain sustainability benchmarks (Álvarez-Rodríguez et al., 2019).

LCA aims to comprehensively evaluate the environmental impact of a product throughout its life cycle, from raw materials to final disposal. This approach helps identify the stages with the greatest impacts, allowing companies to prioritize reduction efforts on the most critical aspects (Baumann et al., 2006). LCA was first introduced in the 1960s and is now defined as a method for assessing environmental impacts and resource use throughout the life cycle of a product, from raw material acquisition, production, and use to waste management (Sillero et al., 2021). Since the early 2000s, the use of LCA has continued to grow in various sectors, such as food, energy, and consumer products. Various LCA software tools, such as SimaPro and GaBi, became available, allowing users to perform the analysis more efficiently. In 2006, UNEP and SETAC published the Life Cycle Initiative, which aims to accelerate the use of LCA globally (Zamagni et al., 2013). LCA is not without its drawbacks (Lewis & Demmers, 1996). Improved environmental performance depends on strong collaboration between partners in the supply chain (Moreira et al., 2022). To be more environmentally friendly, companies need to adapt their supply chains and ensure that each partner complies with environmental and sustainability standards (Nekmahmud et al., 2020). From a product development perspective, Life Cycle Assessment (LCA) is used to assess environmental and social impacts throughout the design, production, distribution, and recycling stages (Liu et al., 2023).

Cradle to Gate is a scope in Life Cycle Assessment (LCA) that covers the stages from the extraction of raw materials until the product leaves the factory, before reaching further operational processes or distribution (Hermawan et al., 2017). This LCA concept focuses on the environmental impacts of upstream industrial processes, covering the stages until the product leaves the factory after being manufactured and assembled. However, the ‘cradle-to-gate’ approach is considered incomplete because it does not take into account downstream stages, such as end-of-life use and management, and thus does not reflect the overall environmental impact (Filimonau, 2016).

In the data processing process, the Life Cycle Assessment (LCA) method is used. Based on the ISO 14040 standard, the application of LCA includes four main stages. The first stage is determining the purpose and scope, which acts as a reference to maintain harmony in the LCA analysis. Additionally, the Life Cycle Inventory (LCI) is one of the four key phases of the LCA methodology (Saavedra-Rubio et al., 2022). The LCI stage will include all relevant process data to be used in producing, transporting, using, and disposing of the selected product (Riyanty dan Indarjanto, 2015). To analyze the inventory, an inventory must be made of the relevant inputs and outputs associated with the specified system (Islam, S., Ponnambalam & Lam, 2016). Life Cycle Impact Assessment is a stage of handling impacts on the environment, all impacts of resource use and emissions generated are then quantified into several impact categories, given according to their level of importance. The data obtained from LCI will be converted into types of environmental impact indicator categories (global warming, acidification, ozone layer depletion, or ecotoxicology), so that it will be easier to understand to obtain environmental information (Gala et al., 2015). LCIA stages are characterization, normalization, weighting, single score (Sitepu, 2011). The determination of the heterogeneous impact category is carried out by SimaPro software according to the method and database used (Hamonangan et al., 2017).

The final stage of Life Cycle Analysis presents conclusions, recommendations, and supports decision-making. The findings of an LCA study can guide decision-makers by identifying areas with the greatest environmental impact, recommending actions, selecting relevant environmental indicators, and aiding in the declaration of environmental performance (Davidson et al., 2021).

Traffic Light Production

This product life cycle refers to the process that occurs from the collection of raw materials to the final use or disposal of the product. The initial stage of this life cycle starts with suppliers who send raw materials to the company using land transportation. The raw materials are then received and stored in the company's inventory warehouse for further processing. After that, the raw materials will be used in the production process to produce two-aspect traffic light products. After the product has been produced, the product will go through the packaging stage before being distributed to consumers. In the next stage, the product enters the stage of use by consumers. When the product is no longer needed or cannot be used, the final step is product disposal. This process includes recycling materials for reuse, shredding for recycling, or disposal following applicable environmental regulations. This research only covers the stages from the production process to distribution. The scope used in this research is cradle to gate.

SimaPro

SimaPro is a software designed to analyze the environmental impact of the entire life cycle of a product. With SimaPro, various environmental aspects can be evaluated, including global warming, ecotoxicity, ozone layer depletion, ozone formation in the lower atmosphere, and land and water use. The software has been used for more than 30 years and is one of the most popular tools among professionals for life cycle analysis (Jeroen, 2002).

