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Life cycle assessment of biodegradable food container from bagasse in Thailand

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Abstract: Biodegradable products are generally considered an eco-friendly alternative to petroleum-based product due to the advantages of using renewable feedstock in their production as well as biodegradability at end-of-life. This study aims to assess the potential impacts and find the pros and cons of lunch boxes in Thailand made from sugarcane bagasse and polystyrene (PS) foam considering different waste management options. A comparative life cycle assessment was performed to this end. The cradle-to-gate results showed that, contrary to popular belief, PS foam lunch boxes performed better than their bagasse-based alternatives in all the impact categories. The major phase contributing to the impacts of bagasse lunch boxes is bleached bagasse pulp production stage followed by the lunch box production stage. However, the analysis of the full life cycle of both lunch boxes showed that bagasse lunch boxes with the recycling option had lower impacts than PS foam lunch boxes in all impacts categories. Recycling is also the most appropriate waste management option for PS foam lunch boxes. Overall, it can be concluded that the bagasse lunch box has a good environmental performance provided that the waste management at the end of life is handled appropriately.

Keywords: Life cycle assessment (LCA), Sugarcane bagasse, Polystyrene (PS) foam, Single use lunch box.

1. Introduction

Most products that consumers buy usually come with the packages which are used to protect the products during storage or transportation, provide convenience, and pass on information. Food and drink packaging products have become a great concern vis-à-vis their impact on the environment since they account for around 69% of packaging use [1]. The food packaging interacts with millions of people. The wastes from the packaging materials have been shown to cause significant risks to human health and the environment as well as in manufacturing activities. The plastic and foam packaging have been used increasingly because of their performance on cost effectiveness, light weight, high durability, and variety of applications, leading to severe waste problems and fossil resource scarcity. According to the draft of Thailand's Roadmap on Plastic Waste Management 2018-2030, four types of single-use plastics will be banned in Thailand, which are lightweight plastic bags less than 36 microns thick, styrofoam food containers for takeaways, plastic cups and plastic straws by 2022 [2]. Globally, the idea of development of alternatives for plastic-foam packaging is becoming more and more important.

To mitigate the impacts on the environment, the concept of utilizing renewable materials as alternative feedstock is one way that can help to decrease the dependence on fossil-based raw materials. The renewable resources are derived from agriculture including, sugarcane bagasse, corn and cassava starch, bamboo, and rice straw. Sugarcane bagasse has a high potential in composite materials due to its bio-degradable features and chemical constituents. Loh et al. [3] indicated that bagasse is a low cost and high quality green end material with various levels of properties and performances, which led bagasse as an ideal raw material in manufacturing of eco-friendly products. Thailand is one of the world largest sugar producers, resulting in large quantities of bagasse production since bagasse is a co-product after juice has been extracted for sugar production. Jeefferie et al. [4] described the usage of sugarcane fiber cellulose combined with tapioca starch as a composite for disposable packaging food container. The study showed that the addition of sugarcane fiber cellulose increased impact strength and flexural properties but decreased tensile strength properties; however, it had bad performance on water absorption and thickness swelling test. Due to the limitation of the applications of the material, Tanthapanichakoon et al. [5] modified its properties by surface coating the product with polyvinyl alcohol (PVA).

To select the optimal option between fossil-based and bio-based packaging, environmental assessment must be performed. Therefore, this study applied life cycle assessment (LCA) as an analysis tool for the evaluation of environmental aspects associated with products or services through the entire life cycle. This method can identify which part of the product life cycle causes major environmental burdens and how to make the product more suitable and more environmentally friendly.

Several studies have used LCA to evaluate environmental impacts of products, especially for comparison between bio-based and petroleum-based products such as egg carton, food tray, lunch box, and carrier bag [6-11]. Pereira et al. [12] studied on the relationships between sugarcane bagasse-based green materials and their impact on sustainable design. It found that the sustainability of packaging depends on variables such as energy consumption and rate of product recycling waste after use. Roes and Patel [13] mentioned that bagasse tray has a negative effect on the environment category such as global warming and fossil resource scarcity due to sugarcane pulp production. There is still a lack of studies including ecotoxicity and human toxicity. Furthermore, there is a very small number of LCA studies on molded bagasse pulp packaging because most studies usually focused on showing its potential as biodegradable product and how to improve its performance. Therefore, a full life cycle assessment (cradle-to-grave) would be appropriate for the energy and environmental evaluation in order to have an overall perspective and to find out the strengths and weaknesses of using biodegradable sugarcane bagasse (molded) packaging.

2. Methodology

The LCA methodology uses the inputs and the outputs of the product; the amount of energy use, materials, resources, and emissions discharge into the environment by assessing environmental impacts. LCA comprises four interdependent phases: goal and scope definition, inventory analysis, impact assessment, and interpretation.

2.1 Goal and Scope Definition

The aim of this study is to evaluate environmental impacts of biodegradable sugarcane bagasse and polystyrene (PS) foam lunch boxes in Thailand and to propose ways that can be helpful to enhance environmental performance of bagasse lunch boxes. The resources and raw material requirements, and energy resources are the inputs whilst air emissions, water emissions, soil emissions, and wastes are the outputs. The unit of analysis is 1,000 lunch boxes of size: 12.0 × 17.20 × 3.6 cm. The weight of a biodegradable bagasse lunch box and PS foam lunch box is 18 and 3.6 g, respectively. Moreover, the study also considered the environmental impacts for the different final disposal methods in order to address the appropriate waste management for these lunch boxes. Waste management scenarios include sanitary landfill, incineration, recycling, and composting. The composting option will be considered only for biodegradable bagasse lunch boxes.

