

## Comparative Assessment of the Greenhouse Gas Emission and Land Use Capacity of Plastics Waste in Thailand

Thanawadee Leejarkpai<sup>a</sup>, Sittinun Tawkaew<sup>b</sup>, Sinsupha Chuichulcherm<sup>b</sup>, Unchalee Suwanmanee<sup>b,\*</sup>

<sup>a</sup>National Metal and Materials Technology Center, National Science and Technology Development Agency, Pathumthani 12120, Thailand

<sup>b</sup>Department of Chemical Engineering, Faculty of Engineering, Srinakharinwirot University, Nakhon Nayok 26120, Thailand. [unchalee@g.swu.ac.th](mailto:unchalee@g.swu.ac.th)

Currently, the annual Municipal Solid Waste (MSW) generation in Thailand was 14 million t. About 15.88% of total MSW was accounted as 2.22 million t of plastics waste which need to be disposed each year. The MSW in Thailand has been steadily increasing which bring a crisis in many area of country because of lack of potential site for the sanitary landfill. The first objective of Life Cycle Assessment (LCA) study was to assess and evaluate the global warming potential (GWP) and land use capacity from cradle to grave of bio-based, PLA derived from sugarcane (PLA') and PLA derived from corn (PLA''), with petroleum-based, PS derived from natural gas and crude oil, plastics. Two waste management scenarios are considered, namely the combination of 75% sanitary landfill cooperation with 25% composting (scenario 1), the combination of 50% sanitary landfill cooperation with 50% composting (scenario 2). It was found that the PS with scenario 1 showed the highest GWP impact and land use capacity of  $1.194 \times 10^4$  t CO<sub>2</sub> equivalent per year and  $2.073 \times 10^6$  m<sup>3</sup> per year. PLA' and PLA'' in scenario 2 showed the lowest GWP impact and land use capacity. The second objective was to assess the GWP impact and land use capacity of all studied boxes from cradle to grave based on 10% of total plastics waste or  $2.22 \times 10^5$  t per year and disposal in scenario 2. It was found that total GWP impact and land use capacity of PLA-based boxes in scenario 2 were lower than those of PS in scenario 1 of 4.63 % and 10% respectively.

### 1. Introduction

The global bioplastics market is forecasted to reach 40% market share of the total global plastic product in 2030. Between 2017 and 2022, the average annual increasing of bioplastic production has been continuous growing approximately 1.74% per year reaching between 2.05 million t and 2.44 million t in 2022 (European Bioplastic, 2017). Thailand is well-known as a large volume of agricultural products such as rice, sugarcane, cassava, corn, palm, etc (Thailand Board of Investment, 2020). Sugarcane and corn are the most promising potential feedstock for bio-based plastics. Thailand is the largest exporter of sugar or about 3 million t accounting to 9.5% of the global market share which worth more than 30,000 million baht. The annual production of corn in Thailand was about 4.53 million tonnes in 2020 (Office of Agricultural Economics, 2020). Pollution Control Department (2020) reported that the Municipal solid waste (MSW) generation in Thailand has been steadily increasing from 24.22 million t per year in 2010 to 24.22 million t per year in 2019. About 15.88% of total waste is the plastic waste which was accounted as 2.22 million t of plastics waste need to be disposed each year. About 74% of Thailand's MSW was disposed in non-regulated open dumps and sanitary landfill and the other was recycled about 26% (Pollution Control Department, 2012; 2020). The bio-based plastic was decomposed by the biological process which can solve the problem of the environmental impact from plastic waste (Norrdahl, 2021). Composting is an alternative for degradable materials to replace conventional disposal methods, landfill or incineration. Biodegradable waste or organic matters can degrade into humic substance, which was recognized as a high quality of fertilizer for agricultural process (Ganjyal et al., 2007; Stramarkoua et al., 2021). MSW management by composting is an environmental friendly method because it can reduce material in the waste stream and save of energy, etc. The first objective of this work to

evaluate and assess environmental impacts of bio-based and petroleum-based plastics for box application using the Life Cycle Assessment (LCA) technique. The materials study were Polylactic acid (PLA) derived from sugarcane (PLA'), PLA derived from corn (PLA'') and conventional polyethylene (PS) derived from petroleum-based. This study focuses on two categories of environmental impacts including global warming potential (GWP) and land use capacity. Two waste management scenarios are considered, namely the combination of 75% landfill cooperation with 25% composting (scenario 1), the combination of 50% landfill cooperation with 50% composting (scenario 2). The second objective was to assess the GWP impact and land use capacity of all studied boxes from cradle to grave based on 10% of total plastics waste or  $2.22 \times 10^5$  t per year and disposal in scenario 2.

