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Greenhouse Gas Evaluation and Market Opportunity of Bioplastic Bags from Cassava in Thailand

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Abstract: Due to the huge amount of feedstock availability, bioplastic products have chance to penetrate in Thailand's plastic market, as most of the plastic products are relying on fossil fuels. Thus, this paper illustrates greenhouse gas emissions from bioplastic bags are manufactured from cassava. This could replace percent conventional plastic bags share by 10% of total plastic bag product in Thailand. The study also focuses on market opportunity for bioplastic by using interview questionnaire. The opportunity can be predicted by analyzing the consumer behavior result and give recommendations for future support to bioplastic products. The results show that on the basis of global warming effects, plastic bags perform better than bioplastic bags. On the other hand, bioplastic bags help to reduce fossil fuel use and offer advantages vis-à-vis less emissions from disposal stage. Consumer behavior analysis revealed that on average a person receives about 140 bags per year from shopping at the supermarket. About 60% of the people interviewed said that they are willing to pay a small extra amount for bioplastic bags.

Keywords: Bioplastic bag, consumer behavior,greenhouse gas, market opportunity,plastic bag.

1. Introduction

Plastic is used almost everywhere for different purposes in our daily lives as it is a cheap, easily available, durable, and versatile material. Although applications and uses of plastic have many proven advantages for industrial and human purposes, plastic production and waste also imposes negative environmental externalities. Plastic waste generation is set to continue growing [1]. It uses limited fossil resources and is usually non-biodegradable, and can therefore remain as waste in the environment for a very long time and it may pose risks to human health and the environment [2].

Public concern about the environment, climate change and limited fossil fuel resources are important drivers for governments, companies and scientists to find alternatives to crude oil. Bio-based plastics may offer important contributions by reducing the dependence on fossil fuels and the related environmental impacts. Bioplastics are types of plastics made partly or wholly from polymers derived from renewable biomass that can be broken down in the environment by micro-organisms [3]. Thus it can help to reduce waste disposal problem. More importantly bioplastics can be manufactured from easily available, cheap raw materials containing large amounts of stored, converted or extracted starch or sugar such as cassava, sugar cane etc.

In this study plastic bags are selected as the product to compare with bioplastic bags based on a life cycle approach. As Thailand is a large producer and exporter of cassava [4], hence this feedstock has a potential to be used for bioplastic production. The use of such feedstock would enable as envisioned by the Thai government to contribute mitigating climate change and improving solid waste management [5]. Many different changes due to the large scale production of bioplastic can be anticipated such as land use change, effects on food prices, impacts on the environment etc [3]. The effects of such changes require investigations to evaluate the magnitude of the potential impacts they may create.

This research focuses on the greenhouse gas (GHG) emissions and energy consumption from replacing petroleum- based plastic bags with bioplastic bags using life cycle assessment. Also assessment is made on market opportunity for bioplastic bags to penetrate Thailand's plastics market by analysing raw material and product situation, questionnaire results and collaborating data from recent studies. Energy consumption and GHG emissions are considered for environmental impacts illustration because they are usually used as a reason to promote bio-based products. However, it must be noted that there are other important impacts too, such as biodiversity, ecotoxicity and water use; these are not considered in the current study but will be in the future.

2. Experimental

2.1 Goal and scope

The goal of this study is to identify the GHG emissions and energy consumption from replacing conventional plastic with bioplastic bags. The life cycle includes production, use and disposal system of plastic and bioplastic bags based on the data available in Thailand. In the case of limited availability of published data in Thailand, the data based on international publications are considered. The study also highlights the cassava situation and state of bioplastics in Thailand associated with consumer behavior as well as environmental impacts.

The environmental impacts considered in this study are global warming potential (GWP) using the IPCC 2007 characterization factors over a 100 year time horizon [6]. To assess the market opportunity of bioplastic bags in Thailand, the cassava situation, state of bioplastics and consumer behavior are considered. The study of consumer behavior was done by using interview questionnaire with 400 people in 7 districts of Bangkok.

