Life Cycle Analysis of Plastic Packaging

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Abstract. Due to the increasing demand of plastic usage all around the world, the production and disposal of plastic packaging have a significant increase in amount. This study is aimed to analyze the environmental impacts throughout the life cycle of Low-Density Polyethylene (LDPE) plastic packaging by using life cycle analysis (LCA) method which implemented as in ISO 14040 and ISO 14044. The system is designed to study the cradle-to-grave process of LDPE plastic packaging which included the production of polymers, manufacture of packaging, distribution of packaging, overall transportation, and the end-of-life treatments, with the functional unit of 1000 kg, using GaBi LCA software and TRACI 2.1 method, to assess the significant environmental impacts throughout the processes which were the global warming (climate change), acidification, smog formation, eutrophication, and particulate matter emission. The findings show that climate change is the most significant impact (43% contribution) while the most relevant unit process is the manufacture of LDPE packaging (52% contribution). Landfill has found to be the best option within end-of-life treatments, with the least pollutant emissions. However, the design of landfill had to be enhanced to cope with the long-lasting effects of plastic in landfill.

1. Introduction
Currently, plastic is one of the major toxic pollutants in the world [1]. The global plastic production shows an increase from 1950 to 2015, which is 407 million tons in 2015, a nearly 200-fold of production compared to 1950 [2]. Most of the plastics are manufactured for packaging used, and a Low-Density Polyethylene (LDPE) type of polymer film is generally used for packaging [3]. The global production of LDPE is second dominant among the plastic production, which was 64 million tons, while the waste generation of LDPE has become the first dominant which was 57 million tons, in 2015 [2]. Unfortunately, LDPE plastics are usually non-degradable [1], and it will cause the accumulated waste in landfills and in natural environment.

Apart from the end-of-life treatments, impacts can also be contributed from the other life cycle stages of an LDPE plastic packaging. During the life cycle of an LDPE plastic packaging from raw materials extraction to the end-of-life treatments, there will be harmful emissions that causing impacts to environment and human life, such as production phase contributed to global warming, and incineration contributed to emissions of toxic gases [1]. The increasing usage of artificial plastics has cause important impacts such as climate change, melting of glaciers, depletion of ozone layer, loss of biodiversity, and water pollution, that post important impacts on human life [4].
This study is aimed to perform life cycle analysis (LCA) of LDPE plastic packaging as implemented in ISO 14040 and ISO 14044, where it assesses the environmental impacts that associated with all the stages of the product's life, which is a cradle-to-grave process [3], to serve the needs of identifying the significant environmental impacts throughout the life cycle, in order to evaluate and determine the major contributor of life cycle stages to the environmental impacts using LCA technique. The end-of-life treatments of LDPE plastic packaging are compared in order to get the best practice of waste management system with the least environmental effects. The identification on impacts allows the manufacturing industries, users and waste management facilities to increase awareness and create useful suggestions in protecting and conserving the environment. The LCA study is able to provide a scientific basis for the policy makers and concerned or related departments to formulate decisions for better management of particular processes or production [5]. Hence, the significant effects such as global warming, air pollution, and acidification level can be minimized.

2. Materials and methods
Life Cycle Analysis (LCA) is a scientifically sound and comprehensive approach that can be used to determine the environmental impact of various processes [6]. It helps to evaluate all the related inputs, outputs and potential environmental impacts of a product throughout its life cycle, from manufacturing to its end-of-life treatment, a cradle-to-grave process [3, 7]. The implementation of LCA is under the guidance from ISO 14040 and ISO 14044 standards, where ISO 14040 stated the principles and framework for LCA, while ISO 14044 provided details in requirements and guidelines [8, 9]. As stated in ISO 14040, an LCA involves of four phases which are (1) the Goal and Scope definition phase; (2) the life cycle inventory analysis phase (LCI); (3) the life cycle impact assessment phase (LCIA); and (4) the interpretation phase.

2.1. Goal and scope definition
In order to evaluate the sustainability of a product, the entire supply chain of the product should be considered. The intended use of this analysis was to quantify and communicate the environmental impacts of LDPE plastic packaging in order to get awareness. The boundaries for this study included the production of polymer from raw materials, fabrication of packaging from polymer, distribution transport to use site, and their end-of-life treatments, as shown in figure 1, which excluded the filling phase as the study was focused on the packaging itself only, and the use-phase since the emission was inconsistent and depending on consumers themselves. The functional unit used was 1000 kg mass of LDPE plastic packaging.

2.2. Life cycle inventory (LCI)
The inventory analysis involved data collection and calculation procedures to quantify relevant inputs and outputs of a product system, in accordance to ISO 14040. The unit process that involved in the inventory were the production of polyethylene (PE) polymer from raw materials, fabrication of LDPE packaging from polymer, distribution transport to use site, overall transportation, and their end-of-life treatments which were landfill, waste-to-energy (WTE) incineration, and recycling. The overall transportation was covering the transport of raw material for fabrication of LDPE plastic packaging, and transport to the sites for waste management. The inventory modelling was made by using GaBi LCA software, where the relevant data of inputs, outputs and emissions relating to the unit processes and the flow of functional unit was calculated to generate the results of the inventory of this system.

2.3. Life cycle impact assessment (LCIA)
This study evaluated the comparative performance of LDPE plastic packaging system using the variety of environmental indicators which were global warming potential (inside category of climate change impact), acidification potential, smog formation potential, eutrophication potential, and particulate matters. The emission in kg unit equivalent (eq.) was calculated for each indicator using TRACI 2.1 method in the GaBi LCA software. Normalization was one of the optional elements of LCIA.
Normalized results were calculated on the emissions which brought the indicators’ results to their relative impact categories in order to compare the significant of impact categories on the same scale unit.

