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Life cycle assessment of expanded polystyrene

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Abstract. Expanded polystyrene (EPS) is one of the most common materials used in packaging. In Malaysia, EPS is a type of plastic which is not in the recycling category. Usually, EPS wastes will end up in landfill and incinerator, leading to severe environmental impacts. Therefore, a cradle-to-grave life cycle assessment (LCA) study of EPS was carried out to investigate the potential environmental impacts of EPS. The most significant potential environmental impact will also be identified. Both will be identified under 2 different scenarios. The study was analyzed using GaBi Education Software with the method of TRACI 2.1 to the environmental indicators of global warming potential (GWP), acidification potential (AP), eutrophication potential (EP), and ozone depletion potential (ODP). In scenario 1, the emission percentage for GWP, AP, EP, and ODP are 99.73 %, 0.21 %, 0.06 %, and 3×10^{-6} %, respectively. As for scenario 2, all the 3 conditions show similar trend with scenario 1. The LCA study of EPS is particularly focused on the manufacturing, distribution, and the end-of-lifetime treatments, with the introduction of recycling into the system. The findings show that manufacturing of EPS is the major contributor of the environmental impacts and GWP contributes to the most significant potential environmental impacts. Overall, recycling was found to have the least impact to the environment, which possibly be used as the new end-of-lifetime treatment of EPS in Malaysia.

1. Introduction

Expanded polystyrene, also known as EPS, it is a very popular material used in the packaging industry. We can widely see the use of this material in the food, shipping, electrical appliances packaging, etc. This shows that it is hard for us to separate our lifestyle with EPS.

However, EPS is a material which carries lots of argumentative topics towards the Mother Earth. In Malaysia, EPS will normally end up in the landfill and incinerator. By sending EPS waste to the landfill and incinerator, it will cause severe environmental impacts, especially when modern regulations are not complied [1]. As to reduce the impacts to the environment, Polystyrene Ban is introduced by the government of Malaysia starting from 1st of September, 2017 [2].



Also, due to the high demand of the usage of EPS, especially during the COVID-19 pandemic where people depending on the use of packaging. According to the GlobalData's E-Commerce Analytics, the e-commerce market in Malaysia is expected to reach MYR 52.6bn by 2040, with the increasing at a compound annual growth rate of 14.3 % for year 2020 to 2040 [3]. With the high demand in the e-commerce, it will indirectly affect the demand of packaging, also the production and manufacturing of this material.

According to Marten and Hicks (2018), recycling EPS wastes have the potential to significantly reduce the energy required across the life cycle of EPS by reduction the high-energy inputs needed to process the virgin materials [4]. Resulting in minimizing the global warming, at the same time, also enhancing the sustainability of the system. During the recycling process of EPS, EPS waste will be compacted, resulting lesser waste produced as approximately 98% of the component of EPS is air. There are a few method in recycling EPS, which include energy recycling, mechanical recycling, chemical recycling, material recycling, etc. However, recycling EPS is not the practiced in Malaysia due to high cost, technology, and lack of systematic method of recycling.

As such, cradle-to-grave LCA study will be carried out, with the introduction of recycling into the system. The aim of the study is to identify the significant environmental impacts of EPS using LCA method according to ISO 14040:2006 with the basis of 1000 kg. Also, to discuss the potential environmental impacts of the manufacturing, distribution, and end-of-lifetime treatment stages of EPS. The study area is shown in Table 1 below.

Table 1. Study area.

Component	Description
Manufacturing	<ul style="list-style-type: none"> • Manufacturing of polystyrene • Processing and production of expanded polystyrene
Distribution	<ul style="list-style-type: none"> • Manufacturing to first user • First user to second user • Second user to end-of-lifetime treatments
End-of-lifetime treatment	<ul style="list-style-type: none"> • Landfill • Incinerator • Recycling (suggestion)

2. Material and Method

2.1. Material used

The studied material of this study is EPS. EPS studied is not limited to any type of the EPS product, but as a whole. EPS is a thermoplastic, made up from petroleum and natural gas. The properties of EPS include low density, good insulation, hydrophobic, and chemical resistances to acids and alkaline [5].