2.2 System boundaries and data sources

The life cycle of plastic and bioplastic bags is studied from "cradle to grave". The study of plastic bag starts from the process of crude oil extraction, production of high density polyethylene (HDPE) resin followed by plastic bag production, and disposal. The study boundary of bioplastic bag starts from growing cassava to the end at disposal of bioplastic bag (including processes such as cassava cultivation, starch production, production of bio resin, bioplastic bag production and disposal of product). Transportation process and the use of product by consumer are not included within the system boundaries as they are not significant to the overall results (obtained from preliminary analysis).

The data used in this study is from published data and the Thai National Life Cycle Inventory Database (courtesy the National Metal and Materials Technology Center (MTEC)). However there is limited information on bioplastics since it's seen the early stage of the technology; therefore data from international publications is used. The source of life cycle inventory for all stages is summarized in Table 1 and details of each bag are described in the following sections.

2.2.1 Characteristics of bag

The bag considered in this study has dimensions of 30.48cm length, 50.8 cm width, thickness 0.06 mm which is commonly used plastic bag dimensions in Thailand's supermarkets. To make carrying capacity of bioplastics bag and plastic bag same at 20 kg, the thickness of bioplastic bag is assumed to increase by mass load calculation. This makes the two bags functionally equivalent. The above mentioned assumptions can be validated from the relevant literature [7,16]. The density and weight of plastic bags are 9.41×10^5 g/m^3 and 8.74×10^{-3} kg while the bioplastics bags are 1.25×10^6 g/m^{3}and 15.48×10^{-3}kg, respectively.

2.2.2 Plastic bags

The life cycle of plastic bag starts with crude oil and natural gas extraction, crude oil extracted from Middle East and natural gas extraction data, from the Gulf of Thailand. Energy consumption from refinery processes is based in Singapore as well as resin production. Emission data associated with HDPE production was obtained from Thai National Life Cycle Inventory Database by the National Metal and Materials Technology Center (MTEC).Assume that virgin resins are use in polymer production since the use of recycled materials is not including in this study. Energy use in bag production, data from UK is study by Edwards and (2011) [11]. As the use phase is excluded from the system boundary, the next stage is disposal. Plastic bag disposal is assumed to be 76% landfill, 22% recycle and 2% incineration. As the report of Pollution Control Department was showing that the about 22% of waste generated in Thailand is recycled [17] and incineration capacity is about 1.71% of total waste generated in Thailand [18-19].

2.2.3 Bioplastic bags

The data for cassava plantation was based on cultural practices in Thailand by on-site data collection by [12]. The process includes the steps from preparing cassava site, cassava growing, and harvesting. Glucose production information was obtained by questionnaire and interview from Chonburi plant in Thailand [13]. Polyhydroxyalkanoates (PHA) is a bioplastic which is biodegradable. Composting of biodegradable plastics would be a preferred option for disposal after use. Energy requirement for PHA fermentation and recovery process is based on fermentation plants in U.S. Air emissions from PHA production stage was considered only from energy use as the most of emissions came from this part [7]. Energy use in bag production is taken from the study of carrier bags in the UK [11]. Similar to plastic bags except for the recycling part, bioplastic bag disposal is assumed to be 76% landfill, 22% compost and 2% incineration.

2.2.4 Cassava and its potential for bioplastic in Thailand

Thailand is a major producer and exporter of cassava in the world. It can be grown throughout the country. A survey of cassava crop plantation in year 2010 shows that, about 1, 227,000 ha, area was under cassava plantation. Approximately 20-25 million tonnes of cassava roots are harvested each year, 75% of which are processed for export [20].

With respect to the trend of alternative energy, use of bioethanol is being promoted in Thailand instead of using fossil fuels. One of the feedstock's for bioethanol production is cassava as it is easily available in market with lower price than other energy crops [21]. In the world market, the unit price of cassava starch is lower than many other starches such as potato, maize and wheat starch [22].

In the year 2011, from the total cassava production of about 22 million tonnes, most of cassava was acquired by starch industry, cassava in the form of chips and pellets used for producing animal feed and some amount was used for ethanol production. But the use of cassava in ethanol production did not help to rise up the cassava price too much as it was controlled by demand and price of ethanol used to produce gasohol. For example, in year 2011, Thailand had11ethanol plants which were based on molasses with total capacity of 1.645 million liters per day and 4 plants which were based on cassava with total capacity of 0.68 million liters per day, while domestic demand was only 1.3 million liters per day [23].

