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A complete life cycle assessment of high density polyethylene plastic bottle

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Abstract. This study was aimed to determine environmental performances of a lubricant oil bottle made from high density polyethylene and to develop potential measures for reducing its impacts. A complete life cycle assessment was carried out to understand a whole effect on the environment from acquiring, processing, using, and disposing the product. Two scenarios of disposal phase; recycle and incineration: were examined to quantify a lesser degree on environmental impact. The results illustrated that major impacts of the two scenarios were at the same categories with the highest contributor of raw material acquisition and pre-processing. However, all impacts in case of recycling provided a lower point than that in case of incineration, except mineral extraction. Finally, feasible measures for reducing the environmental impact of high density polyethylene plastic bottle were proposed in accordance with 3Rs concept.

1. Introduction

Nowadays, plastic products are growing rapidly as the high demand for greater use. Among the variety of plastics, high density polyethylene (HDPE) was launched in the global market for using in daily life in various applications such as bottle, bag, packaging containers, drums, toys, and household appliance. To supply a greater use, a huge quantity of energy was consumed in entire life cycle of products approximately 4.27 million GJ a year and emitted a great amount of greenhouse gas (GHG) emission about 204 million ton in EU [1].

Among many techniques for estimating environmental impacts of product, life cycle assessment (LCA) defined by the International Organization for Standardization in the ISO 14040-44:2006 was considered as a valid tool to be used because it is the compilation and evaluation of the inputs, outputs, and the potential environmental impacts of a product system throughout its life cycle, which can help to understand the environmental impacts of product from the acquisition of raw materials to final disposal [2]. This methodology was widely applied in many products; for instance, textile, building, and food [3,4,5].

Despite environmental impact assessment of plastic products was interested in many researches, most of them were aimed at determining only GHG emissions in a scope of cradle to gate [6,7,8]. In this study, therefore, environmental impacts of a lubricant oil bottle made from HDPE was evaluated through life cycle assessment tool in a scope of cradle to grave, covering raw material acquisition,

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plastic bottle production, use, and waste disposal. Moreover, two scenarios in the end-of-life phase; recycling and incineration, based on a fact pattern were examined to emphasize the difference of environmental performances on a variety of waste management. Consequently, feasible measures will be proposed according to the findings of this study for leading to the global goal of growing green properly.

2. Methodology

LCA, a method to evaluate environmental impacts in a whole life cycle of product, was used in this study for estimating the environmental performances of lubricant oil bottle made from HDPE. Following ISO 14040-44:2006, the methodology is divided into four steps as follows:

2.1. Goal and scope definition

Firstly, goal of this study was quantifying the level of environmental performances of a lubricant oil bottle made from HDPE to understand a hotspot and a key factor in entire process. Two scenarios of waste management based on a fact pattern were established to emphasize the suitable approach for handling the lubricant oil bottle waste in Thailand. The former was recycle which was introduced by waste management company and by observing user behavior, while the latter was incineration which conformed to the governmental policies as the product type of lubricant oil bottle was declared as a hazardous waste.

Functional unit, a reference unit for collecting the inventory data, was a lubricant oil bottle with capacity of 6 liters or 350 grams, and boundary of this study covered all stages of life cycle related to the HDPE bottle production including raw material acquisition, ethylene production, HDPE pellet production, plastic bottle manufacturing, use and waste disposal as demonstrated in Fig. 1.Some text.

2.2. Inventory analysis

Life cycle inventory data of resources, material and energy consumption of lubricant oil bottle classified by phase of life cycle as raw material acquisition and pre-processing, plastic bottle production, bottle usage, and bottle waste disposal were collected from relevant sources. Firstly, raw material data obtained from olefin and HDPE plants. Secondly, plastic processing plant provided the inventory data during a bottle production phase. Thirdly, using the bottle cause no additional harm, there were neither data nor impacts for estimating. Lastly, the data of waste disposal phase was referred to the newly released ecoinvent V.3 database.

As shown in Fig. 1, the lubricant bottle with weight of 0.350 kg was produced from 0.385 kg of HDPE pellets by blow molding process. Approximately 0.1% of this amount would become wastes which were transported to external recycling plant. Furthermore, it was clearly observed that the greatest amount of energy was required for the olefin plant.

2.3. Impact assessment

The impact assessment was performed by SimaPro V.8.2 using IMPACT2002+ V.2.12 method. The results would be expressed a quantity of 15 midpoint environmental impact categories per the functional unit. In addition, the normalization was applied to analyze the contribution of each factor to the environmental performance with different scenarios of waste management.