The customer use phase is excluded from the study because it is considered as an insignificant contributor to environmental impacts due to no energy or resource required for usage of lunch boxes [8, 13-14]. The system boundaries of the two types of boxes are shown in Figure 1 and Figure 2.

For the analysis of the environmental impacts, the allocation is based on the economic values. Since bagasse is a by-product with low economic value and not the main driver for cultivating sugarcane, it seems reasonable to allocate less environmental burdens to bagasse. This is the same for PS foam lunch box that uses economic allocation to share the burdens between the PS foam packaging and scraps that will be used as raw material in PS foam lunch box production.

2.2 Life cycle inventory analysis

In the study, primary data were collected using questionnaires and interviews with a biodegradable packaging factory in the central region of Thailand. The questionnaires consisted of both quantitative and qualitative data such as general information about factory, input-output of the production process, and waste management. The secondary data such as raw material extraction and energy were obtained from the Thai National LCI database, Ecoinvent 3 databases, literature, government sector information and private companies' public documents.

2.2.1 Bleached bagasse pulp production

The sugarcane bagasse used in the factory is from sugar mills. The bleached bagasse pulp production includes materials preparation, pulp cooking, pulp washing, pulp screening and pulp bleaching. The data was derived from the Thai national LCI database.

2.2.2 Biodegradable lunch box production from bagasse

The biodegradable lunch box production consists of nine production processes; pulp mixing and pulp beating, wet forming, dry forming, edge cutting, appearance checking, metal detecting, UV disinfection, sealing and packing. The data collected is annual data that is averaged over the period, September 2018 to September 2019.

2.2.3 PS foam packaging production

The data were extracted from the study by Ingrao et al. [8] and Juangthaworn [10]. There are five main processes in PS foam packaging production which are: adding color, mixing scraps, GPPS (general purpose polystyrene) and HIPS (high impact polystyrene) pellets, extrusion, thermoforming, and packing.

2.2.4 Transportation

Sugarcane is transported 50 km from the sugarcane field to the sugar mill by a 10-wheel truck (16-tonne capacity). The transportation distance from the sugar mill to the bleached bagasse pulp plant is zero as the plants are located in the same area. The trailer truck (18 wheels, 47-tonne capacity) is used to transport bleached bagasse pulp to a bagasse lunch box plant located 23.5 km away. Meanwhile, the crude oil is imported from the Middle East to the petroleum refinery plant at Rayong by ocean tanker shipping (6,700 km). Crude oil is refined to naphtha and cracked to ethylene at the refinery plant itself. Ethylene is transported from the plant to the styrene monomer plant about 2 km away by a 10-wheel, 16-tonne truck and then is transported to the GPPS and HIPS pellet plants 3 km away by a 10-wheel, 16-tonne truck. The 6-wheel truck (15-tonne capacity) is used to transport GPPS and HIPS pellets from the plant to the PS foam lunch box plant over a distance of 165 km. The distance from finished goods to customer is assumed as 10 km; transportation of bagasse and PS foam lunch boxes use pickup van (1.5-tonne capacity) and 6-wheel truck, respectively. After consumer use, both lunch boxes are sent to disposal facilities about 65 km away by 10-wheel waste dump type truck. Finally, the study also includes the empty return trip of the respective vehicles after delivering the materials.

2.3 Impact assessment

The ReCiPe midpoint hierarchist method (2016) was selected in this study. Calculations were performed for the eleven most relevant impact categories including global warming, terrestrial acidification, freshwater eutrophication, marine eutrophication, terrestrial ecotoxicity, freshwater ecotoxicity, marine ecotoxicity, human carcinogenic toxicity, human non-carcinogenic toxicity, land use, and fossil resource scarcity.

Table 1. The data sources for performing LCA.

Life cycle stage	Data sources
Raw materials production	
Sugarcane production	[15-16] and Ecoinvent 3 database
Sugar production	[16-18] and Ecoinvent 3 database
Bleached bagasse pulp production	[16]
Crude oil production and naphtha production	Ecoinvent 3 database
Ethylene, styrene monomer and polystyrene production	[16] and Ecoinvent 3 database
Fuels and electricity	[16] and Ecoinvent 3 database
Lunch box production	
Biodegradable lunch box production from bagasse	Primary data from company
PS foam lunch box production	[8,10]
Transportation	
Distances	[10] and primary data from company
Operation of car	[16] and Ecoinvent 3 database
Disposal	
Sanitary landfill	Ecoinvent 3 database and primary data from company
Incineration	Ecoinvent 3 database
Recycling	Ecoinvent 3 database
Composting	Ecoinvent 3 database and primary data from company