In this research, the EDIP 2003 (Environmental Design of Industrial Products 2003) method is used as an approach in LCIA using SimaPro software. This method is a development of EDIP 1997, which applies a regionalization approach to increase the accuracy of environmental impact calculations, especially in the acidification and eutrophication categories. EDIP 2003 in SimaPro. This approach allows a more systematic and measurable analysis in evaluating the product life cycle based on the database available in SimaPro.

RESEARCH METHOD

This research applies Life Cycle Assessment (LCA) with the help of SimaPro software, which is then complemented by the Simplified Scoring System method. The main objective of this study is to quantify the number of emissions and environmental impacts generated during the production and distribution process of traffic lights from two main aspects. The production process is divided into three stages, namely the sub-production of cutting and forming raw materials, the sub-production of processing and treatment, and the sub-production of finishing and assembly. Followed by packaging and distribution. The data required is divided into independent variables and dependent variables. The dependent variable is the amount of emissions in each production and distribution process of the two-aspect Traffic Light, and the environmental impact of each manufacturing and distribution process of the two-aspect Traffic Light. The independent variables include the number of inputs and outputs in the production process of two-aspect traffic lights, the processing process of two-aspect traffic lights, energy demand data, and types of vehicles for the distribution of two-aspect traffic lights.

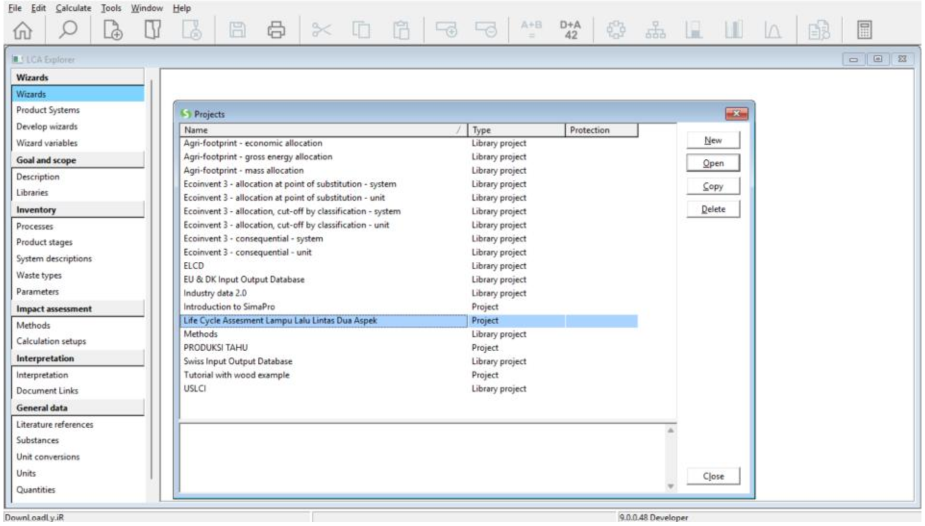
From the explanation above, it is divided into two stages, namely:

a. Life Cycle Assessment (LCA) Stage

There are four stages in LCA, including:

1. Goal and Scope Definition

Defining the objectives and scope is our pointer that can help ensure the consistency of the LCA study. The objective should indicate why the study is being conducted and what it is for. The scope describes the research methods used, assumptions, and limitations.

