The Importance of Data Quality in Using LCA Approach as A Decision Supporting Tool: Comprative Case Study between Injection Moulding Machines in Processing Polypropylene

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Abstract

Indonesia is developing an awareness of life cycle perspective, where a product cannot only be analysed in a certain phase but shall be analysed throughout its life cycle. In developing this concept, the understanding of data quality in selecting and recording datasets is important. Many LCA practitioners often neglected the importance of understanding different types of datasets and tracking and documenting dataset. The objective of this paper is to understand the effect of technology coverage in data quality of Life cycle assessment (LCA) and the use of LCA approach as a decision supporting tool. A case study comparing two production methods of a product made of polypropylene (PP) is conducted. Injection moulding machines used in these two plants are different in terms of technology aspect. Comparison between injection moulding machines in these plants was conducted and actual data from the production site were gathered. SimaPro 8 by Pre Consultants is used for life cycle assessment of the machines. Two types of methods, i.e. TRACI and ReCipe, are used in impact assessment stage. The result implied that the technology difference shows significant variation of impact related to energy consumption between both plants. Therefore careful consideration must be taken when using and recording datasets to ensure suitability of the datasets for reuse.

Keywords: *Life Cycle Assessment*; *Technological Representativeness*; *Injection Molding Machine*; *Data Quality*

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1. INTRODUCTION

In Indonesia, following the increase of awareness of sustainable consumption and production as the Goal number 12 in the United Nations Sustainable Development Goals[1], Life Cycle Assessment (LCA) is promoted and introduced to a wider audience for industrial applications. By performing life cycle assessment, producers can identify the potential environmental impact throughout the life cycle of the product. Starting from the extraction of raw materials to the disposal of products or recovery of material in the end of life of the product[2]. Therefore, LCA can help as decision supporting tool to improve the process and products as in minimizing their energy and resource consumption.

LCA is an iterative process consists of four phases (i.e. Goal and Scope Definition, Life Cycle Inventory (LCI), Life Cycle Impact Assessment (LCIA) and interpretation. This is standardized through the ISO 14040 series.

Since the application of LCA has just started in Indonesia, it is important to set the ground rules in performing and documenting LCA studies. Performing LCA in a proper manner shall takes into account its important aspect, which is the data quality, as defined in ISO 14044 as characteristic of data. Documenting the right data to be used for other users is important to ensure the quality of an LCA study. Data quality within LCA is a significant issue for the future support and development of LCA as a decision supporting tool and its wider adoption within industry[3].

For a reliable LCA study, as the ISO 14044 stated, the data quality requirements are required to be specified in order to fulfill the goal and scope of the study. It is affecting the result of the LCA study as well as its effectiveness as the decision supporting tool for the decision makers. Low data quality will be followed by low interpretation. Therefore, taking the data quality into account and assessing it diligently are important, particularly for comparative study which is intended to be disclosed to the public.

According to ISO, the data quality requirements include the following, time-related coverage, geographical coverage, technology coverage, precision, completeness, representativeness, consistency, reproducibility, sources of the data, and uncertainty of the information[4].

This paper presents a case study to compare the environmental impact of two injection moulding machines with similar specifications, which are used to process Polypropylene (PP). The injection machines are differ by age. The environmental data for these machines ares compared to show the influence of data quality to the results. Therefore, care must be taken in documenting life cycle inventory and selecting datasets to ensure the quality of an LCA Study.

In Indonesia, plastic industry is one of the largest industries in Indonesia. It is a promising business throughout its supply chain with great opportunity to gain profit, despite of many issues that came out concerning with its potentially harmful impacts to the environment. According to the Minister of Republic Indonesia, Airlangga Hartarto, currently there are 925 companies of plastic industry in Indonesia which can absorb approximately 33,000 workers. These companies produce various type of plastic products with total production amount is 4.68 million tonnes[5].