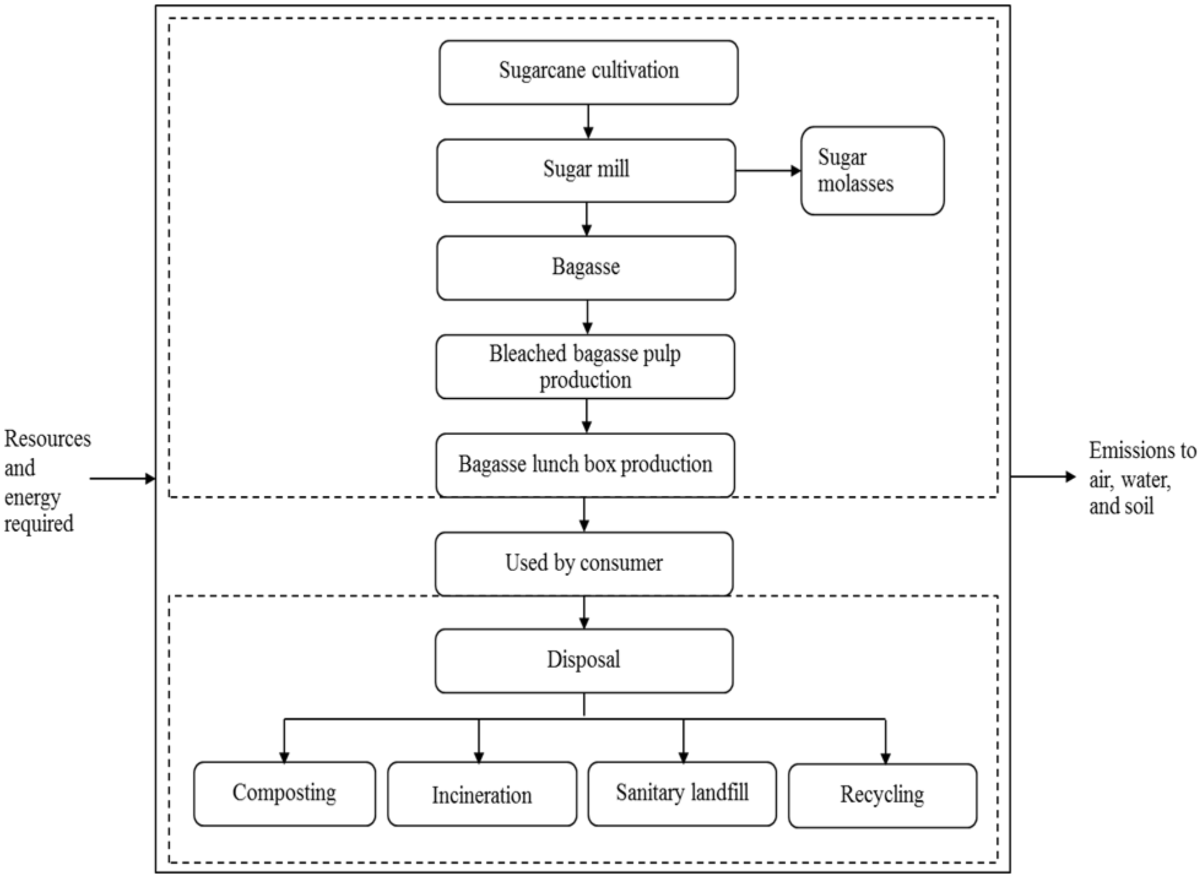

Figure 1. System boundary of single-use biodegradable bagasse lunch boxes.

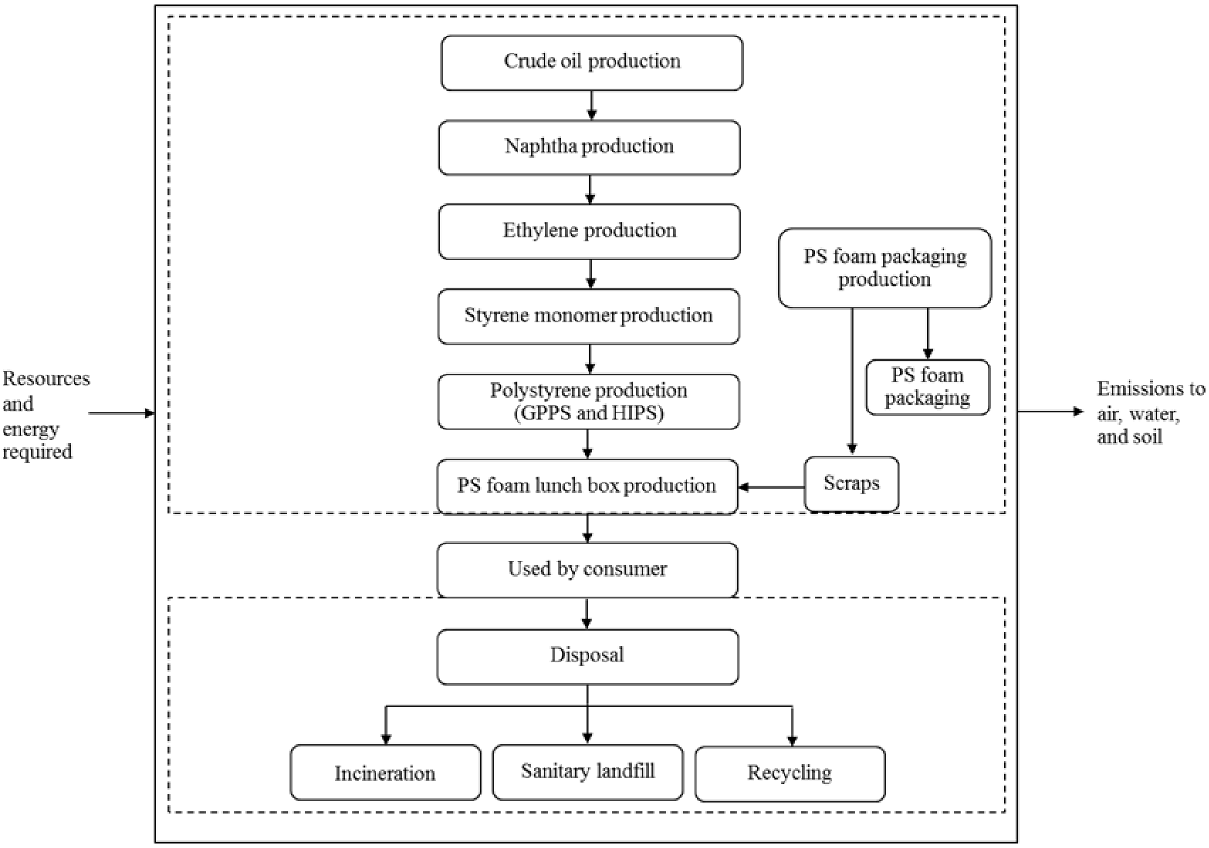

Figure 2. System boundary of single-use PS foam lunch boxes.