2.2. Method used

The study was carried out by using GaBi Education software, which is a LCA modelling software, with the help of TRACI 2.1 method to analysis the secondary data from the GaBi Education Database. The studied environmental indicators include GWP, AP, EP, and ODP. GWP stands for global warming potential, allowing the comparisons of the global warming impacts of different gases, which measuring the emissions' energy of one ton of a gas will absorb over a given period of time. Usually, carbon dioxide (CO₂) will be used [6]. AP, acidification potential, refers to the contributions of SO₂, NO_x, HCl, NH₃, and HF to the potential acid deposition, i.e. on their potential to form the hydrogen (H⁺) ions. As for eutrophication potential (EP), is the potential of causing over-fertilization of water and soil. At fourth environmental indicator, which is ozone depletion potential (ODP), indicates the potential of emissions

of chlorofluorohydrocarbons (CFC_s) and chlorinated hydrocarbons (HC_s) for the depletion of ozone layer [7].

The analysis will be based on two scenarios which is shown in Table 2. Both scenarios will be the highlight of the study, forming the background of the study.

Table 2. Scenarios of the study.

Scenarios	Description
Scenario 1	EPS waste will end up in landfill, incinerator, recycling plant, and other end-of-lifetime treatment according to the waste treatment method practiced in Malaysia by Samsudin and Don.
Scenario 2	Assumption of 100% EPS waste will end up in landfill, incinerator, and recycling plant respectively by Ratio and Proportions Method

Table 3 shows the waste distribution ratio to the end-of-lifetime treatment and Equation 1 shows the formula derived from the ratio and proportions method.

Table 3. Waste distribution method practiced in Malaysia [8].

End-of-lifetime treatment	Percentage (%)	Amount (kg)
Landfill	53.2	532
Incineration	16.8	168
Recycling Plant	22.0	220
Others	8.0	80

$$Emission (1000 \text{ kg basis}) = \frac{1000 \text{ kg}}{Input \text{ Data}} \times Input \text{ Data Emission} \quad (1)$$

The secondary data will be extracted from the GaBi Education database according to the unit processes and flow as shown in Figure 1. Referring to Figure 1, the focusing study of life cycle assessment of EPS are the manufacturing, distribution, and end-of-lifetime treatment of EPS. 1000 kg of EPS will be first produced in the manufacturing process and distributed to primary (restaurant) and secondary (home user) user. At the end of the life cycle, waste EPS will then be transported to different end-of-lifetime treatment, according to the values shown in Table 3. The study within primary, secondary user, and others end-of-lifetime treatment is not included in this assessment.

In this study, the location of all the facilities will affect the travel distance. The distance of transportation is 15 km for manufacturing factory to primary user, 2 km from primary to secondary user, 40 km from secondary user to landfill, 130 km from secondary user to incinerator, 140 km from secondary user to recycling plant, and 10 km from secondary user to others end-of-lifetime treatment. Then, the data will be analyzed with the help of TRACI 2.1 method in the software.

