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Life Cycle Management of Bioplastics for a Sustainable Future in Thailand: Sa-med Island Model

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This research aimed to evaluate the environmental performance of selected bioplastic product produced from polylactic acid (PLA) and polybutylene succinate (PBS) based on life cycle approach. Raw materials used to produce bioplastic were cassava and sugarcane and garbage bag was selected as a model product to study. The environmental performance was then compared with the same product produced from conventional plastics (HDPE, LDPE, LLDPE). The scope of the study covered the entire life cycle of the bioplastic product, including plantation, harvesting, resin production, plastic processing, product use and disposal of the bioplastic product in Thailand. Initiated as the National Innovation Agency (NIA) pilot project, Sa-med island was selected as a model to study the use and disposal of bioplastic product by composting. The functional units were 1 kg bioplastic resin and 1 kg bioplastic product. The data were compiled and analyzed using SimaPro 7.0 with the CML baseline 2000 and the Eco-Indicator 95 methods to identify the environmental burdens with a focus on global warming potential (GWP). The cradle-to-gate results showed that GWP of PLA resin was lower than GWP of conventional plastic while the GWP of PBS was higher than GWP of conventional plastic resins, but it could potentially be reduced by applying practical improvement option. When the whole life cycle environmental impact of bioplastic was considered (cradle-to-grave), the results obtained using Sa-med island as an experimental site show that the performance of bioplastic in term of GWP is better than conventional plastics and composting is an appropriate waste management to gain highest environmental benefits from bioplastics.

1. Introduction

For decades, plastics have been used to substitute natural products in many areas and have become an indispensable part of our lives, and thus, it is not surprising that the consumption of plastics is increasing more and more. Most of conventional plastics being used nowadays is derived from petroleum and does not degrade naturally. As a result, this has led to increasing environmental problems in waste management as well as global warming the world is facing. Recently, bioplastic has been proposed as an alternative way to solve these environmental problems as it is made from renewable resources/biomasses such as corn starch, cellulose, cassava and sugarcane. Moreover,

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some bioplastics can also be degradable biologically by microorganisms in natural environment which results in microbial metabolic end-products such as water and carbon dioxide. These bioplastics are usually known as “Biodegradable plastics”. Since Thailand has abundant natural biomass resources, there are great potentials to convert these resources to eco-friendly products such as bioplastics. There have been several studies conducted in Thailand on bioplastics in many aspects such as properties, processing ability, suitable applications, etc. However, there is very little study in environmental aspect and the proper management of bioplastics and their products. Therefore, in this research, we focus on the management of bioplastics and their product based on a life cycle perspective. Two bioplastics (PLA and PBS) and their product (garbage bag) are selected in this study in order to evaluate the environmental performance of bioplastics and to compare with the same product produced from conventional plastics. Samed Island is chosen as a model site to study the management of bioplastic product because it has been set as an experimental site by National Innovation Agency (NIA) to promote the use and proper disposal of bioplastic in Thailand where a composting plant has been built. The scope of the research covers the inventory data collection (raw materials, chemicals, energy, utilities and emissions) throughout the entire life cycle of bioplastic product. This includes raw materials, the monomer and bioplastic production, usage and disposal of the product. The results were analyzed by using LCA software, SimaPro 7.0, with Eco-Indicator 95 and CML 2 baseline 2000 methods to identify the environmental burdens in various impact categories such as global warming, acidification, and eutrophication. Finally, suggestions for environmental improvements offered.

2. Methodology

2.1 Goal and scope

The goal of this LCA study was to assess the environmental impacts of 2 bioplastics (PLA from cassava and PBS from sugar cane) and their product (garbage bag). The methodology used in this study was based on ISO14040 series. The inventory data collected were compiled by using SimaPro 7.0 software and the environmental impacts of the bioplastic were evaluated using Eco-Indicator 95 and CML 2 baseline 2000. The environmental impacts of bioplastics were compared with conventional plastics and the same product produced from conventional plastics.

2.2 Functional unit

The functional unit is set to be one kg of plastic resin and one kg of plastic product (garbage bag).

2.3 System boundary

The system boundary covers the entire life cycle of bioplastics including plantation, harvesting, resin production, plastic processing, use, disposal and transportation in all stages as shown in Figure 1.