3. Results and Discussion

The study has been conducted for two system boundaries, cradle-to-gate and cradle-to-grave, so that the results can clearly show how the different disposal management options affect the results from raw materials extraction to factory gate.

3.1 Life cycle impact assessment results: Cradle to gate and transport to customer

The environmental impact results of the lunch boxes from cradle to finished products delivery are displayed in Figures 3-13. The details of each impact are discussed as follows.

Global warming

The global warming impact from the raw material acquisition to delivery of products for bagasse and PS foam lunch boxes are 76.03 kg CO_2 eq. (equivalent)/FU and 17.75 kg CO_2 eq./FU, respectively. The major contributor to the global warming of bagasse lunch boxes is bleached bagasse pulp production (69% of total) due to the utilization of chemicals at plant, accounting for 84% of the total global warming impact from bleached bagasse pulp production followed by electricity consumption (4%), and sodium chlorate production (3.9%). The second largest contributor is the bituminous coal combustion that is used in boilers to generate steam in the drying process. Meanwhile, the main contributor to global warming impact of PS foam lunch boxes is from styrene production, which is about 35% of the total followed by PS foam lunch box production, HIPS production, and GPPS production, accounting for 22%, 16%, and 15% of total, respectively.

Terrestrial acidification

The terrestrial acidification impact of bagasse lunch boxes is 0.095 kg SO_2 eq./FU. The main contributor is steam generation during the drying process (93%) of lunch box production. This followed by the transportation of chemicals, accounting for 30% of bleached bagasse pulp production impact. For sugarcane plantation, the impact is caused by the production and application of fertilizers. The terrestrial acidification impact of PS foam lunch boxes is slightly lower than bagasse lunch boxes by 0.004 kg SO_2 eq./FU. The major contributor is styrene production (51% of total) which caused by SO_2 emissions, followed by HIPS production (26%) and PS foam lunch boxes (13%), respectively.

Freshwater eutrophication

The freshwater eutrophication impact results of bagasse and PS foam lunch boxes are 0.0042 kg P eq./FU and 0.0012 kg P eq./FU, respectively. The major cause of this impact for bagasse is bleached bagasse pulp production (60% of total), mostly from sodium hydroxide production (41.8%) and sodium chlorate production (41.7%). This is followed by bagasse lunch box production (20% of total) and sugarcane cultivation (19% of total), respectively. The wastewater is the major contributor to the emissions of nutrients from box production whist the fertilizer application, from sugarcane cultivation. On the other hand, the major contributor to PS foam lunch boxes is box production, accounting for 86% of the total, especially from the process of producing nitrogen in the lunch box production step.

Marine eutrophication

The marine eutrophication impact results of bagasse and PS foam lunch boxes are 0.0067 kg N eq./FU and 1.4×10^{-4} kg N eq./FU, respectively. The main phase that contributed the most to marine eutrophication impact for bagasse lunch boxes is lunch box production (50% of total) due to the wastewater release. This is followed by sugarcane cultivation and bleached bagasse pulp production, with about 41% and 8% of the total, respectively. For the PS foam lunch box as well, box production is the major contributor to marine eutrophication impact (42%). It is mostly caused by nitrogen production, followed by GPPS production (23%), styrene production (12%), ethylene production (11%), HIPS production (5.1%), and crude oil extraction and production (5%).

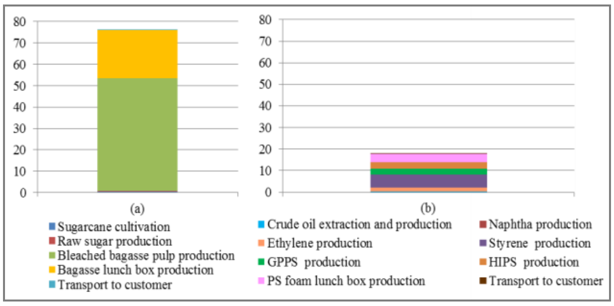

Figure 3. (a) Global warming impact of bagasse lunch box production and transport to customer per 1,000 lunch boxes; (b) Global warming impact of PS foam lunch box production and transport to customer per 1,000 lunch boxes.

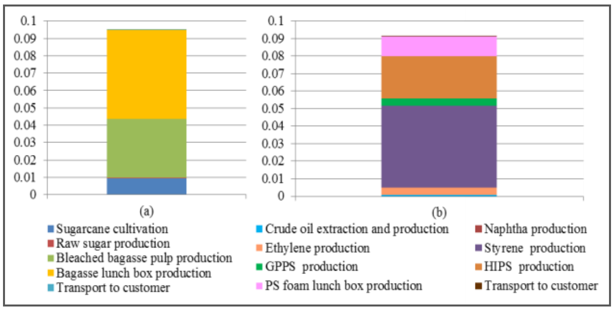

Figure 4. (a) Terrestrial acidification impact of bagasse lunch box production and transport to customer per 1,000 lunch boxes; (b) Terrestrial acidification impact of PS foam lunch box production and transport to customer per 1,000 lunch boxes.