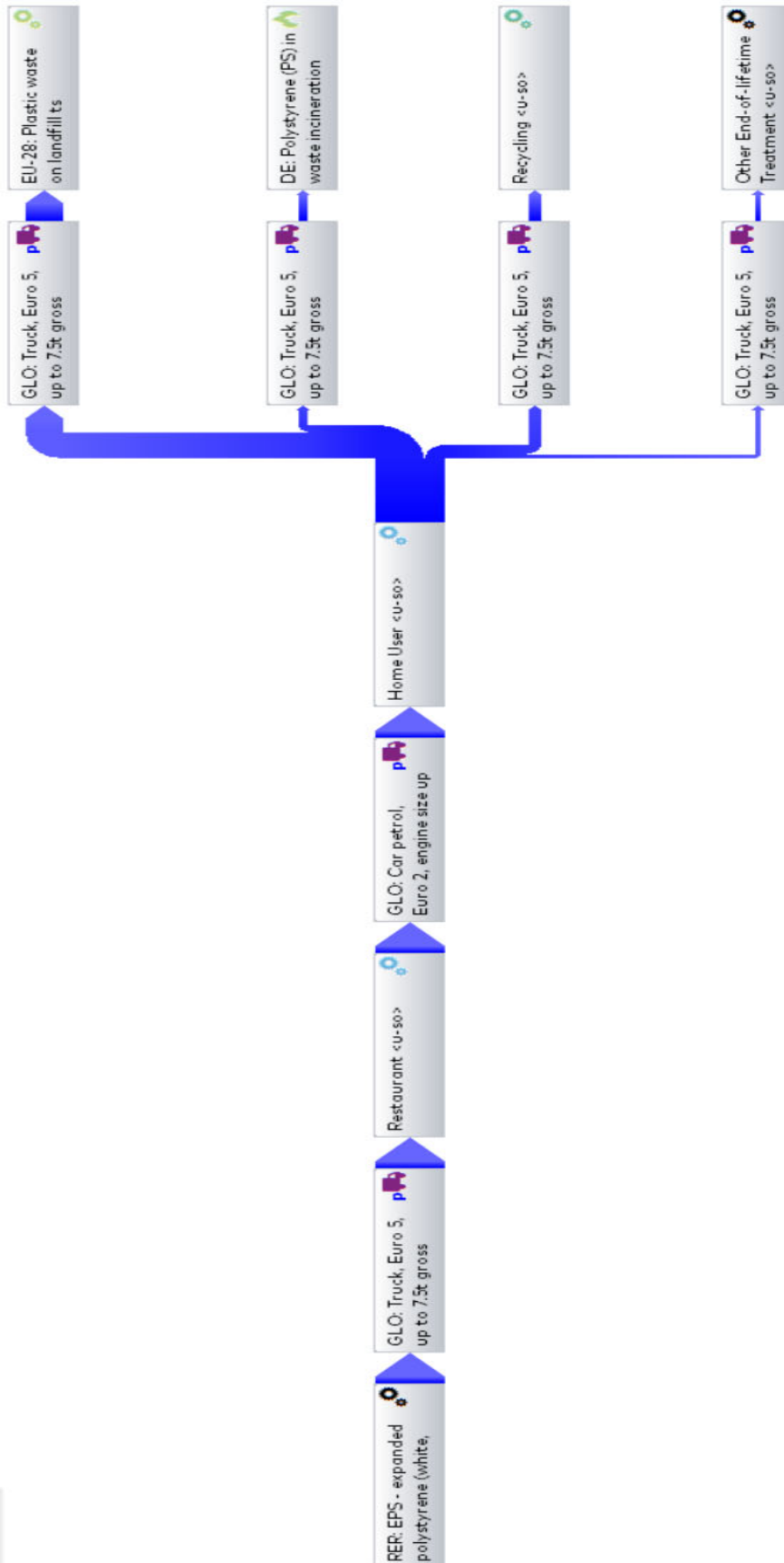


Figure 1. Process flow for LCA of EPS.

3. Result and Discussion

3.1. Waste distributed to the end-of-lifetime treatment based on practiced in Malaysia.

In the analysis of EPS, the discussion will be based on the three major components, which are manufacturing, distribution, and end-of-lifetime treatment reflecting on the real situation of waste distribution. Figure 2 shows the result of potential environmental impacts emission for each of the unit process reflecting on the real situation generated by GaBi Education.

Overviewing the result, the total emission in the system based on waste distribution treatment method practiced in Malaysia is 3657.09 kg emission eq. From the total emission of the system, the major contributor is coming from the manufacturing process, which is 82 %, 2997.74 kg emission eq. While the least contributor is from recycling plant, which is nearly 0 % with the emission of 1.89 kg emission eq.

As for the potential environmental impacts, GWP shows the most significant environmental impacts, which is 3647.11 kg emission eq, follow by AP with 7.68 kg emission eq, EP with 2.31 kg emission eq, and least from ODP with 1.21×10^{-4} kg emission eq.