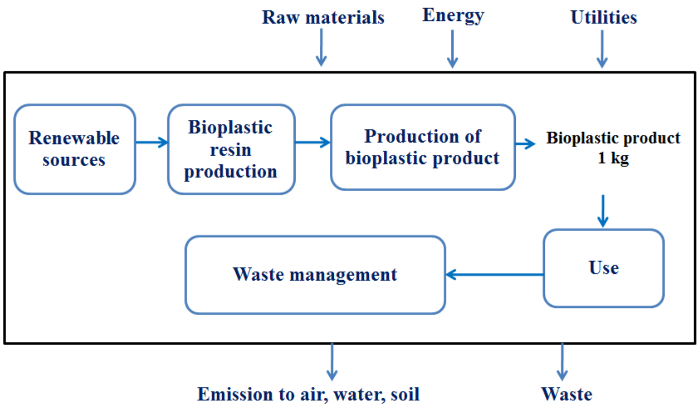

Figure 1: System boundary of the LCA bioplastic study

2.4 Data sources

The sources of the inventory data used in this study are shown in Table 1. For disposal phase, 4 different waste treatment technologies and 2 waste management scenarios based on waste management at a demonstration site (Sa-med Island) were used to evaluate the environmental impacts of end-of-life phase.

Table 1: Sources of the inventory data used in this study

Phase	Type of data	Data source
Cassava cultivation & harvesting	Primary data	Kasetsart University
	Secondary data	Literature
Sugarcane cultivation & harvesting	Secondary data	Thailand database (MTEC)
Cassava starch production	Primary data	Sima Inter Product Co., Ltd. Sanguan Wongse Industries Co., Ltd.
	Secondary data	Literature
Sugar production from sugarcane	Secondary data	Thailand database (MTEC)
Sugar production from cassava starch	Secondary data	Literature
Monomer and Resin production	Secondary data	Literature
	Primary data	Manufacturer (Purac)
Garbage bag production	Primary data	Thai Plastic Bag Co., Ltd.
Use	Primary data	Demonstration site (Sa-med)
Disposal phase	Primary data	Demonstration site (Sa-med)
	Secondary data	Thailand database (MTEC)
Transportation	Secondary data	Pollution Control Department (PCD) for trucks
		Thailand database (MTEC)

Table 2: Scenarios for waste management in Sa-med Island

Waste management scenario	% Landfill without energy recovery	% Composting	% Incineration	% Recycle
Current scenario	40	-	40	20
Scenario with bioplastic	-	40	40	20

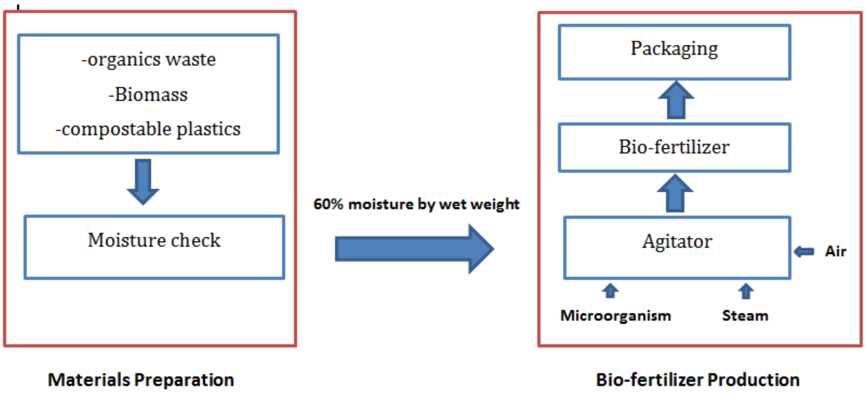

Figure 2: The system boundary of composting technology

2.5 Sa-med Island as a demonstration site

Sa-med island in Rayong province in the eastern part of Thailand was selected by National Innovation Agency (NIA) to be the demonstration site for promoting the use and proper disposal of bioplastic in the country. In this case, NIA persuaded over 70 retailer shops to join the project where bioplastic garbage bags were distributed and the local municipality also distributed specific trash containers to collect organic waste separately for producing bio-fertilizer within the Island. The project aimed to decrease amount of plastic bags on the Island, to enhance waste separation as well as to produce bio-fertilizer. It is expected to reduce about 100 tons of waste per month. To produce fertilizer from organic wastes, composting plant has been built on the island using technology of Suranaree University of Technology, Thailand. The system boundary of composting plant at Sa-med is shown in Figure 2.