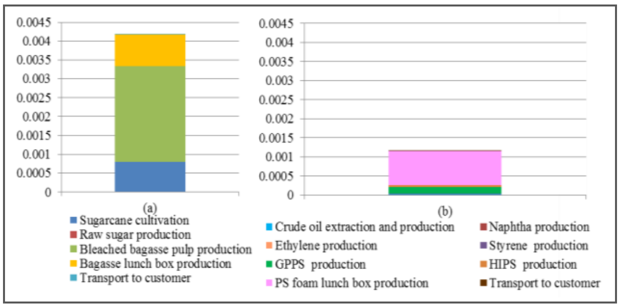

Figure 5. (a) Freshwater eutrophication impact of bagasse lunch box production and transport to customer per 1,000 lunch boxes; (b) Freshwater eutrophication impact of PS foam lunch box production and transport to customer per 1,000 lunch boxes.

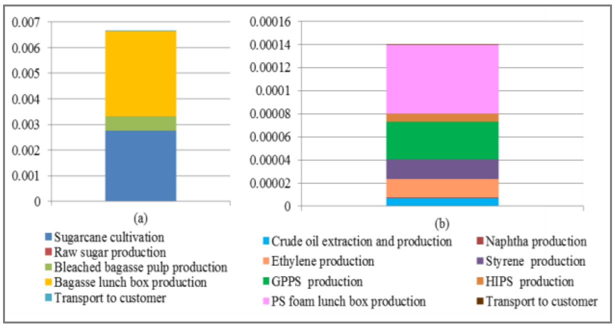

Figure 6. (a) Marine eutrophication impact of bagasse lunch box production and transport to customer per 1,000 lunch boxes; (b) Marine eutrophication impact of PS foam lunch box production and transport to customer per 1,000 lunch boxes.

Terrestrial ecotoxicity

The terrestrial ecotoxicity values of bagasse and PS foam lunch boxes are 33.89 kg 1,4-DCB eq. per FU and 5.88 kg 1,4-DCB eq. per FU, respectively. For bagasse lunch boxes, the lunch box production emits 64% of the total, which comes from bituminous coal combustion. The second contributor is bleached bagasse pulp production, accounting for 33% of the total impact, and caused by sodium hydroxide production. Besides, the largest contributor to terrestrial ecotoxicity impact for PS foam lunch box is the box production step, as it accounts for 64% of the total. This is followed by HIPS production, with 19% of the total.

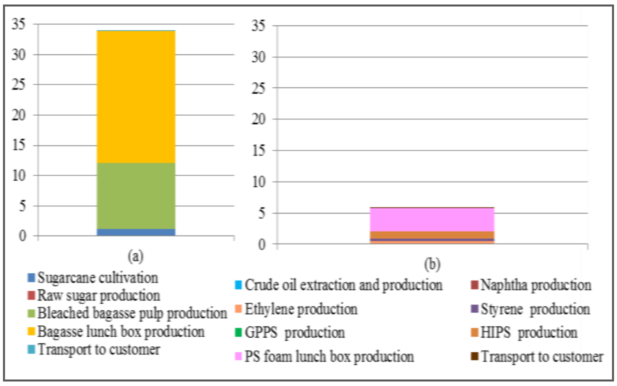

Figure 7. (a) Terrestrial ecotoxicity impact of bagasse lunch box production and transport to customer per 1,000 lunch boxes; (b) Terrestrial ecotoxicity impact of PS foam lunch box production and transport to customer per 1,000 lunch boxes.

Freshwater ecotoxicity

The freshwater ecotoxicity impact of bagasse lunch boxes is 0.46 kg 1,4-DCB eq. per FU. Around 77% of the total impact is from bleached bagasse pulp production. It is due to high chemical use including phosphoric acid and sulfuric acid. This is followed by bituminous coal production which is used as fuel for the boiler in the lunch box production step. The freshwater ecotoxicity impact of PS foam lunch boxes is 0.069 kg 1,4-DCB eq. per FU. The major contributor is lunch box production accounting for 41% of this impact, followed by styrene production, HIPS production, and crude oil extraction and production at 24%, 20%, and 12%, respectively.

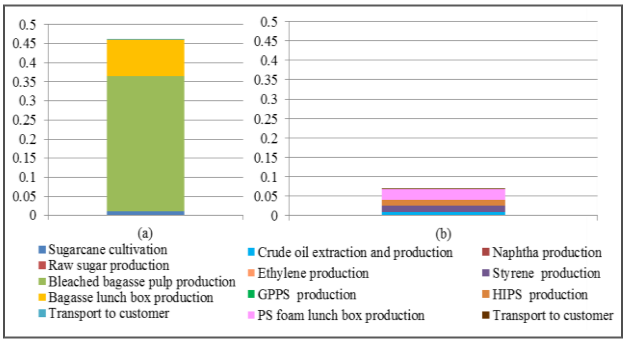

Figure 8. (a) Freshwater ecotoxicity impact of bagasse lunch box production and transport to customer per 1,000 lunch boxes; (b) Freshwater ecotoxicity impact of PS foam lunch box production and transport to customer per 1,000 lunch boxes.

Marine ecotoxicity

The marine ecotoxicity values of bagasse and PS foam lunch boxes are 0.37 kg 1,4-DCB eq. per FU and 0.1 kg 1,4-DCB eq. per FU, respectively. For bagasse lunch box, the results mostly followed the same pattern as freshwater ecotoxicity impact. The major contributor is bleached bagasse pulp production, which accounts for 62% of the total, followed by lunch box production (33%) and sugarcane cultivation (3%), respectively. For the PS foam lunch box, box production is the major contributor, followed by styrene production, HIPS production, and crude oil extraction and production with 43%, 21%, 20%, and 12% of the total, respectively.