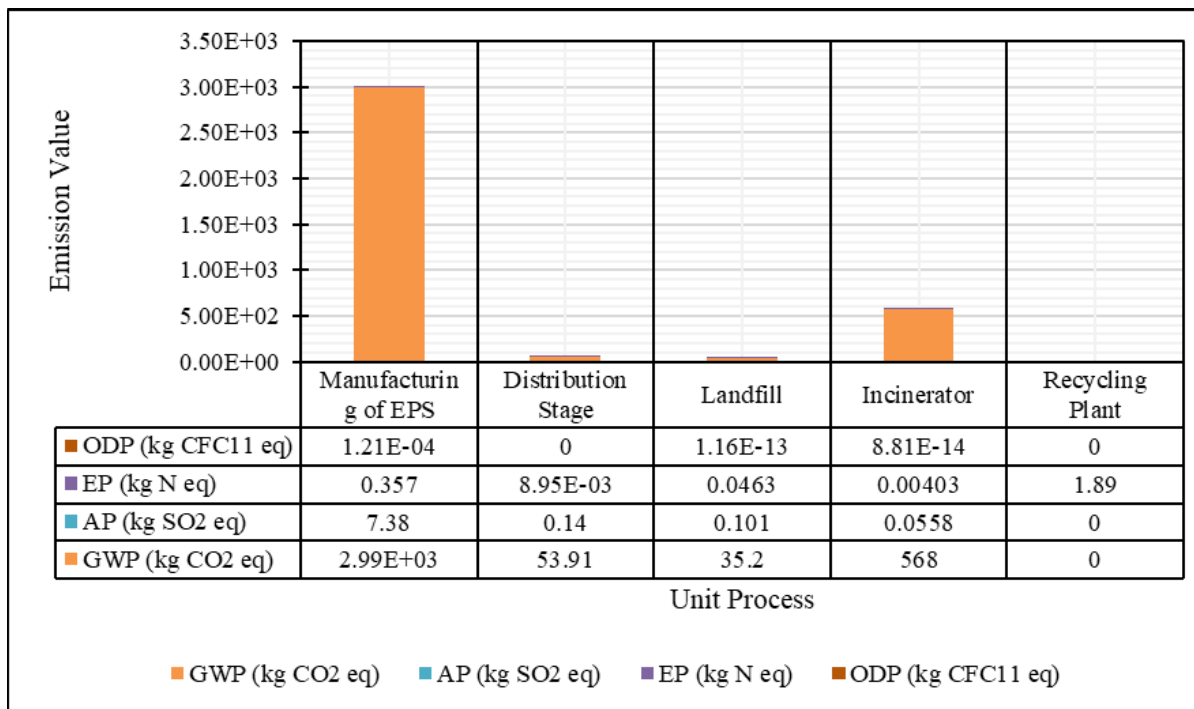


Figure 2. Results of potential environmental impact emission for each unit process based on real situation reflection.

3.2. 100% EPS waste distributed to landfill, incinerator, and recycling plant respectively.

In the 2nd assumption, the input data for distribution to end-of-lifetime treatment, and end-of-lifetime treatment will be adjusted to 1000 kg. From the finding by comparing three different conditions in end-of-lifetime treatment of EPS waste shown in Table 4, sending EPS waste to the incinerator will cause the highest amount of potential environmental impacts emission, which is 6446.88 kg emission eq. The total emission in the condition of sending waste to the landfill is halved of sending to the incinerator, which is 3109.58 kg emission eq. From the result shown, sending EPS waste to the recycling plant emitted the least impacts to the environmental throughout its life cycle, which is 3076.67 kg emission eq.

Table 4. Result of potential environmental impact emission for each unit process with uniform basis of 1000 kg.