Table 1. Life cycle inventory of bag.

Life Cycle Stage	Data required	Data source
Plastic bags		
Crude oil and natural gas extraction	- Energy consumption - Air emissions	- Khoo, et al. (2010a) [7] - Phumpradab, et al. (2009) [8]
Resin production (High density polyethylene, HDPE)	- Energy consumption - Air emissions	- Khoo, et al. (2010a) [7] - Thai National LCI Database [9] - Kellenberger, et al. (2004) [10]
Plastics bag production	- Energy consumption	- - Edwards and Fry (2011) [11]
Bioplastic bag		
Cassava cultivation	- Fertilizer use - Herbicide use - Diesel use	- Nguyen, et al. (2007) [12]
Glucose production	- Fuel oil use - Energy consumption - CH_4 from wastewater	- Taengwathananukool (2010) [13]
PHA production	- Energy consumption	- Khoo, et al. (2010a) [7]
Bioplastic bag production	- Energy consumption	- Edwardsand Fry (2011) [11]
Disposal		
Landfill	- Energy consumption - Air emissions	- Khoo, et al. (2010b) [14]
Incineration	- Energy consumption - Air emissions	- Khoo, et al. (2010b) [14]
Compost	- Air emissions	- Khoo, et al. (2010b) [14]
Recycling	- Energy consumption - GHG emission	- Edwards and Fry (2011) [11] - EPA (2011) [15]
Electricity		
Crude oil extraction (Natural gas-fired power from Middle East)	- Air emissions	- Khoo, et al. (2010a) [7]
Other remaining stage	- Air emissions	- Thai National LCI Database [9]

Cassava can be used as raw material for bioplastic packaging that could be another opportunity for cassava producers to increase the product price. Thailand has wide potential for bio-degradable plastics industry, where cassava used as a raw material is cheap and can be obtained in large quantity. A study has shown that if cassava is used as a feedstock for bioplastic production then there are chances to increase the cassava value as high as 200,000 million baht (from the current 40,000 million baht) [24].

Thailand's research sector is equipped with many researchers and experts who make useful contribution in the bioplastics research. The entire cycle of bioplastic production process ranges from the upstream, midstream to downstream industries [24]. Thailand has potential to support upstream industries as biomass raw materials are available and many plastics factory to support downstream industries. The National Roadmap for the Development of the Bioplastics Industry phase 2, 2011-2015 by NIA (National Innovation Agency) mentioned the target of a bioplastics pilot plant with a capacity of 10,000 tons per year by 2015 [25].

2.2.5 Consumer behavior study

In this study, use phase is outside of the system boundary however, the data in use phase were derived from a survey conducted in Bangkok where 400 consumers were interviewed via a questionnaire. Consumers were surveyed in the areas of Bang Khen, Lat Phrao, Phaya Thai, Ratcha Thewi, Patumwan, Rat Burana and Thung Khru. The objective of this consumers' survey was to investigate their behavior with regards to supermarket carrier bag and their attitudes toward bioplastic bags in Bangkok.

2.3 Functional Unit

The functional unit (FU) in this study is the plastic bags produced and distributed in Thailand in one year, or about 47,000 tonnes of plastic bags [26-27] which is equivalent to 5,377 million bags as referred from section 2.2.1. The study uses a 10% replacement of plastic bags by bioplastics bags following the National Bioplastics Roadmap Phase 2.

3. Results and Discussion

3.1 Greenhouse gas emissions and energy use

Emissions occur and energy consumption for each process is described as follow. Plastic bags: To produce 1 kg plastic bag, 790 g of HDPE, 110 g of LLDPE (linear low density polyethylene) and 100 g of chalk are used [11]. 1 kg of HDPE is produced from 1.22 kg of crude oil and 0.4 kg of natural gas [7]. GHG emissions from recycling process of HDPE are 1.38E-03 kg CO_2 eq. per kg of HDPE recycled [15]. The major contributor to GHG emissions of plastic bags life cycle is the stage of monomer production comprising about 63% of total GHG emissions. For bioplastic bags, 1 kg is produced from 1 kg PHA resin. About 3.33 kg of glucose needed to produce 1 kg of PHA [7] and to produce 1 kg of glucose 4.32 kg of cassava is used [13]. GHG emission from cultivation process is 3.055E-02 kg CO_2 eq. per kg cassava (from fertilizer, herbicide and diesel use) [12] and 1.99 kg CO_2 eq. per kg of glucose (from fuel oil use and CH_4 from wastewater) [13]. The major contributors to GHG emissions of bioplastic bags life cycle are the stages of PHA and glucose production comprising about 85% of total GHG emission. Energy required in each stage is shown in Table 2.