3. Results and discussion

3.1 Cradle to Gate (Resin Production)

3.1.1 PLA resin production

After the life cycle inventory (LCI) of PLA resin production was completed, a life cycle impact assessment (LCIA) could be analyzed for one kilogram of PLA resin for the relevant impact categories using CML 2 baseline 2000 and Eco-Indicator 95. As PLA resin was produced in Thailand by PURAC so the production of PLA resin based on the process of PURAC (Thailand) is used as a base model for this study. Inventory data from Groot and Borén, 2010 were used with a modification that cassava was to be used instead of sugar from corn. In this work, we focus on global warming potential (GWP) which is represented by GHG emission (kg CO_2 eq.) as shown in Figure 3 where GWP results of bioplastics were compared with those of conventional plastics (HDPE, LDPE, and LLDPE). From this figure, it can be seen that the net GHG emission for cassava-based PLA resin production is 1.80 kg CO_2 eq./kg resin. The major CO_2 emission (about 95%) comes from polymerization process due to energy consumption which includes steam and electricity. Other parts of emission come from sugar and starch production as shown in details in Figure 4(a). In addition, the improvement option for starch production was studied by utilizing biogas generated from wastewater of cassava production. From this wastewater treatment plant, electricity was produced from biogas and used in the plant as well as to supply to the national grid-mix and it was considered as an avoided GWP from electricity generated by Electricity Generation Authority of Thailand (EGAT). With the utilization of biogas and the compensation, GWP of PLA has significantly reduced and the net GHG can be reduced to 1.47 kg CO_2 eq./ PLA resin.

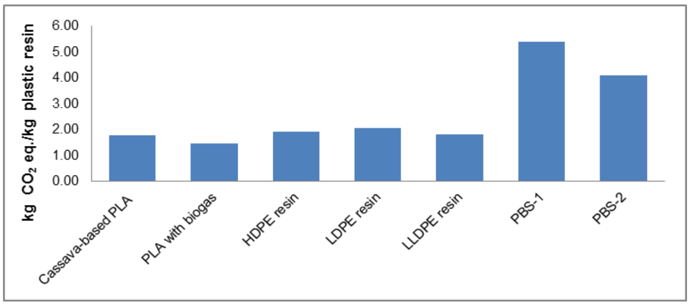

Figure 3: Comparison of GWP of bioplastic and conventional plastic resins by using CML 2 baseline 2000

3.1.2 PBS resin production

It should be noted that the life cycle inventory analysis for PBS was carried out in a different way compared to PLA because there is no PBS manufacturing plant in Thailand. The data were partially given by a supplier company and were further completed by using secondary data from various sources. As a consequence, there is an inevitably high uncertainty in the inventory data of PBS resin production. After LCI was done, the life cycle impact assessment (LCIA) could be analyzed for one kilogram of PBS resin for the relevant impact categories using both CML 2 baseline 2000 and Eco-Indicator 95. In this research, we studied two types of PBS: PBS 1 is produced form succinic acid (SA) which is derived from bio-based and 1, 4-butanediol (BDO) from petroleum based whereas PBS 2 is produced from SA and BDO which both come from bio-based. The primary data for sugar production from sugarcane were provided by MTEC while data for CO_2 uptake during sugarcane plantation (-0.189 kg CO_2/kg sugarcane) were used from previous study (Nguyen and Gheewala, 2008). The PBS resin production includes sugarcane production, sugar production, succinic acid production, BDO production, and polymerization process. As shown in Figure 3, the total GWP of PBS1 resin production is shown to be 5.38 kg CO_2 eq. The major contribution (about 50%) comes from BDO (2.62 kg CO_2 eq.) as illustrated in Figure 4(b) which is due to its petroleum originality. The second highest contribution is from succinic production which about 70% comes from energy consumption, including steam and electricity from natural gas and about 25% from the use of ammonia. It can also be seen from Fig.3 that GHG emission from PBS 2 is lower than that of PBS 1 as it has significantly decreased when it is produced from bio-SA and bio-BDO.

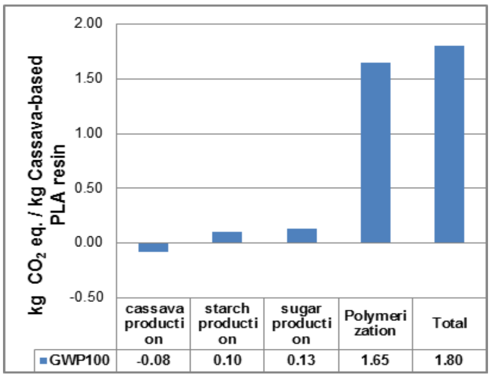

Figure 4(a): GHG emission of Cassava-based PLA resin production for each unit process by using CML 2 baseline 2000