Potential environmental impact	100% waste to landfill			100% waste to incinerator			100% to recycling plant		
	Manufacturing	Distribution	Landfill	Manufacturing	Distribution	Incinerator	Manufacturing	Distribution	Recycling Plant
GWP (kg CO ₂ eq)	2990	45.27	66.17	2990	67.65	3380.95	2990	70.15	0
AP (kg SO ₂ eq)	7.38	0.12	0.19	7.38	0.18	0.33	7.38	0.18	0
EP (kg N eq)	0.357	7.65x10 ⁻⁴	0.09	0.357	1x10 ⁻²	0.02	0.357	1x10 ⁻²	8.59
ODP (kg CFC11 eq)	1.21x10 ⁻⁴	0	2.18x10 ⁻¹³	1.21x10 ⁻⁴	0	5.24x10 ⁻¹³	1.21x10 ⁻⁴	0	0
Total	3109.58 kg emission eq			6446.88 kg emission eq			3076.67 kg emission eq		

By comparing the potential environmental impacts, GWP shows the most significant amount which is 3101.44 kg emission eq, 6438.60 kg emission eq, and 3060.15 kg emission eq for the three condition, landfill, incinerator, and recycling plant respectively. In contrast, ODP appears to be the least significant impact to the environment with the amount of 1.21x10⁻⁴ kg emission eq for all three conditions respectively. The trend of most significant environmental impacts is the same for sending EPS waste to landfill and incinerator, which is from GWP, AP, EP, and lastly ODP. However, a slightly different in sending EPS waste to recycling plant, which is from GWP, EP, AP, and last follow by ODP for its life cycle.

3.3. Discussion

As shown in the result presented above, GWP shows the most significant environmental impact among the studied environmental indicators. In scenario 1, the percentages of these impacts are 99.73 %, 0.21 %, 0.06 %, and 3.31x10⁻⁶ %, respectively. As for scenario 2, similar trend was shown comparing to scenario 1, which GWP is the most significant environmental impact in the life cycle of EPS. The percentages of GWP's impact are 99.73 % for sending all EPS wastes to both either landfill or recycling plant, and 99.72 % for sending the wastes to incinerator. Similarly with the life cycle analysis of plastic packaging, climate change, which related to the global warming shows the most significant impact throughout the studied system [9].

Manufacturing is the major contributor to the potential environmental impacts, especially in the GWP, which due to the fossil fuel resources used for the fuel and feedstock for the plastic resin and blowing agent. Also, the insulation process in the manufacturing which involved the combustion of fuels contributes to the source of GWP [10]. Also, in an LCI study by Ingrao and Giudice, it is mentioned that GWP is one of the major contributor in the production of 1 kg EPS [11]. During the manufacturing process, components such as CO₂, volatile organic compounds (VOC_s), methane (CH₄), nitrous oxide (N₂O), etc. will be produced. While in the distribution stage, the source of GWP is mainly due to the combustion of fossil fuels in the vehicles for the supply of the energy to the vehicles. During the incineration of waste, combustion will be taken placed. As such, the GWP contribution will show relatively higher compared to other potential environmental impacts. Before disposing of waste

materials, the incineration, open burning, landfills capacity, greenhouse and hazardous gases and other issues must be assessed [12].

Throughout the findings, ODP shows the least impact to the environmental. The main source of ODP is coming from the chlorofluorocarbons, known as CFC and other halogen gases to the atmosphere [13]. According to this study, nearly no input of components that will lead to ODP. However, there still will be little amount of halogenated compounds emission and inert chemical wastes which will cause to the ODP. As for AP, it is mainly due to the emission of acidified component such as sulphur dioxide and nitrogen monoxide. On the other hand, the eutrophication potential is mainly due to the organic emission. In the recycling plant, it shows that EP is the most significant potential environmental impacts, mainly due to the organic emission to the water in the cleaning and rinsing process. Other environmental indicators appear to be zero emission in the recycling plant as in this system, the recycling process is to convert the EPS waste into flakes.

4. Conclusion

In conclusion, throughout the life cycle of EPS, manufacturing process shows a relatively higher emissions to the environmental impacts. Consequently, the most significant impacts, which is GWP, turn out to be the main cause of the impacts to the environment. In comparison, sending EPS waste to recycling plant appear to be a better choice based on both of the assumption. By referring to the findings, recycling could be the future solution of EPS in Malaysia. EPS-to-EPS recycling has the potential to reduce the environmental impacts significantly as the waste will be recycled into a new form of EPS. As such, it will indirectly reduce the emissions from the major contributor, which is the manufacturing of EPS.

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