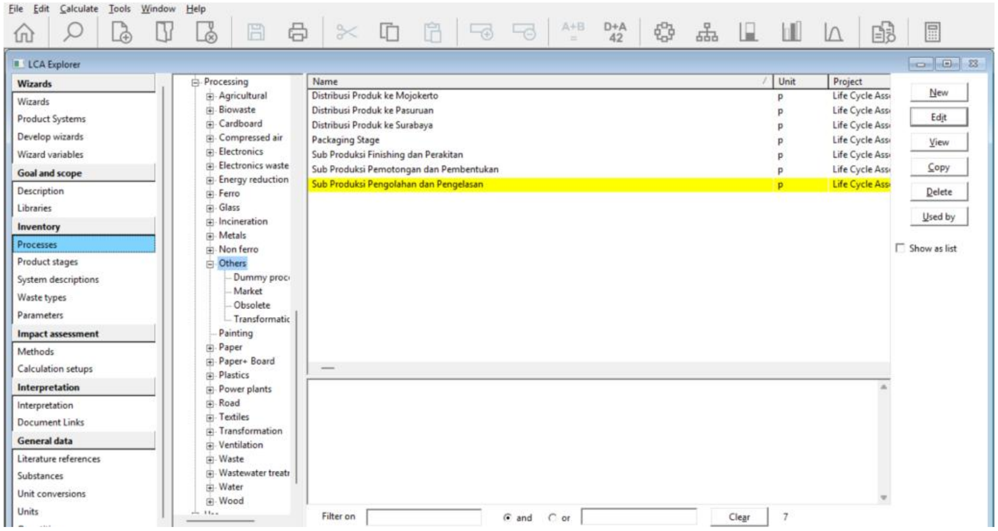


Name	Type	Protection
Agri-footprint - economic allocation	Library project	
Agri-footprint - gross energy allocation	Library project	
Agri-footprint - mass allocation	Library project	
Ecoinvent 3 - allocation at point of substitution - system	Library project	
Ecoinvent 3 - allocation at point of substitution - unit	Library project	
Ecoinvent 3 - allocation, cut-off by classification - system	Library project	
Ecoinvent 3 - allocation, cut-off by classification - unit	Library project	
Ecoinvent 3 - consequential - system	Library project	
Ecoinvent 3 - consequential - unit	Library project	
ELCD	Library project	
EU & DK Input Output Database	Library project	
Industry data 2.0	Library project	
Introduction to SimaPro	Project	
Life Cycle Assesment Lampu Lalu Lintas Dua Aspek	Project	
Methods	Library project	
PRODUKSI TAHU	Project	
Swiss Input Output Database	Library project	
Tutorial with wood example	Project	
USLCI	Library project	

Figure 1.
Database Input in SimaPro 9.0 Software

2. Life Cycle Inventory (LCI)

This stage will create an inventory of the resource use, energy use and environment associated with the selected system. The LCI stage will include all relevant process data to be used in producing, transporting, using and disposing of the selected product. This step will take the longest time when compared to the other steps. This is due to the major influence of data quality, accuracy, and representation on the final results obtained (Boggia et al., 2010).

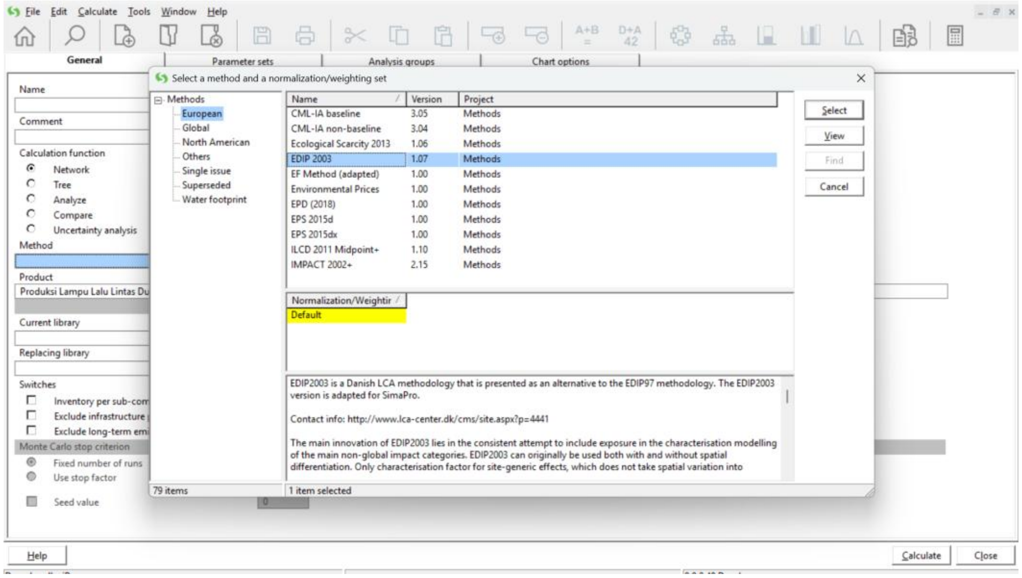


Name	Unit	Project
Distribusi Produk ke Mojokerto	p	Life Cycle Ass
Distribusi Produk ke Pasuruan	p	Life Cycle Ass
Distribusi Produk ke Surabaya	p	Life Cycle Ass
Packaging Stage	p	Life Cycle Ass
Sub Produksi Finishing dan Perakitan	p	Life Cycle Ass
Sub Produksi Pemotongan dan Pembentukan	p	Life Cycle Ass
Sub Produksi Pengolahan dan Pengelasan	p	Life Cycle Ass