The contribution of the various life cycle stages to the global warming potential is presented in Figure 1. After replacing 10% of total plastic bags used in Thailand in one year (about 5,377 million bags) by bioplastic bags, the results show that GHG emissions increase by about 20% from conventional use. However, replacing 10% of plastic bags by alternative carrier bags helps to reduce the use of crude oil and natural gas by 4,166 and 1,410 tons respectively. The reduction of non-renewable resource consumption will significantly affect abiotic resource depletion. Another disadvantage of plastic bags is the energy used in the disposal phase which is about 6 times higher than bioplastic bags.

Table 2. Summary energy consumption per 1 kg bag in different stages.

Life Cycle Stage	Energy Use	
	MJ/kg plastic bag	**MJ/kg bioplastic bag**
Crude oil and natural gas process	40.18	-
HDPE / PHA production	19.05	52.53
Cassava cultivation	-	0.82
Glucose production	-	21.84
Bag manufacture	2.73	3.76
Disposal	0.50	0.03
Total	**62.47**	**78.98**

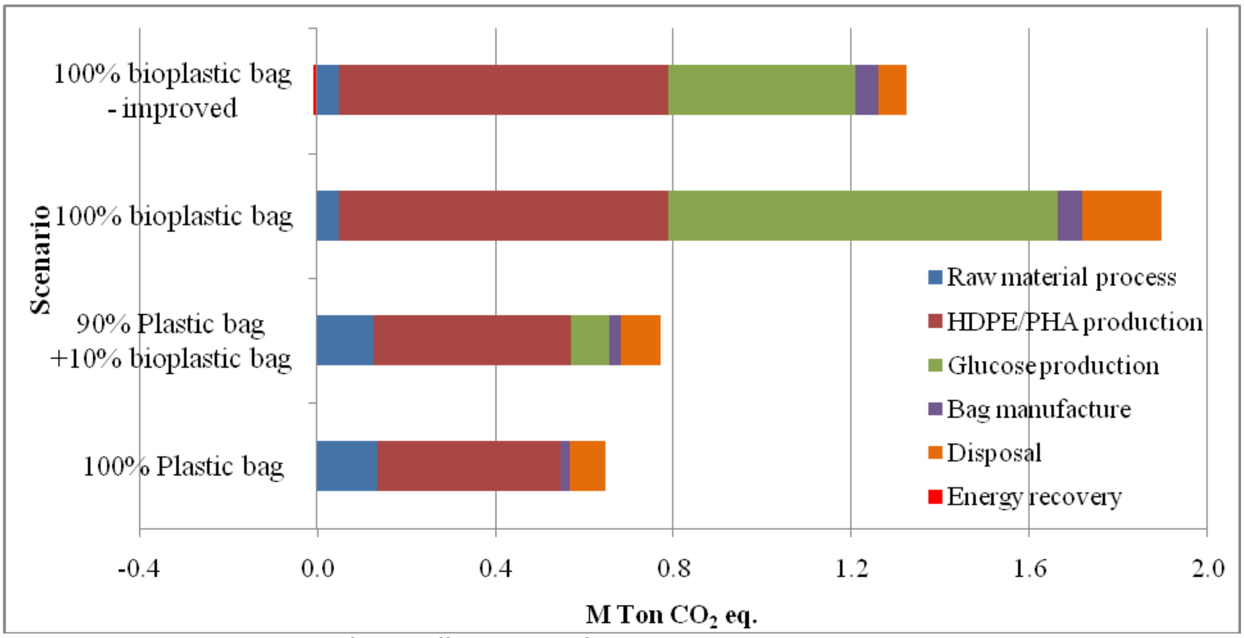

Figure 1. Global warming potential for the different stages of plastic and bioplastic bags.