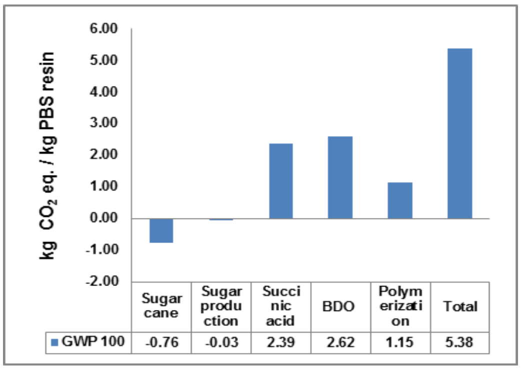

Figure 4(b): GWP of PBS-1 resin in various life cycle stages by using CML 2 baseline 2000

3.2 Cradle to Grave (Whole Life Cycle)

The life cycle GWP of PLA and PBS garbage bag including disposal phase for all waste management scenarios are shown in Figure 5. From this figure, it can be seen that the carbon dioxide emissions occur mainly in the resin production step. In addition, it can be obviously seen that different management in the disposal phase plays an important role in reducing life cycle GWP of bioplastic. Without proper waste management of bioplastic, the GWP from disposal phase could be as high as 30 % of the life cycle GWP. However, when proper waste management is applied, the GWP of disposal phase could be reduced to almost negligible when compared to the life cycle GWP of bioplastic. Comparing to the base case where the garbage bag is produced from mixed polyethylene (HDPE, LDPE and LLDPE), the results show that GWP of bioplastic (PLA) bag is lower than those of PE bags. In addition, as PLA and PBS are compostable, they can be degraded biologically to soil containing substance in the composting plant which can further be mixed with animal manure and utilized as fertilizer. Thus, with bioplastic being converted to organic fertilizer through composting, the GWP of the disposal phase should be compensated by the GWP of chemical fertilizer production. As a result, the net GWP of the composting process is -1.18 kg CO_2 eq./kg bioplastic treated. For this reason, scenario with PLA bioplastic has shown to have about 30 % lower in GWP when compared with the base case scenario (current waste management at Sa-med). The scenarios with PBS-1 and PBS-2 were higher in GWP than base case of 20.94 % and 1.92 %. The scenario with mixed bioplastics 1 was higher in

GWP than current scenario of 6.34 % due to the high GWP in resin production step but the scenario with mixed bioplastics 2 was lower in GWP than current scenario about 10 %.

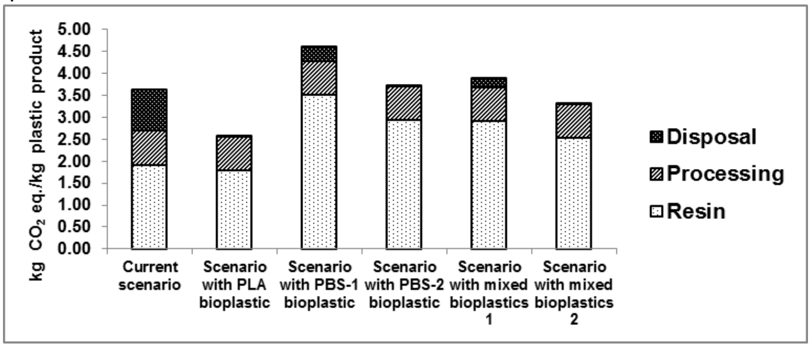

Figure 5: Comparison of the environmental performance of plastic product (cradle-to-grave) based on one kilogram of garbage bag by using CML 2 baseline 2000

4. Conclusions

In this study, the life cycle environmental impact assessment (LCIA) was performed for two types of bioplastics (PLA and PBS) and the selected product which is garbage bag. In this study, we focused on global warming potential (GWP) which is represented by GHG emission in term of kg CO2 eq. per units of interest (kg resin or kg product). The study was divided into 2 parts: cradle-to-gate (up to resin production) and cradle-to-grave (whole life cycle, including use and disposal). The management of bioplastic in the disposal phase was also studied using various waste management scenarios. The cradle-to-gate results showed that GWP of PLA resin was lower than GWP of conventional plastic (PE) while the GWP of PBS was higher than GWP of conventional plastic resins. We have shown that the impacts could potentially be reduced by applying practical improvement options. For PLA resin, the overall GWP can be lowered by the utilization of biogas produced from wastewater from cassava plant to produce electricity. In case of PBS resin, the impact can be reduced by switching to bio-based feedstocks (both succinic acid and BDO) and by reducing energy consumption in the process. When the whole life cycle environmental impact of bioplastic was considered (cradle-to-grave), the results obtained using Sa-med island as a demonstration site show that the environmental performance of bioplastic in term of GWP is better than conventional plastics and composting has shown to be an appropriate waste management to gain highest environmental benefits from bioplastics.

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