Among several methods of processing plastic, the most common method used for processing plastic is injection molding[1]. Injection molding process is one of the most used processes for producing plastic products, ranging from disposable food containers to high precision engineering components[7]. Since utilisation of these machines consumes a great amount of energy, it is important to effectively manage the energy utilisation of these machines and addressing their environmental impact.

Injection molding process may seems to be environmentally friendly due to its low direct emission levels. However, in previous LCA studies of injection molding machines, it was found that it contributes a lot of indirect emission due to the energy consumption. The burning of fossil fuels for electricity generation is the largest single anthropogenic source of the greenhouse gas (GHG) emissions responsible for global warming[8]. Furthermore, particulate matters emitted from the process also possess impact to human health impacts in the form of respiratory problems[9].

According the result of LCA study that has been conducted by Elduque, et al., about injection molding processing of Ecoinvent, the environmental impact assessment under ReCiPe methodology shows that the environmental impact resulted by this process is significantly dominating on climate change for more than 90% compared to other life cycle phases i.e. manufacturing, transporting, and recycling[10]. Similarly, a study conducted by Krauss-Maffei – a German company who produce injection molding machine, their injection molding machine specifically in processing PP has high contribution 93.5% to the GHG potential during the first year of operation, and the percentage will rise to 99.6% over an assumed total operating life of 18 years[10], whereas a study conducted by Gantar, et al. resulting up to 92% contribution. The high contribution of this process is most of due to electricity consumption (62%)[10].

This case study will only focus in comparing at the operating stage as the early study's result shows that this stage appeared has dominant contribution of the energy consumption during use with significant environmental impacts.

The aim of this study is to emphasize how data quality will contribute to the effectiveness of LCA approach as one of the decision supporting tools of manufacturers, especially in reusing the datasets for an LCA study. This paper is outlined as follow. Section 2 describes the research method and assumptions used in this paper. Section 3 interprets the results from the life cycle assessment as well as discussion. Finally section 4 presents conclusions from the research and future recommendation.

2. METHOD

A Life Cycle Assessment was conducted to two injection moulding process. The data used in this paper were based on the studies conducted by Timman[12] and Saputra[13]. Both studies assessed production process of household products made of Polypropylene (PP) using injection molding machines.

Data were collected from the processing plants in Bogor, West Java[12] and Jakarta[13] and gate-to-gate LCA was conducted on both facilities. Based on the data quality requirements, both machines have some similarities on the time-related coverage, geographical coverage, precision, completeness, representativeness, consistency, reproducibility, source of data and uncertainty of the information.

Each of the data were collected during mid 2015 for around 3 months. Data were collected from two sites located in Jakarta Greater Area. Since both data collection methodologies are the same, the precision, completeness, and consistency of data are similar.

According to the ISO 14044:2006 on LCA requirements and guidelines, data quality is required to be addressed. There are ten data requirements that has to be addressed. These are time-related coverage, geographical coverage, technology coverage, precision, completeness, representativeness, consistency, reproducibility, source of data, and uncertainty of the information[4]. All those ten data quality requirements have been considered in this case study.

The overall production process in manufacturing consists of five main processes, namely Mixing, Injection Moulding Process, Inspection and Scrap Cleaning, Assembly and Packaging. First, is mixing process between PP and coloring powder using mixing machine. Second, injection molding process, followed by inspection and scrap cleaning, assembly process, and the last process is packaging. For each process, data that are collected consist of input, output, energy, and emission/waste data.

Fig. 1 shows the flow diagram of the product's production process as mentioned previously as well as the boundary of this study which were injection molding processes. The functional unit was 1 kg of coloured PP processed in injection molding machine.