The weak point of bioplastic bags is the large emissions coming from the process of glucose and PHA production. The environmental performance of bioplastic bags can be improved through energy recovery system by using wastewater from glucose production and methane gas from landfill to produce biogas to generate electricity. This helps reduce GHG emissions by about 30% from the baseline scenario. Upflow anaerobic sludge blanket (UASB) reactor technology could possibly be used for anaerobic wastewater treatment. This technology can capture 100% biogas and generate electricity with an efficiency of 30%; however, 30% of the produced electricity is used by the system itself (parasitic use). The electricity generation of 3 kWh is considered from 1 m^3 CH_4. In this case, the process can reduce about 0.456 M ton CO_2 eq. Landfill gas capture is considered by assuming 75% of CH_4 can be captured to produce electricity with the same conditions as that for electricity generation from wastewater. The GHG emission can be reduced by 0.118 M ton CO_2eq with the benefit of about 11,300 MWh of electricity.

As the bioplastic industry is still in the nascent stage, it is anticipated that the PHA production process can be improved in future to help to reduce the GHG emission from this stage. The global warming potential of the various life cycle stages from 100% bioplastic in the baseline situation and 100% bioplastic with improved conditions are presented in Figure 1.

3.2 Market opportunity

Cassava has a considerably low price in Thailand as it's depends on market driven factors such as uncertain demand and price from the export countries. So to add value to fresh cassava by taking the product to the next level before sale will help to add an extra value to the fresh product. Another lucrative way to add the value to cassava is by transforming fresh cassava to bioplastics, which will help to add value to cassava as many as 10 times [28]. If small and medium scale industries are well established and have the capability to produce wide range of products according to the National Roadmap for the Development of the Bioplastics Industry plan [25]. Hence, the full cycle of the bioplastic production can begin with the countries upstream production of bioplastic. Next barrier for bioplastic products is consumer behavior as they are the main factor to drive the sustainable consumption of the products.

The results from interview of 400 people show that people go to shopping on an average about 3 times per month and get about 5plastic bags per shopping trip; or about 11.5 bags per month. After using the plastic bag, approximately 7% people throw the maway, 40% reuse them and about 53% use them as a garbage liner. Only 2 people among the 400 interviewed people admitted that they collect and sell plastic bags. The interview results showed that about 51% people were interested to use bioplastic bags. About 45% were neutral but said that they may use bioplastic bags depending on factors such as availability in supermarkets for free or if they have to pay in acceptable limit. While 4% were not interested in using bioplastic bags because they wish to use plastic bags for long time unlike bioplastic bags (which they perceive as being degradable and hence having a short life) and as a source of small revenue generation. Furthermore, 60% of consumers are willing to pay to use bioplastic bags while 40% refused to pay even a small extra amount for it. Many of the consumers (71% of those who are willing to pay extra) accepted to pay surplus amount at 0.25 baht per bag. Some of them (18%) agreed to even an extra amount of 0.50 baht and few people were ready to pay 1 (9%) and 2 (2%) baht per bag.

4. Conclusions

The study shows that conventional plastic bags have better performance in terms of global warming when compared with bioplastic bags. However, replacing plastic bags by bioplastic are more beneficial through reducing fossil fuel consumption and ability to degrade during the disposal phase. One of the primary reasons for paying attention on bioplastic in Thailand is that, it is an agricultural country with abundant biomass resources. Thus promoting bioplastic would encourage the use of local agricultural resources thus reducing dependence on imported fossil fuels and also increase the price of cassava. To reduce GHG emissions from the bioplastic product, improvement in efficiency of glucose and PHA production process are important. Capturing and utilizing methane emissions from anaerobic treatment of wastewater as well as landfill gas could provide significant reduction in GHG emissions. Also utilization of renewable energy sources would be beneficial because most of the GHG emissions in this process are from energy use.

A questionnaire survey showed that many people are concerned about environment and are interested in using bioplastic bags. Most of the people showed willingness to pay an extra amount for bioplastic bags, though only if they have to pay a nominal amount. Hence government may consider providing subsidy for bioplastic bags in the earlier stage for promoting their use. The continuous use and proven benefits of bioplastic will compete in the plastic market and would be acceptable by consumers in the future. Another important issue to pay attention to the group of people who were indifferent to the introduction of bioplastic bags; more information on the benefits of bioplastic products could be provided to change their mindset.

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