## 2. Life cycle assessment (LCA)

The methodology of LCA can be described by four steps including goal and scope definition, inventory analysis, impact assessment and interpretation.

### 2.1 Goal and scope definition

The goal of this LCA study was to assess and compare the environmental impacts from cradle to grave of PLA derived from sugarcane (PLA'), PLA derived from corn (PLA''), and PS boxes. The scope of the study, raw materials extraction starts from sugarcane for PLA', corn for PLA'' and crude oil and natural gas for PS. The following stage is resin production, box forming, transportation during intermedia production, packaging waste transportation to disposal site and finally waste management. Two types waste management scenario, namely; the combination of 75% landfill cooperation with 26% composting, the combination of 50% landfill cooperation with 50% composting. The system boundary of PLA', PLA'' and PS boxes from raw materials extraction to waste management are shown in Figure 1. LCA is an environmental tool to evaluate and quantify the potential of environmental burden of product's life cycle or service in accordance to the standard ISO 14040 (2006), ISO 14044 (2006). The investigation is based on National Electricity Generating Authority data of Thailand in 2007. The first objective of this work to assess the environmental impacts, GWP impact and land use capacity, based on 1% of total plastics waste or  $2.22 \times 10^4$  t in each year. The total  $\text{CO}_2$  absorption during photosynthesis of sugarcane and corn is 1.089 kg/kg sugarcane<sup>6</sup> and 1.416 kg/kg corn. The land use capacity was proposed accordance to landfill capacity or capacity of volume ( $\text{m}^3$ ) (Suwanmanee et al., 2012). The density of all boxes was reported as  $1.31 \times 10^3$  kg/ $\text{m}^3$  for PLA' and PLA'' boxes and  $1.07 \times 10^3$  kg/ $\text{m}^3$  for PS box.