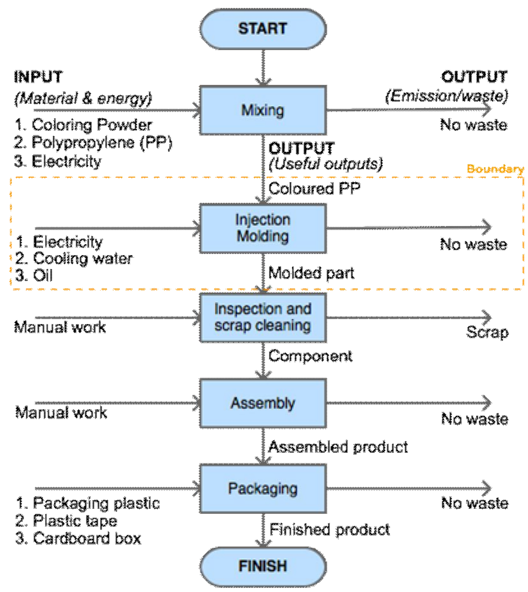

Fig 1. Diagram Flow of Production Process

In the beginning of an injection molding process, resin is melted in the injection molding machine. A variety of resins can be processed in an injection molding machine. Typical materials include: polypropylene (PP), general purpose polystyrene (GPPS), polycarbonate (PC), acrylonitrile-butadiene-styrene (ABS), and nylon (also known as polyamide, or PA).

There are two main parts in injection molding machine, the injection part and the molding part[3]. In the injection part unit, plastic is loaded into a hopper and pushed through a heated chamber by a screw to bring the resin to a semifluid state. The molten plastic is then injected through a nozzle into the clamped molding unit. The mold is cooled to return the material to a solid state. Cooling is typically achieved by circulating water through chambers within the molding plate. The mold then unclamp and eject the part for finishing. Finishing steps may include printing and packaging[7].

In this case, in the injection molding process, there are coloured PP as the material input made by mixing coloring powder and PP with comparison of 1:49[12] in mixing machine. The injection molding machines utilize electricity, cooling water and oil during the operating time.

In Timman[12] and Saputra[13], all data for the functional unit were generated from the data of 8 hours operating time. Exact measurements of electricity consumption were not feasible. Therefore, data of the machines electricity consumption were based on calculation of power consumption specified in each of the machines factored by efficiency rate of electricity input from the grid. The amount of cooling water and oil consumed by the machines were also taken into account.

The two machines are mainly distinguished by their age. The injection molding machines in plant for Timman case study (Plant X) are less than 5 years old. However, the injection molding machine in plant for Saputra's case study (Plant Y) are more than 10 years old. Although the hover capacity of both types of machines are equal, the injection molding machine in Plant X able to process more amount of PP during 8 hour operating time i.e. 400 kg/ 8 hr, while the injection molding machine in plant Y can only process 153 kg/ 8 hr.

This difference in machine operation is one of the aspects of comparison for the machines, for example, energy requirements of an old machine usually much larger of the total energy use, compared to newer ones. The calculations are based on energy and water consumption figures of the injection molding machines of different age, the data is shown in Table 1 of the inventory of each plant for the injection molding process. Plant X indicates data generated from Timman[12] and Plant Y indicates data generated from Saputra[13].

Table 1. Inventory of Plant X and Plant Y in Injection Molding Process for Functional Unit (1 kg coloured PP)

Inventory	**Plant X (Age < 5 yrs.)**	**Plant Y (Age > 10 yrs.)**
Electricity	0.72 kWh	1.1704 kWh
Cooling Water	60 L	224.72 L
Oil	0.00373 L	0.004969 L
Useful Outputs	1 kg Molded Part	1 kg Molded Part
Waste	No waste	No waste

The assessment was conducted by using SimaPro 8, an LCA software developed by Pre Consultants. Data from Ecoinvent version 3 and USLCI database were used in addition to the data collected at the plants. To calculate the impact assessment, ReCipe (I) and TRACI were used.

3. RESULTS AND DISCUSSION

Impact assessment is conducted by using two different impact assessment methods, i.e. ReCipe (I) and TRACI to compare potential impacts which might be produced by each machine for midpoint category. The result of impact assessment which is calculated by each method shows that in midpoint category there are three most significant impacts that might occur as shown in Table 2.

Based on World ReCipe (I) method, injection molding machine in Plant X compare to the machine in Plant Y, injection molding machine in Plant Y significantly have higher impact potential for each impact category as shown in Fig. 2. The most significant potential impact is marine ecotoxicity. For this category, for both plant the primary substance that causes the impact is Nickel (contribution >50%) which significantly due to the use of electricity (contribution >90%).