Figure 2.
Two Aspects of Traffic Light Production and Distribution Process Input

3. Life Cycle Impact Assessment (LCIA)

Life Cycle Impact Assessment (LCA) is the stage where environmental impacts are analyzed by measuring resource use as well as emissions, which are then categorized based on their level of significance. This process evaluates potential environmental impacts by utilizing data from life cycle inventories, providing important insights that support interpretation in the final stage of the assessment (Hermawan et al., 2017). The data obtained from the Life Cycle Inventory (LCI) stage will be classified into various categories of environmental impact indicators, such as global warming, acidification, ozone layer depletion, and ecotoxicity. This process aims to present environmental information in a clearer and easier-to-understand manner (Gala et al., 2015). LCIA stages are characterization, normalization, weighting, and single score (Sitepu, 2011).



Product: Produksi Lampu Lalu Lintas Du

Name	Version	Project
CML-IA baseline	3.05	Methods
CML-IA non-baseline	3.04	Methods
Ecological Scarcity 2013	1.06	Methods
EDIP 2003	1.07	Methods
EF Method (adapted)	1.00	Methods
Environmental Prices	1.00	Methods
EPD (2018)	1.00	Methods
EPS 2015d	1.00	Methods
EPS 2015dx	1.00	Methods
ILCD 2011 Midpoint+	1.10	Methods
IMPACT 2002+	2.15	Methods

Normalization/Weightir
Default

EDIP2003 is a Danish LCA methodology that is presented as an alternative to the EDIP97 methodology. The EDIP2003 version is adapted for SimaPro.

Contact info: http://www.lca-center.dk/cms/site.aspx?p=4441

The main innovation of EDIP2003 lies in the consistent attempt to include exposure in the characterisation modelling of the main non-global impact categories. EDIP2003 can originally be used both with and without spatial differentiation. Only characterisation factor for site-generic effects, which does not take spatial variation into

Figure 3.
Selection of Methods in Impact Assessment

4. Interpretation

The final stage of the life cycle analysis aims to draw conclusions, provide recommendations, and support the decision-making process based on the results of the environmental impact assessment.

b. Simplified Scoring System Stage

This stage is an additional step in the research before going into the interpretation stage. Simplified Scoring System (SSS) is a method used in the evaluation of environmental impacts in Life Cycle Assessment (LCA). This approach aims to simplify the scoring process to make it easier to understand and apply, especially for users who do not have an in-depth technical background. In this system, environmental impacts are categorized into several main aspects, such as greenhouse gas emissions, energy consumption, water use, and waste production. Each category represents an important aspect of the product or process lifecycle (Hamn, 2016).

RESULTS AND DISCUSSION

Life Cycle Assessment

1. Goal and Scope

The objective of this LCA study is to assess the emissions and environmental impacts generated at each stage of the production process, from raw materials to distribution at this company using the Environmental Design of Industrial Products (EDIP) impact assessment method. According to Sirait (2020), the EDIP 2003 method provides a systematic approach to evaluating environmental impacts, emphasizing emission reduction and resource efficiency throughout the product life cycle. The scope of this LCA research is limited to a cradle-to-gate approach, which analyzes the production process from raw material acquisition to the distribution stage. This approach was selected because the study focuses on the environmental impacts arising from waste generated within the company's internal supply chain activities, particularly in the production phase (Kautzar et al., 2015). There are several environmental impacts resulting from EDIP 2003 on Simapro software:

Table 1.
Impact Category EDIP 2003

No	Impact Category	Keterangan
1	Global Warming	Increase in the average temperature of the atmosphere, ocean, and land due to emissions of greenhouse gases such as CO_2 and CH_4
2	Ozone Depletion	The decrease in stratospheric ozone concentration, which increases the penetration of ultraviolet light to the Earth's surface, is caused by emissions of compounds such as CFCs and halons.
3	Ozone Formation (Vegetation)	Ozone formation in the tropospheric layer affects plant health.
4	Ozone Formation (Human)	The formation of ozone in the tropospheric layer impacts human health.
5	Acidification	Increased environmental acidity due to emissions of gases such as SO_2, NO_x, and NH_3, which can cause