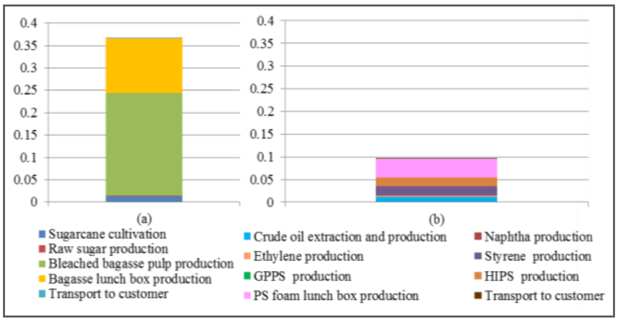

Figure 9. (a) Marine ecotoxicity impact of bagasse lunch box production and transport to customer per 1,000 lunch boxes; (b) Marine ecotoxicity impact of PS foam lunch box production and transport to customer per 1,000 lunch boxes.

Human carcinogenic toxicity

The human carcinogenic toxicity impact of bagasse and PS foam lunch boxes are 0.44 kg 1,4-DCB eq. per FU and 0.14 kg 1,4-DCB eq. per FU, respectively. The major contributor for bagasse lunch boxes is bleached bagasse pulp production (74% of total) due to the process of producing sodium chlorate, which accounts for 58%. This is followed by lunch box production at about 24%, due to rosin production. The main contributors for PS foam lunch boxes are HIPS production and lunch box production, which accounts for 48% and 45% of the total, respectively.

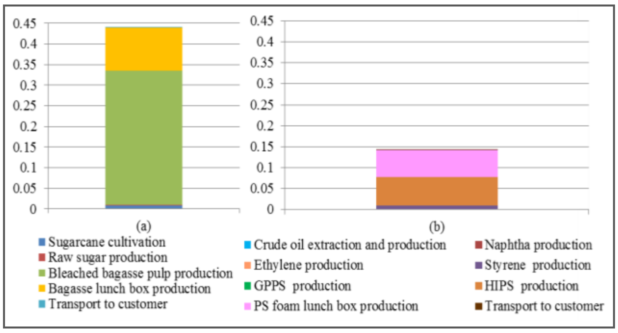

Figure 10. (a) Human carcinogenic toxicity impact of bagasse lunch box production and transport to customer per 1,000 lunch boxes; (b) Human carcinogenic toxicity impact of PS foam lunch box production and transport to customer per 1,000 lunch boxes.

Human non-carcinogenic toxicity

The human non-carcinogenic toxicity values of bagasse lunch boxes is 7.25 kg 1,4-DCB eq. per FU. The results have similar pattern as human carcinogenic toxicity impact. The biggest contributor for bagasse lunch boxes is bleached bagasse pulp production with about 61% of the total impact, caused by sodium hydroxide production. Meanwhile, for PS foam lunch boxes, it is 2.24 kg 1,4-DCB eq. per FU, mainly from lunch box production (36%) followed by styrene production (32%), crude oil extraction and production (18%), and HIPS production (10%).

Land use

The land use impact of bagasse and PS foam lunch boxes are 5.39 m^2a per FU and 0.014 m^2a per FU, respectively. The sugarcane cultivation phase contributes 52% of the total, followed by lunch box production (39%). The much higher impact of bagasse boxes is because of the agricultural land required for sugarcane cultivation and rosin production for lunch box production.

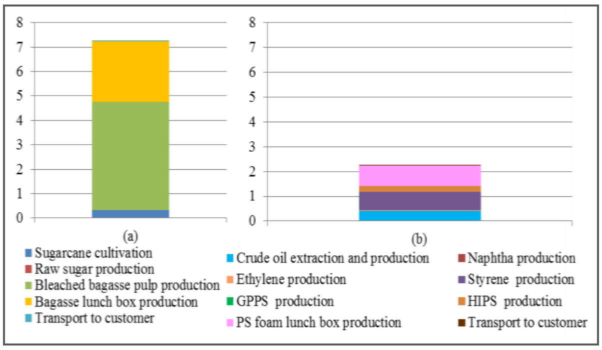

Figure 11. (a) Human non-carcinogenic toxicity impact of bagasse lunch box production and transport to customer per 1,000 lunch boxes; (b) Human non-carcinogenic toxicity impact of PS foam lunch box production and transport to customer per 1,000 lunch boxes.

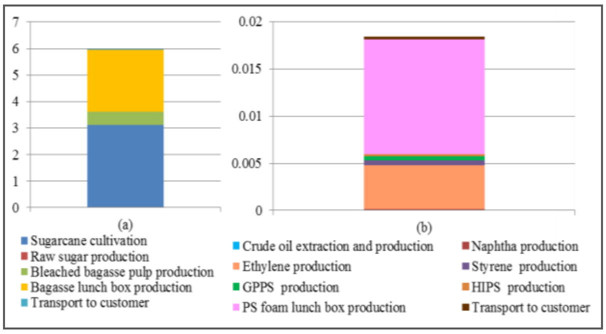

Figure 12. (a) Land use impact of bagasse lunch box production and transport to customer per 1,000 lunch boxes; (b) Land use impact of PS foam lunch box production and transport to customer per 1,000 lunch boxes.

Fossil resource scarcity

The bagasse lunch boxes contribute 22.35 kg oil eq. per FU while PS foam boxes contribute 14.9 kg oil eq. per FU. The major contributor for bagasse lunch boxes is lunch box production (91% of total impact) due to the utilization of bituminous coal. This is followed by bleached bagasse pulp production with 7%. For PS foam lunch boxes, the largest contributor is styrene production (36%), followed by ethylene production, HIPS production, GPPS production, crude oil extraction and production, and lunch box production, which are 19%, 11%, 10.5%, 9%, and 7% of total impact, respectively.