Table 2. Three Significant Midpoint Impact Categories based on ReCipe (I) and TRACI Method

No.	**Midpoint Impact Category**	
	World ReCipe (I)	**TRACI**
1.	Marine ecotoxicity	Carcinogenic
2.	Freshwater ecotoxicity	Eco-toxicity
3.	Freshwater eutrophication	Respiratory effects

The second most significant impact based on World ReCipe (I) is freshwater ecotoxicity, similar to marine ecotoxicity, for both plant the primary substance that causes the impact is Nickel (contribution >40%) which also significantly due to the use of electricity (contribution 90%).

For the third most significant impact freshwater eutrophication, both plant potentially generating impact to freshwater eutrophication from Phospate with more than 90% contribution. The phosphate is significantly due to the use of electricity (contribution 90%).

Similar to the results which is generated by using World ReCipe (I) method, injection molding machines in Plant Y also contribute higher impact potential for each impact category compared to Plant X when using TRACI method. This can be seen in Fig. 3.

The most significant potential impact based on TRACI impact assessment method is carcinogenic. The primary substance that causes the impact is Chromium VI (contribution >90%). This occurs at both plants.

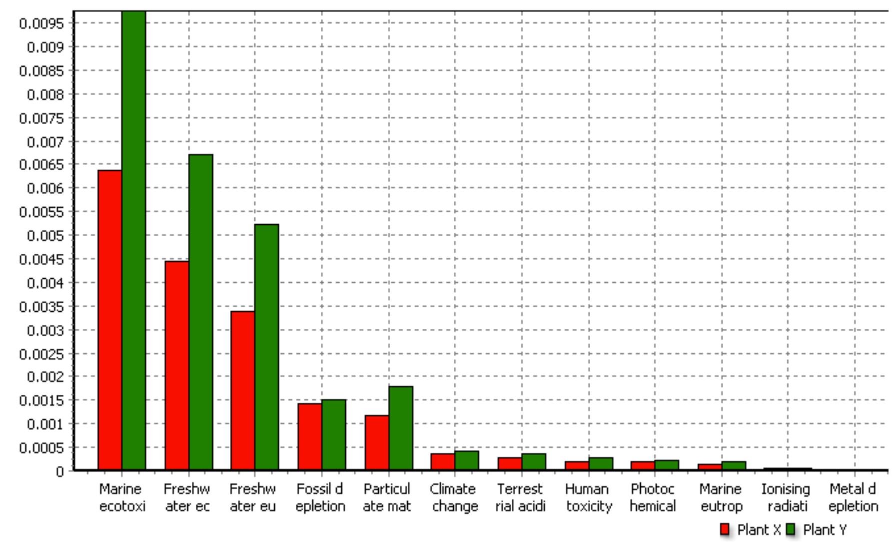

Fig 2. Midpoint Impact Category Results Based on World ReCipe (I) After Normalization