No	Impact Category	Keterangan
		damage to terrestrial and aquatic ecosystems.
6	Terrestrial Eutrophication	Increased nutrients, especially nitrogen, in terrestrial ecosystems lead to changes in species composition.
7	Aquatic Eutrophication EP (N)	Increased nitrogen nutrition in aquatic ecosystems leads to algal overgrowth and reduced water quality.
8	Aquatic Eutrophication EP (P)	Increased phosphorus nutrition in aquatic ecosystems has similar effects.
9	Human Toxicity Air	Negative impacts on human health through exposure to airborne pollutants.
10	Human Toxicity Water	Negative impacts on human health through exposure to pollutants in water.
11	Human Toxicity Soil	Negative impacts on human health through exposure to pollutants in soil.
12	Ecotoxicity Water Chronic	Long-term impacts on aquatic organisms from exposure to pollutants.
13	Ecotoxicity Water Acute	Short-term impacts on aquatic organisms due to exposure to pollutants.
14	Ecotoxicity Soil Chronic	Long-term impacts on soil organisms due to exposure to pollutants.
15	Hazardous Waste	Waste containing toxic or hazardous materials that requires special handling.
16	Slags / Ashes	The residue of combustion or metallurgical processes can impact the environment if not handled properly.
17	Bulk Waste	Large quantities of waste require specialized management.
18	Radioactive Waste	Waste containing radioactive materials that requires special handling and storage.
19	Resource	Use of natural resources may lead to depletion and impact future availability.

2. Life Cycle Inventory

Inventory analysis in this study is divided into five processes, namely sub-production 1, 2, 3, packaging stage, and distribution to consumers. At this stage it is used to determine the material and energy inputs used, as well as the output of the two-aspect traffic light production process. After knowing the input and output, it will then be analyzed into SimaPro Software. The process and stages of traffic light production can be seen in the figure

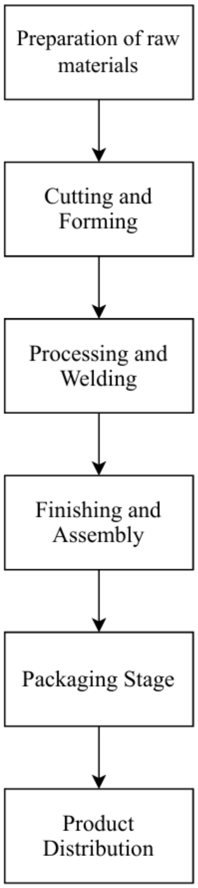


Figure 4.
Process Flowchart

3. Life Cycle Impact Assessment

In this study, the EDIP 2003 (Environmental Design of Industrial Products 2003) method was used as an approach in LCIA using SimaPro software. Adspun impact categories that exist in the EDIP 2003 method include Global Warming, Ozone Depletion, Ozone Formation (Vegetation), Ozone Formation (Human), Aquatic Eutrophication EP (N), Aquatic Eutrophication EP (P), Human Toxicity Air, Human Toxicity Water, Human Toxicity Soil, Ecotoxicity Water Chronic, Ecotoxicity Water Acute, Terrestrial Eutrophication, Ecotoxicity Soil Chronic, Acidification, Hazardous Waste, Slags / Ashes, Bulk Waste, Radioactive Waste, Resource (Hauschild & Potting, 2005).

A. Characterization

The characterization stage is the stage where all inputs and outputs will be assessed for their contribution based on the impact categories that have been determined in the previous process in the two-aspect traffic light product cycle starting from the production process, packaging to the distribution stage to consumers.

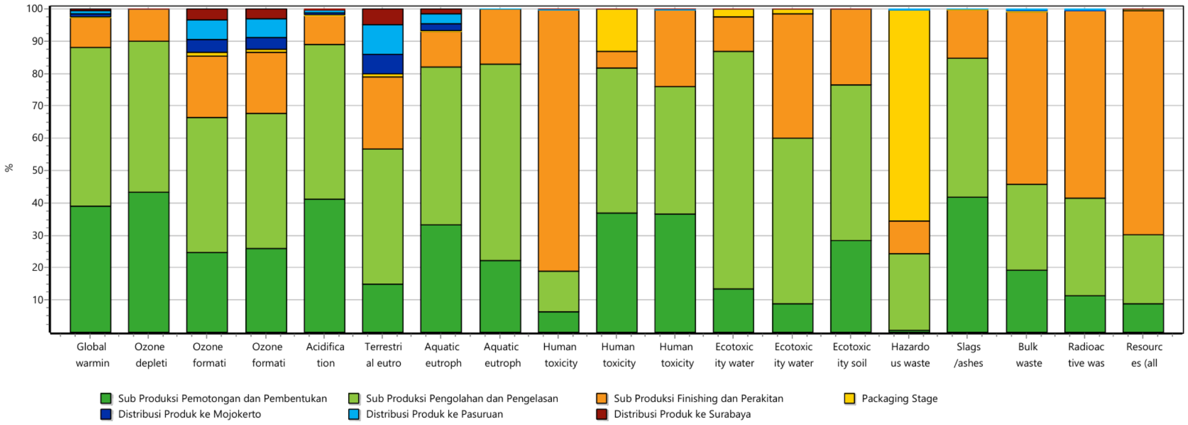


Figure 5.