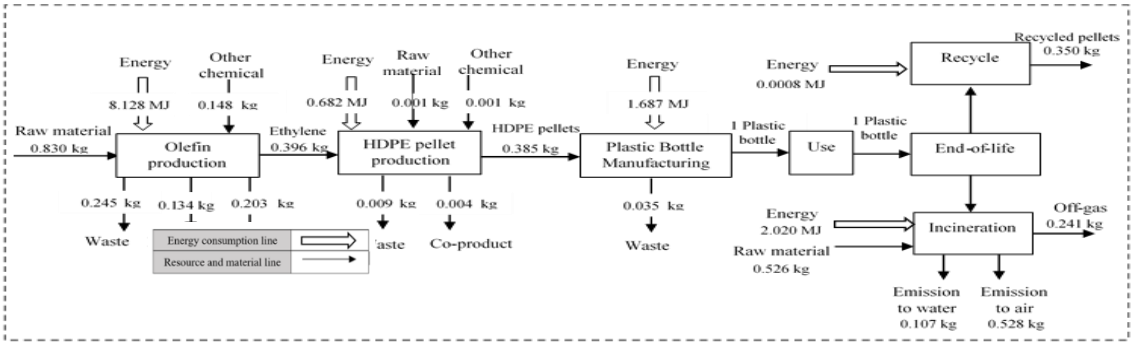

Figure 1. System boundary of a lubricant oil bottle

2.4. Interpretation

The findings of the impact assessment would be interpreted to reveal a critical point of environmental performances both in term of a major impact and a main contributor. Of what findings in this study, feasible measures for reducing the environmental impact of high density polyethylene plastic bottle would be proposed in accordance with 3Rs concept. However, the measures should be practical and consider the cost-benefit ratio in more detail.

3. Results

LCA, a method to evaluate environmental impacts in a whole life cycle of product, was used in this study for estimating the environmental performances of lubricant oil bottle made from HDPE. Following ISO 14040-44:2006, the methodology is divided into four steps as follows:

3.1. Environmental impacts

In this study, a complete cradle-to-grave LCA of lubricant oil bottle made from HDPE was presented in two scenarios which differed in the end-of-life phase; recycle and incineration. Fifteen midpoint impact categories of one HDPE bottle were presented in Fig. 2. It was found that the level of all impact categories in scenario 1 were less than that in case of disposal by incineration except mineral extraction. Therefore, it could be concluded that disposal by recycling is a better method for reducing environmental impact of plastic production.

The normalized results of two scenarios in this study was shown in Fig. 3(a). It emphasized a level of difference of environmental impacts between the two scenarios which focused only on a group of major categories including non-renewable energy, global warming, carcinogens, non-carcinogens, respiratory organics, and respiratory inorganics. The others impact categories were omitted as a cut-off rule of 95% based on the level of environmental significance [9].

Based on the majority of environmental performances, total point of six impact categories were summarized and classified the contributions among 4 contributors. Because the term of raw material acquisition and pre-processing in this study covered ethylene production and HDPE pellet production, as shown in Fig.1, this phase, therefore, was a hotspot of plastic bottle production obviously with a contribution of 80% in scenario 1 and of 60% in scenario 2 as shown in Fig. 3(b).

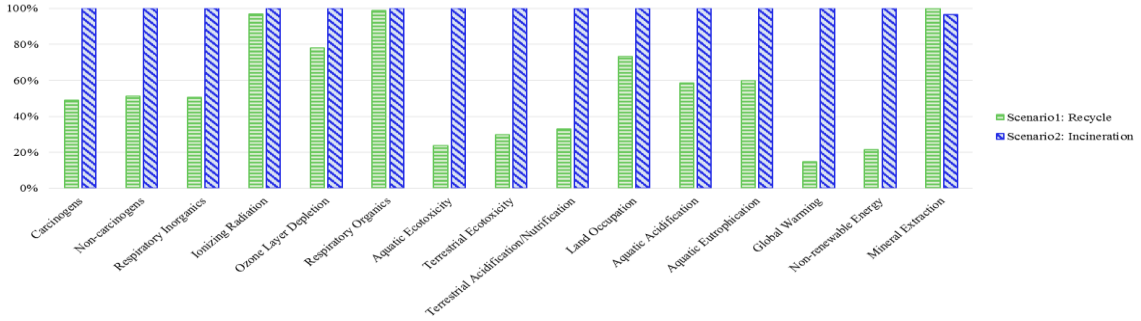

Figure 2. Environmental impact assessment in fifteen impact categories using IMPACT2002+ method