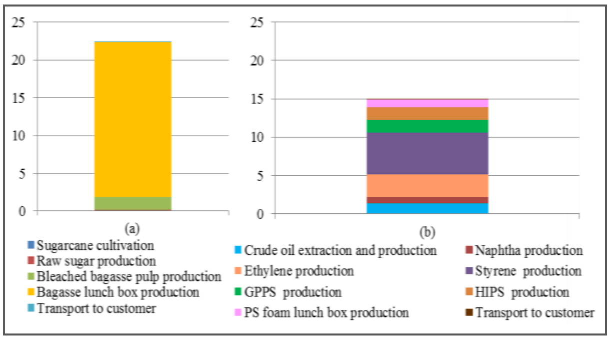

Figure 13. (a) Fossil resource scarcity impact of bagasse lunch box production and transport to customer per 1,000 lunch boxes; (b) Fossil resource scarcity impact of PS foam lunch box production and transport to customer per 1,000 lunch boxes.

3.2 Cradle to grave with disposal options

The disposal options applied for the end of life in this study include composting (only for bagasse lunch box), incineration (with energy recovery), sanitary landfill, and recycling. The results of four waste managements are listed in Table 2. The environmental burdens over the whole life cycle are illustrated in Figure 14.

Cradle to grave with composting option

The composting option is considered only for bagasse lunch boxes since they can be degraded. Under aerobic conditions, the bagasse lunch boxes turn in to a nutrient organic compound. The carbon dioxide during the composting process is considered as biogenic carbon, thus it does not contribute to the global warming impact. The urea fertilizer is added in order to increase the compost's nutrients (e.g. N and P contents). This was the major contributor for all the impact categories investigated, especially from the production of urea fertilizer. However, the compost from the aerobic digestion can substitute chemical fertilizers (e.g. N, P_2O_5, K_2O fertilizers), thus avoided emissions from these chemical fertilizer production lead to benefits for all environment impacts, especially from global warming and fossil resource scarcity.

Cradle to grave with incineration option

Producing electricity from incineration avoids the environmental impacts caused by conventional (fossil-based) electricity production from the grid. One thousand bagasse and PS foam lunch boxes save 10.1 and 0.78 kWh of grid electricity generation, respectively. Whereas incineration caused positive impacts for all studied impacts, but in case of PS foam, it also released greenhouse gas emissions (e.g. CO, CO_2 SO_X) and heavy metal substances (e.g. copper, cobalt, nickel, and selenium). This mostly contributed to global warming, human non-carcinogenic toxicity, and terrestrial ecotoxicity impacts.

Cradle to grave with sanitary landfill option

Under sanitary landfill condition, the moisture content and temperature are low, which leads to long time of decomposition and a small amount of methane gas. Thus, methane is not collected to produce electricity. There were no energy credits from landfilling of bagasse lunch boxes in this study. PS foam lunch boxes cannot be degraded under sanitary landfill condition. Thus, it is assumed that there are no emissions from landfill site. However, there are some emissions from the activities at the landfill site including transportation, compaction and loading waste process which require fossil fuel and electricity. The higher environmental impacts of bagasse lunch boxes come from its degradation in the sanitary landfill.

Cradle to grave with recycling option

Recycling of bagasse lunch boxes is possible via paper recycling since it is similar to waste paper. Bagasse lunch box wastes will rather be used for paper application than for the production of lunch boxes. The bagasse lunch box wastes in this study are recycled as kraft paper. Meanwhile, PS foam lunch box wastes will be transformed in to recycled PS pellets in the recycling process. This helps to decrease the production of virgin PS pellets. The overall results show that recycling of bagasse lunch boxes made the entire life cycle impacts be the lowest for six out of the eleven impact categories investigated when compared to PS foam lunch boxes (see Figure 14).

Table 2. Impact results of disposal options.

Impact category	Unit	Bagasse lunch box				PS foam lunch box		
		Composting	Incineration	Sanitary landfill	Recycling	Incineration	Sanitary landfill	Recycling
Global warming	kg CO_2 eq.	-7.16E+00	-2.05E+01	6.62E+00	-2.75E+01	1.13E+01	8.23E-01	-4.51E+00
Terrestrial acidification	kg SO_2 eq.	1.33E-03	2.45E-03	8.15E-03	-5.93E-02	1.37E-03	1.26E-03	-1.01E-02
Freshwater eutrophication	kg P eq.	-2.04E-04	2.15E-04	3.47E-04	-4.24E-03	2.18E-05	1.50E-05	2.78E-04
Marine eutrophication	kg N eq.	4.69E-05	2.49E-04	1.38E-02	-3.52E-04	2.44E-05	4.69E-04	8.53E-06
Terrestrial ecotoxicity	kg 1,4-DCB eq.	1.72E+00	3.17E+00	2.53E+00	-3.59E+01	4.95E+00	4.43E-01	-3.45E-01
Freshwater ecotoxicity	kg 1,4-DCB eq.	-8.62E-03	3.50E-01	7.24E-01	-3.15E-01	3.40E-01	6.57E-01	-6.52E-03
Marine ecotoxicity	kg 1,4-DCB eq.	-1.02E-02	4.59E-01	9.82E-01	-4.48E-01	4.72E-01	9.25E-01	-8.61E-03
Human carcinogenic toxicity	kg 1,4-DCB eq.	-4.37E-03	2.88E-01	4.49E-02	-5.90E-01	1.36E-01	5.18E-03	-5.46E-02
Human non-carcinogenic toxicity	kg 1,4-DCB eq.	-3.01E-01	2.00E+00	9.25E-01	-1.06E+01	7.98E+00	1.02E+01	-1.21E-01
Land use	m^2a	-6.97E-02	1.73E-02	6.40E-02	-2.48E+01	2.77E-03	4.19E-02	7.70E-03
Fossil resource scarcity	kg oil eq.	-1.12E+01	5.91E-01	6.50E-01	-2.59E+00	1.22E-01	1.20E-01	-2.32E+00