Characterization Results

Based on the analysis of the characterization results, the two-aspect traffic light production process has various contributions to pollution and emissions, with the largest impact on human toxicity of water, which reaches 9.78E7 person. This impact mainly comes from the Cutting and Forming Sub-production, which produces emissions of toxic substances into the air, affecting human health. In addition, the hazardous waste category also shows a significant figure, totaling 3.78E6 kg, mainly from the Finishing and Gluing Sub-Production, which is related to the use of chemicals in the final stage of production. Human toxicity water is also a major concern, totaling 1.64E5 m³, caused by the discharge of toxic waste into water sources, mainly in the Processing and Welding Sub-production. In terms of ecosystem pollution, ecotoxicity water acute had a major impact, indicating the presence of pollution affecting water quality and aquatic life. In addition, the Global Warming Potential is also significant, with total emissions of 3.18E3 kg CO2 eq, of which most comes from energy consumption in the Processing and Welding Sub Production.

B. Normalization

The Normalization stage is a stage where the overall impact that has been assessed will be compared and simplified based on the same size. The purpose of the assessment is to get the same comparative value for each type of impact so as to facilitate further interpretation.

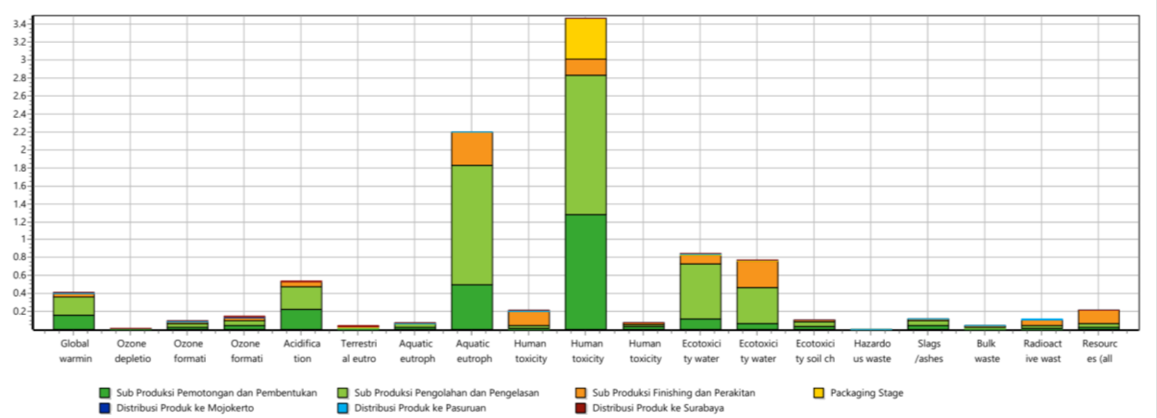


Figure 6.
Normalization Results

From the graphical and tabular analysis, the largest environmental impact category is human toxicity (water) at 3.47, with the main contribution from the processing and welding sub-production at 1.28 and the processing and welding sub-production at 1.55. Another category that has a significant impact is aquatic eutrophication EP (p) at 2.2, with the main sources from the processing and welding sub-production at 1.33 and the cutting and forming sub-production at 0.493. In addition, human toxicity (water) of 0.206 is dominated by finishing and gluing sub-production of 0.167, while ecotoxicity water chronic of 0.841 mainly comes from processing and welding sub-production of 0.616 and cutting and shaping sub-production of 0.113. Acidification of 0.536 also has a considerable impact, with the main contribution from the processing and welding sub-production of 0.257. Overall, the production stages with the largest environmental impacts are the processing and welding sub-production and the finishing and gluing sub-production, while the packaging and distribution stages make smaller contributions.

C. Weighting

The weighting stage is the process of calculating the results of the impact category indicators will be multiplied by the weighting factor and accumulated as a total score. Weighting is the stage where all assessed impacts will be compared and simplified based on the same measure. This is because in comparing all types of potential environmental impacts, the assessment needs to be made relative so that the units used will be uniform, namely using Pt (Points) units.