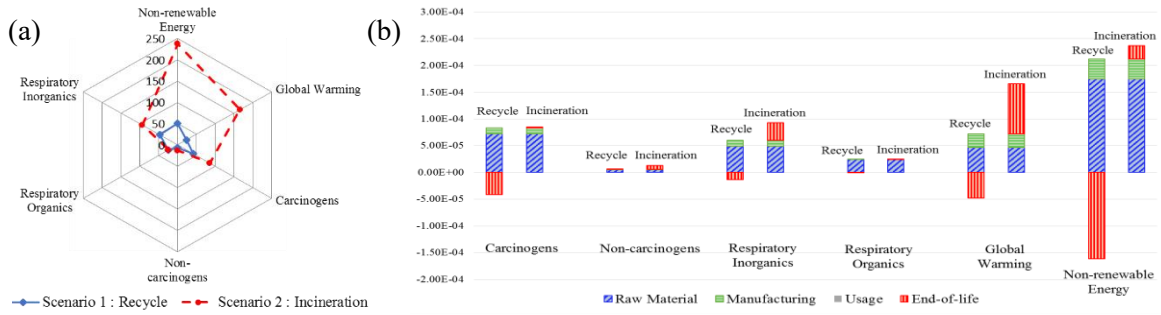

Figure 3. Normalization results: (a) Level of environmental impacts and (b) Environmental impacts contribution in different scenarios of waste management

3.2. Comparison of GHG emissions with other researches

From literature review, it was found that most researches have studied the environmental performances of plastic bottle made from polyethylene terephthalate (PET), which plastic is not a same type as conducted in this study [10,11]. However, Wrap (2010) revealed an impact of GHG emissions of milk bottle made from HDPE at 2.74 $kgCO_2eq./kg$ of HDPE pellet in case disposal by recycle and at 4.70 $kgCO_2eq./kg$ of HDPE pellet in case disposal by incineration [12]. To compare the results of such research with this study, only impact of climate change would focus only in term of $kgCO_2eq./kg$ of HDPE pellet, which differed from the functional unit as mentioned above. After recalculating, it was found that GHG emissions in case of disposal via recycle of this research (0.89 $kgCO_2eq./kg$ of HDPE pellet) was less than the point mentioned above. It might be because the different types of raw material. Lubricant oil bottle in this research used ethane as cleaner raw material, while others used a various kind of raw material such as naphtha and LPG [13]. In case of disposal by incineration, however, the result of this study displayed a higher value of impact (5.48 $kgCO_2eq./kg$ of HDPE pellet) than the point mentioned by Wrap because the product was treated as a hazardous waste whilst it was a municipal waste for the other cases.

4. Discussion

As the results of life cycle assessment, non-renewable energy was a main issue due to the use of natural gas as raw material for producing ethylene to use in HDPE production consequentially and that made the phase of raw material acquisition and pre-processing as a hotspot. To reduce environmental impacts of lubricant oil bottle, therefore, feasible measures should be focused on the effect on non-renewable energy and the impact of raw material acquisition deeply. The 3Rs concept, the basis of sustainable waste management was applied and proposed in this study as follows:

- Non-renewable energy reduction. Currently, energy security in Thailand is declined because it ran out of non-renewable energy and relied heavily on imported energy. A promotion of alternative energy development such as solar, wind, hydro power, biomass, biogas, municipal solid waste, and biofuels (ethanol and biodiesel), therefore, is crucial [14].
- Energy conservation. Improving energy efficiency in the process at plant through any facilities and/or equipment does not only help saving an amount of energy but also help cutting off some energy cost and decreasing an impact of global warming as well [6]. Some instances of energy conservation measure including controlling a percentage of excess oxygen in furnace and changing fan blade should be promoted and implemented [15].
- Recycle of raw material. Although, bioplastic is another option for reducing both raw material origin and GHG emission, however, it is costly and might affect food security [16]. Plastic product and its scrap should be recycled as raw material for producing plastic bottle. It is beneficial not only in reducing raw material origin but also reducing fuel consumption and waste generated [17].

- Waste management. Another option for minimizing consumption of natural resources was sustainable industrial waste management toward zero landfill waste. As shown in Fig.1, the biggest amount of waste generated from olefin plant of which 30% of raw material would become waste such as activated carbon, coke, and oligomer. The main options for waste management were selling to recycling plant, reusing and recycling, and industrial waste landfilling [18].

5. Conclusion

This research was aimed at estimating the environmental impacts in the entire life cycle of high density polyethylene lubricant oil bottle and developing feasible measures for reducing its impacts. Two different scenarios in the end-of-life phase; recycle and incineration: were examined to identify a suitable alternative of environmental performances for plastic bottle production in Thailand. The results revealed total environmental impact from entire life cycle of lubricant oil bottle made from HDPE provided lesser point in recycle scenario than disposing by incineration. A majority in both scenarios was the same category even differed in sequence including non-renewable energy, global warming, carcinogens, non-carcinogens, respiratory organics, and respiratory inorganics. Based on the majority, a hotspot of plastic bottle production obviously occurred in the phase of raw material acquisition and pre-processing with the main impact of non-renewable energy. Therefore, the recommendations for reducing environmental performances of plastic bottle product would be mainly focused on reducing non-renewable energy consumption and minimizing a number of origin materials by using alternative energy, applying energy conservation measure, recycling plastic product and its scrap as raw material and managing industrial waste properly which will contribute to the sustainable development product.

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