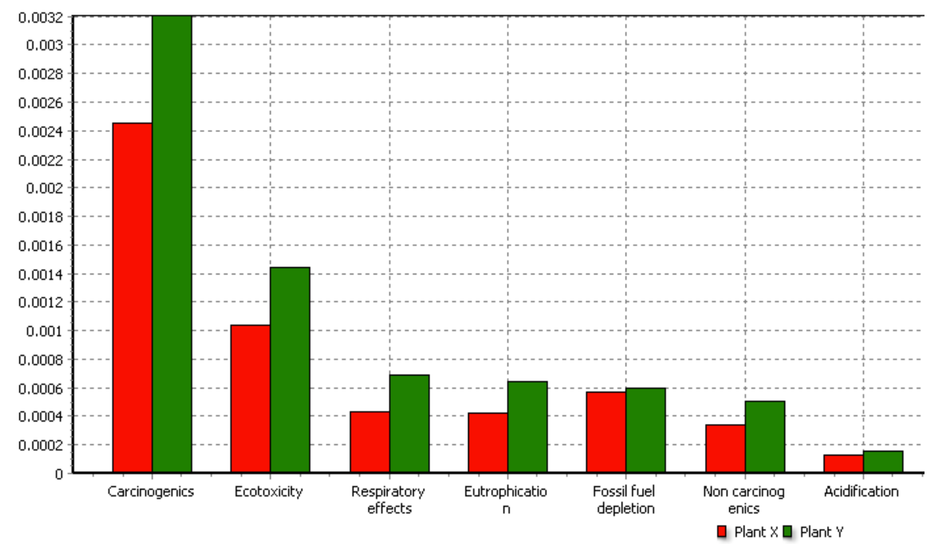

Fig 3. Midpoint Impact Category Results Based on TRACI After Normalization

At Plant X, this is due to the processing of PP in the injection molding machine and also the use of electricity (contribution >45%). While in Plant Y this is significantly due to the use of electricity alone (contribution >50%) over the processing of PP (contribution >35%).

Apply equally to the both plant, the second most significant impact is ecotoxicity, the primary substance which cause the impact is Zinc, by itself contributes for more than 35%. The Zinc occurs significantly (>90% contribution) due to the use of electricity. The third most significant impact is respiratory effects, particulates (<2.5um) is the primary substance causes this impact with more than 90% contribution, occurs due to the the use electricity.

Based on the result of impact assessment using two methods i.e. World ReCipe (I) and TRACI, we can conclude that significantly both injection molding machines, potential impacts that might occurred significantly due to the use of electricity. When analysis is done to the inventory data, it becomes reasonable for the injection molding machines in Plant Y has higher potential impacts than in Plant X, because injection molding machines in Plant Y, consume higher amount of electricity compared to injection molding machine of Plant X. This results show that the old injection molding machine in Plant Y consumes more resource, while the new injection molding machine in Plant X saves up to 38% of the energy compare to the energy used in Plant Y.

These results indicate information for the decision makers, considering the resource efficiency and environmental aspects, it might necessary to replace the old machines with the new one. In addition, the new machine is much more efficient because can process almost two times than the old injection molding machine, in this case the injection molding machine of Plant Y. However, actually whether it is worth to substitute the old machine and use a new one cannot be answered precisely. The answer depends on the decision maker evaluation of the time span, which is acceptable for the environmental and economic payback period. A further study, which includes model of when the machine should be replaced is recommended for more reliable result. Moreover, life cycle optimization requires detailed modeling of a further set of scenarios, which has not been undertaken as part of this study.

This result of the study shows the usability of LCA approach as decision supporting tool. This result signifies the importance of data quality indicator description when conducting LCA.

4. CONCLUSIONS

In using database or creating dataset for database, it is important to indicate data quality assessment. Choosing less accurate dataset might influence the result of the LCA study. This emphasize the importance of data documentation in developing a LCI database.

As presented through this case study, data collected from different technological and temporal representativeness resulted different potential environmental impact. This will affect the reliability of the study result. Therefore, the data quality which is highly related to data documentation, management, as well as comments regarding the data used, is important. Assumptions related to the data collection procedures may also contribute to variations in result. In this research, both data collection were based on the product specification information of the machines. Assumptions regarding the energy efficiency were calculated and not measured. Further study should include direct measurement of the machines, as there might be variations on the machine's' energy efficiency.

Based on the comparative case study that has been conducted, it can be concluded that the injection molding machine in Plant X is more efficient and have less potential impacts compare to the injection molding machine in Plant Y. Significantly, both injection molding machines' potential impacts might have occurred due to the use of electricity. This results provide information for decision maker it may be beneficial environmentally to replace the old machine with the new one immediately. However a comprehensive LCA study is necessary to be conducted by including other aspects such as economic. From the comparative case study conducted, it is well understood that LCA supports decision maker by providing information particularly related to environmental aspects to make a decision along with the other methods to achieve strategic objectives.

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