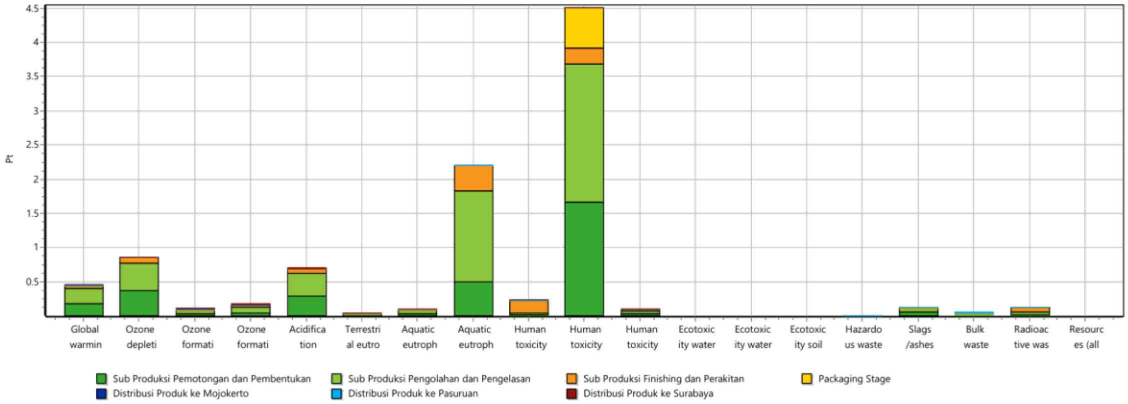


Figure 7.
Weighting Results

Based on the weighting results, the analysis per impact category shows that human toxicity water has the largest impact with a total of 4.51 Pt, where the main contribution comes from the processing and welding sub-production of 2.02 Pt. Another category with significant impact is aquatic eutrophication ep (P) at 2.2 Pt, with the largest contribution from the processing and welding sub-production at 1.33 Pt. In addition, acidification at 0.699 Pt, global warming 100a at 0.451 Pt, and ozone depletion at 0.373 Pt also have considerable contributions, especially from cutting and processing. From the graph, it can be seen that the majority of the contribution comes from the production stage, especially the cutting and welding sub-production, while the distribution and packaging stages have a smaller impact. This shows that the production process has a dominant role in environmental impacts, especially in the human toxicity category.

D. Single Score

After the weighting stage is carried out, all potential environmental impacts are converted into one score. This stage will show the value generated from each process towards the impact category.

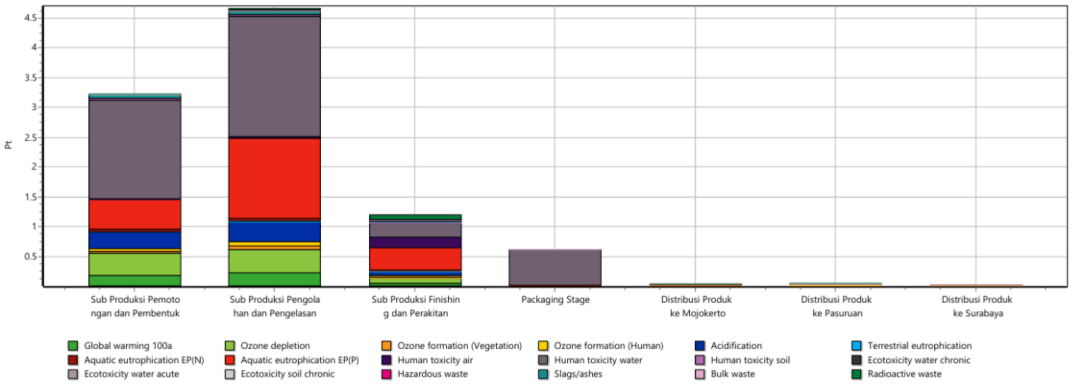


Figure 8.
Single Score Results

E. Simplified Scoring System and Interpretation

A simplified scoring system is a method that simplifies environmental impact assessment by collecting relevant data, identifying assessment criteria such as CO2 emissions or energy use, and then assigning a score to each criterion based on certain rules. These scores are summed over a range of 1 to 5, and the final result is interpreted to determine how much environmental impact an activity or product has. This system facilitates the evaluation process with a more concise and direct approach.