2.4. Interpretation
Interpretation of the study was elaborated in several scenarios which were the most relevant impact category, the most relevant life cycle stage, and the best practice of end-of-life treatment, where the highest percentage contribution on that particular impact category or unit process indicated the greatest pollutant emissions to the environment to cause impact, while the lowest percentage contribution among the comparison of end-of-life treatments indicated the best practice for the treatment with the least pollutant emissions. All the results were presented in percentage form.

![Figure 1. System boundary of the study.](image-url)

3. Results and discussion
The results were presented in several scenarios which were the most relevant impact category, the most relevant life cycle stage, and the best practice of end-of-life treatment.

3.1. Most relevant impact category
The normalized results were used in order to compare the indicators with the same scale, as tabulated in table 1. The result shown that climate change, which was from the indicator of global warming potential, had the highest percentage contributors which was 43 percent, followed by acidification with 29.5 percent and particulate matters with 21.9 percent. These three impacts shown the significance of them to contribute towards the environmental impacts [3]. The climate change was mainly caused by the high emission of carbon dioxide to the air, especially from the raw material extraction process, combustion of feedstock such as natural gas and crude oil, polymerization process, and incineration of LDPE packaging waste [1]. The greenhouse gases emitted will cause the increased in temperature as they trapped the heat in atmosphere.
3.2. Most relevant life cycle stage
The percentage contribution was calculated according to the normalized impact results within the life cycle stage, as shown in table 2, so that the impacts can be compared with the same scale, within a unit process. It was not necessary to indicate that the highest percentage was the highest emission mass in the stage, on the contrary, it had the most significant emission throughout that particular process comparing to the other indicators. It can be concluded that the first phase which was process of LDPE packaging production from raw materials until the finished product of the packaging, was the major contributor to the environmental impacts [4]. During this stage, the process of polymerization or polycondensation and film extrusion were carried out, in order to produce the plastic packaging. The amount of pollutant emissions in this phase was relatively larger than other phases because of the processes which needed large amount of energy and materials inputs, and hence increasing the outputs and emissions.

3.3. Best practice of end-of-life treatment
Based on the result tabulated in table 2, it shown the best practice of the end-of-life treatment was the landfilling. A landfill can be a better option for waste treatment than incineration, although it may not be the best option for sustainability [10], since landfill has contributed lower impact to the environment comparing to incineration and recycling, as shown in the results. However, the leachate produced and the long-lasting effects of plastic in landfill may become a major problem [5]. Hence, it is necessary to consider the design of landfill especially for landfill gas monitoring, leachate management, landfill closure and land used after life in a more sustainable way, to cope with the effect of plastics so that to reduce the pollutant emissions.

| Impact Category       | Normalized Result | Percentage (%) |
|-----------------------|-------------------|----------------|
| Climate Change        | 0.6756            | 43.0           |
| Acidification         | 0.4644            | 29.5           |
| Particulate Matters   | 0.3447            | 21.9           |
| Smog Formation        | 0.0764            | 4.9            |
| Eutrophication (marine)| 0.0116           | 0.7            |

Table 1. Most relevant impact categories.

| Unit Process                     | Normalized Result | Percentage (%) |
|----------------------------------|-------------------|----------------|
| Manufacture of LDPE packaging    | 0.8135            | 52             |
| End-of-life treatment            | 0.3830            | 24             |
| (Landfill)                       | (0.0009)          | (0.3)          |
| (WTE incineration)               | (0.0901)          | (23.5)         |
| (Recycling)                      | (0.2917)          | (76.2)         |
| Production of PE polymer         | 0.3453            | 22             |
| Overall transportation           | 0.0274            | 1.7            |
| Distribution of LDPE packaging   | 0.0035            | 0.3            |

Table 2. Most relevant life cycle stages.

3.4. Relationship between environmental impacts and life cycle stages
An LCA evaluates the inputs, outputs and potential environmental impacts of a product throughout its life cycle [7]. From the results, it can be concluded that the first phase which was the process of LDPE packaging production from raw materials until the finished product of the packaging, was the major contributor to the environmental impacts. Hence, it is important to determine the correlation between environmental impacts and that particular life cycle stage, in order to get the precise and effective
implementation to decrease the pollutant emissions to the environment. The consideration to reduce pollutant emissions can be concentrated especially the process in first phase of life cycle, which is from the process of raw material extraction, polymerization, film extrusion, to the production of LDPE plastic packaging, to mainly decrease in the emissions towards global warming (greenhouse gases), acidic substances, and particulate matters, for which they will accumulate in the atmosphere to cause significant effects towards environment and human.

4. Conclusion
Based on the results, it shows that climate change is the most significant impact while the most relevant unit process is the manufacture of LDPE packaging. It is mainly caused by the pollutant emissions such as carbon dioxide, acidic substances and particulate matters from the polymerization and film extrusion process. Landfill shows the lowest emission of pollutants which is the best practice of the end-of-life treatments. However, due to the leachate produced and the long-lasting effects of plastic, considerations on design of landfill has to be specified in monitoring the emissions. By identifying the impacts, it enables the related departments to formulate decisions for better management of particular processes or production. For further study on the title, it is suggested to update the datasets which can be used locally and revise on the emissions of end-of-life treatments to get the precise amount of emissions.

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