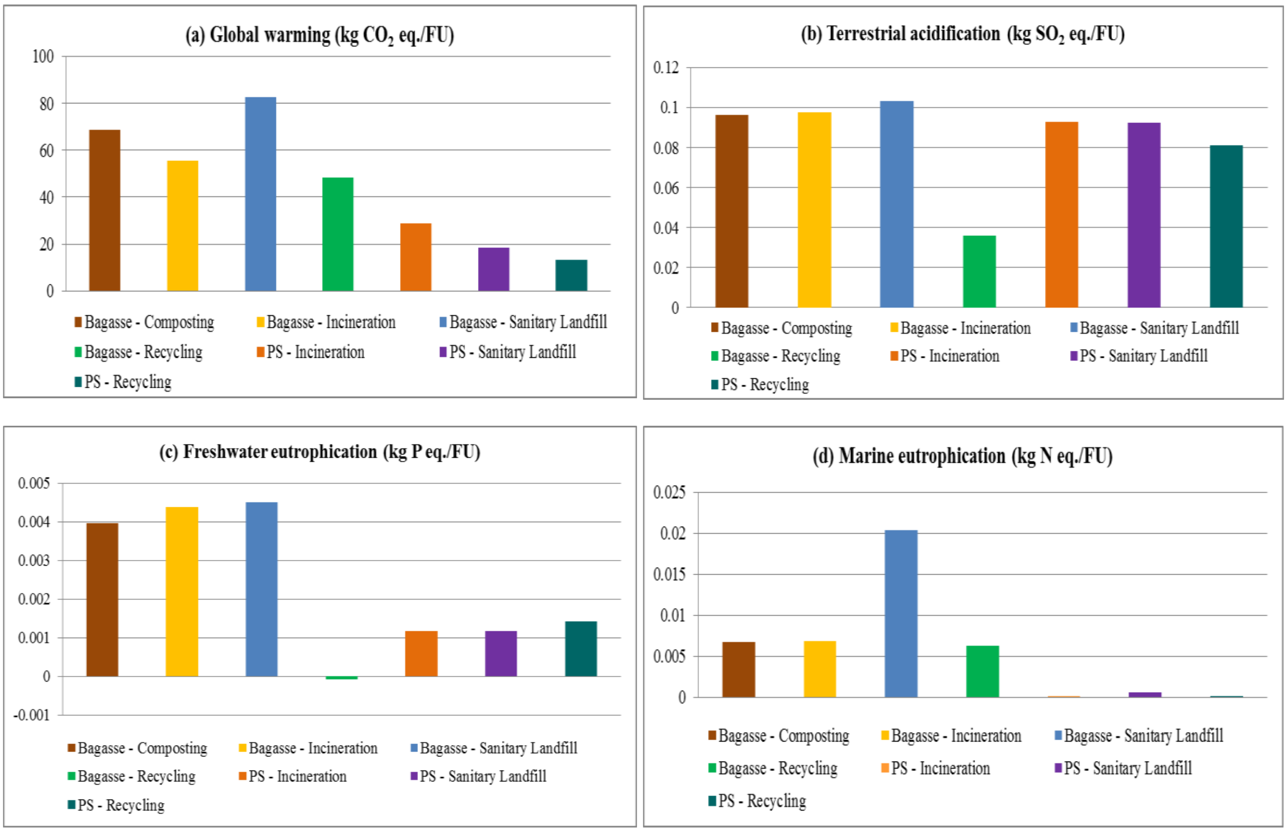

Figure 14. Life cycle impact results, cradle to grave.

Figure 14. Life cycle impact results, cradle to grave (continued).

4. Conclusions and Recommendations

In this study, the environmental life cycle impacts of bagasse lunch boxes were evaluated and compared to PS foam lunch boxes. It appears that the bagasse lunch boxes have higher environmental burdens than PS foam lunch boxes, if considering only cradle to gate and transport to customer. Bleached bagasse pulp production has a significant contribution to almost all the impacts. The major reason that makes the environmental impacts of bagasse lunch boxes larger than PS foam lunch boxes is the weight of bagasse lunch box, which is five times of PS foam lunch box. The second reason is the use of chemicals in the bleaching process. It is recommended to use unbleached bagasse instead since the impacts will be reduced by 20-30%; the human non-carcinogenic toxicity will be reduced by more than 50%. However, the recycling option also plays a key role in reducing the impacts of bagasse lunch boxes so that they are lower than PS foam lunch boxes. It is clearly seen that many challenges need to be overcome, if biodegradable sugarcane bagasse packaging is to be promoted based on its environmental preference. This is starting from the sugarcane cultivation stage that has chemical fertilizers and pesticide problems as well as sugarcane pre-harvest burning practices. This also includes the preference of white color for packaging, especially for food packaging that leads manufacturers to choose bleached bagasse pulp as raw material. Selecting the appropriate waste management system in the most efficient manner with the least negative impacts is of paramount importance, especially with regard to waste sorting and recycling. In addition, applying clean energy such as solar energy along the life cycle of the product may reduce the impacts. Lastly, there are some essential environmental impacts where bagasse lunch box would be more favorable than PS foam such as staying long time in landfill sites, marine plastic pollution, and micro- and nanoplastic contamination in the food chain since the impacts cannot be included in the LCA study yet [6].

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