Table 2.
Simplified Scoring System Result

Stage	Carbon Emission	Energy Consumption	Raw Material Usage	Waste Production	Total
Cutting and Forming	4	3	2	4	13
Processing and Welding	5	5	3	4	17
Finishing and Assembly	5	5	3	4	11
Packaging Stage	2	0	1	1	4
Product Distribution	4	3	1	1	9

Source: Primary Data Processed in 2025

Furthermore, after being assisted using a simplified scoring system. Then, interpretation is carried out, namely, analyzing and drawing conclusions from the results of Life Cycle Inventory (LCI) and Life Cycle Impact Assessment (LCIA). Processing and maintenance sub-production has the highest value, followed by cutting and forming sub-production, followed by cutting and forming packaging stage, and product distribution to consumers. Reinforced through the results of Life Cycle Impact Assessment (LCIA) diagrams and tables. That the processing and treatment sub-production has high environmental impact values such as Global Warming, Ozone Formation (Vegetation), Acidification, Ozone Formation (Human), Terrestrial Eutrophication, Aquatic Eutrophication EP(P), Acidification, Human toxicity water, Human toxicity soil, Ecotoxicity soil chronic, Ecotoxicity soil acute, Ecotoxicity water chronic, Slags/ashes, Hazardous waste, Bulk waste. The highest value is in human toxicity water and water. Environmental pollution that adversely affects human health through air media (human toxicity water) and environmental pollution that adversely affects human health through water media (human toxicity water).

Provision of Recommendations

The following are some suggestions for improvements that can be applied to optimize the use of materials in the production process based on the production needs table :

1. Optimization of Aluminium Scrap Utilization

What is meant by aluminum scrap here is fine particles of aluminum formed due to the sanding or honing process. This company has not done any further processing of this aluminum powder. If explained in more detail, aluminum powder has a complex environmental impact because it can affect various aspects such as air, water, and soil. Aluminum soil pollution that is not handled properly can accumulate in the soil and disturb the mineral balance for plants (Putra Suwanto, 2018). For optimization, aluminum scrap can be collected, melted, and reused for further production or given to companies that are experts in processing aluminum powder waste.

2. Efficiency Improvement in Powder Coating

Powder coating residue that does not adhere to the workpiece can be in the form of overspray, production dust, or residue from equipment cleaning. Powder coating residue that enters the environment, especially water, can be harmful because it contains polymers, pigments, and chemical additives that do not break down easily. Powders containing heavy metals (such as lead, chromium, or cadmium) can leach into water and pollute the ecosystem.

In the use of powder coating, an improvement recommendation is to use a recovery system to capture the remaining powder and reuse it.

3. Digitalization and Automation for Production Efficiency

Leveraging IoT and AI technologies to optimize raw material usage and reduce waste (enabled for digital record keeping). Reduce wastage with a leaner and more efficient approach to production.

4. Optimizing the Use of Water and Soap

Washing using water and soap can generate liquid waste, and if the soapy water is discharged into waterways or open water bodies (rivers, lakes, etc.), it can cause water pollution. harmful chemicals contained in soap, such as phosphates, can cause eutrophication, which is a decrease in water quality that results in excessive algae growth. There are recommendations for improvement, namely the installation of a filtration system so that the water used can be reused in the production process. Using soap based on natural ingredients that are more biodegradable and do not pollute the environment.

CONCLUSION

Based on the results and analysis of this study, it can be concluded that the production process to the distribution of two-aspect traffic lights produces a large value of emissions and environmental impacts according to Simapro software including global warming of 0.451 Pt, ozone depletion of 0.859 Pt, ozone formation (vegetation) of 0, 115 Pt, ozone formation (human) by 0.174 Pt, acidification by 0.697 Pt, terrestrial eutrophication by 0.046 Pt, aquatic eutrophication by 2.2 Pt, human toxicity water by 0.227 Pt, human toxicity water by 4.51 Pt, human toxicity soil by 0.0917 Pt, and radioactive waste by 0.122 Pt. Of all the environmental impacts and emissions, the largest value is in human toxicity water of 4.51 Pt. In addition, from the production stage to the distribution stage, it is found that the stage that has the greatest impact on the environment is in the processing and maintenance stage ranked using a simplified scoring system with a total score of 17. Therefore, the urgency for improvement is in the processing and maintenance production sub-stage with recommendations for improvement, namely optimizing the utilization of aluminum scrap can be done by collecting it first and then sending it to a third party to make it more useful and installing a filtration system so that the water used can be reused in the production process.

Future research can focus on analyzing the environmental impact of other production activities at this company to complete the company's overall Life Cycle Assessment (LCA). This study has a limitation on the evaluation of environmental impacts specifically for two-aspect traffic light products, so further studies are needed to provide a more comprehensive picture of the environmental footprint of all production activities at this company.

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