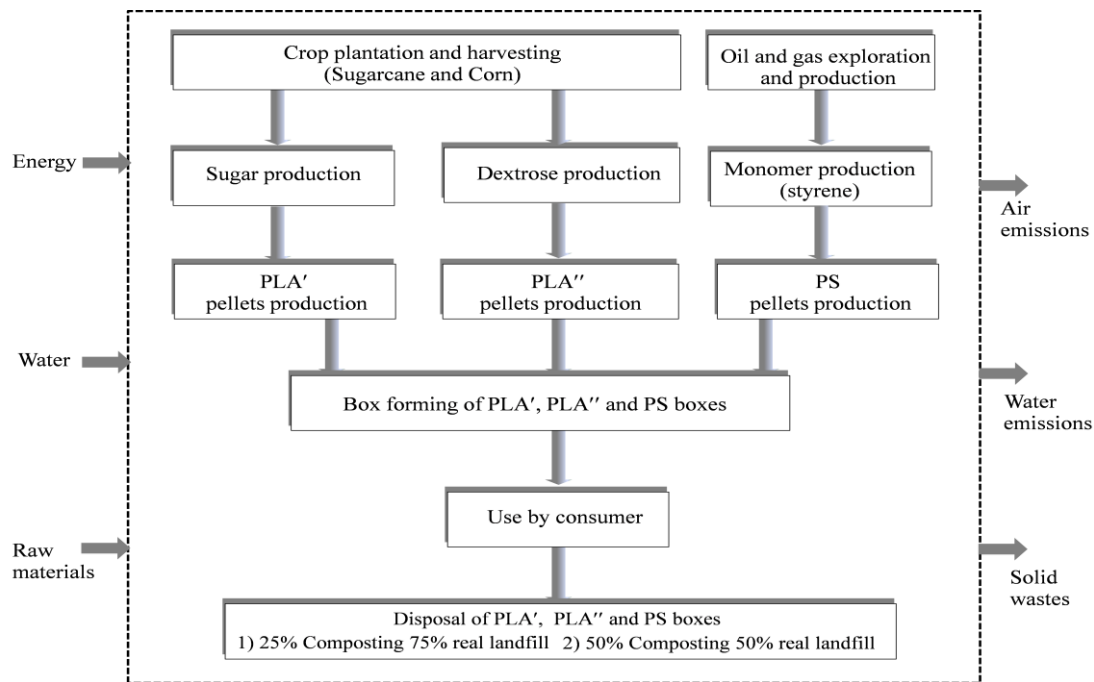


Figure 1: System boundary of PLA', PLA'' and PS boxes with waste management

## 2.2 Life cycle inventory analysis

For PLA' box production, life cycle inventory (LCI) of sugarcane plantation were reviewed and verified with average data collection in the three regions of Thailand including Central, North-eastern, and North regions (Suwanmanee et al., 2012). Sugarcane plantation usually consisted of six stages. The process begins with soil preparation, followed by seeding, fertilization, weeding, watering, and harvesting, in turn. Four major steps of PLA pellet derived from sugarcane: the conversion of sugarcane into sugar by sugar milling, processing of sugar into lactic acid by fermentation, conversion of lactic acid into lactide, and polymerization of lactide into polylactide. The energy used in PLA pellet production was expressed in units of electricity and natural gas. The thermoformed box was produced in plastic manufacturing plant<sup>9</sup>. In the study, the location of MSW sites was assumed to be used for sanitary landfill and composting near area of Bangkok region. The average distance from the centre of waste collection plant in Bangkok to landfill site, in Chachoengsao, Suphanburi, Nakhon Pathom and Nontaburi province is about 76 km (Department of Highway, 2020). The distance between waste collection plant in Bangkok and organic composting plant in Pathum Thani and Nonthaburi provinces is about 33 km. For PLA'' box production, detailed information of corn plantation covered 75 rai which was taken from Khao Chakan district, Sakaeo province, in the East of Thailand. The amount of fertilizers, herbicides, diesel, and corn yield were obtained from field interviewed farmers (Suwanmanee et al., 2012). PLA pellet production produced from corn was divided into four major steps: the conversion of corn into dextrose by wet milling, processing of dextrose into lactic acid by fermentation, the following have the same stages as PLA produced from sugarcane. The LCI of PS boxes start from crude oil and natural gas extraction, monomer production (styrene), PS pellet production, PS box forming, and PS box transportation were available and reported in Suwanmanee et al (2012).

The biodegradation of all materials studied, PLA', PLA'' and PS, under real landfill conditions was carried out at the sanitary landfill of Suphanburi province (Department of Highway, 2020). This study assumed that the biodegradability potential of all boxes studied was performed in an anaerobic degradation condition and the biodegradation behavior of PLA' and PLA'' are the same. The study of biodegradation of PLA', PLA'' and PS boxes during composting were determined from secondary data which was obtained from composting experiment accordance to ISO 14855-1 (Suwanmanee, 2010). This study assumed that the biodegradability potential of PLA' and PLA'' under composting condition is the same. The biodegradation percentage of test material was calculated from the cumulative amounts of carbon dioxide evolution.

## 3. Results and discussion

### 3.1 Life cycle impact assessment: part 1

It was found that PS shows only 3.10% weight loss after testing for 20 months. It can be concluded that PS is not degraded under real landfill conditions. Whereas, the biodegradation of PLA can be visually detected within 4 months and the full degradation of PLA could be observed within 16 months. The biodegradability potential of PLA is performed in an aerobic degradation condition accordance to ISO 14855-1 and Suwanmanee (2010). The biodegradability potential of PS was supplemented data from compost PE, which was about 0.56 %. It can be presumed that PS is not degraded under composting conditions. Whereas the biodegradability potential of PLA is 85.75%. The bonuses obtained from composting treatment for agriculture is fertilizers (N-P-K), and carbon sequestration (Razza et al., 2009) for PLA because the biodegradability potential closes 90% ISO 14855-1. Carbon sequestration was determined from organic carbon of the compost of 11.26% (Suwanmanee, 2010).

Figure 2 shows the GWP impact of the various waste treatment options when bio-based boxes, PLA' and PLA'', are an alternative for degradable materials to replace petroleum-based materials, PS, accounting as 1% of total plastics waste or  $2.22 \times 10^4$  t in each year. It was found that the combination of 75% landfill cooperation with 26% composting contributed the highest GWP impact for PS box or  $1.194 \times 10^4$  t CO<sub>2</sub> equivalent per year. The second highest GWP impact of  $1.179 \times 10^4$  t CO<sub>2</sub> equivalent per year of PS box, where it was disposed by 50% landfill and 50% composting. It can be clearly observed that resin and pellets productions of PS box has the highest portion of GWP impact by 81.23% of total impact (Suwanmanee et al., 2012). The results revealed that PS boxes have zero GHG emission when they were disposed by real landfill or composting. Whereas the land use impact from both scenario 1 and 2 were very highest impact for PS boxes about  $2.073 \times 10^6$  m<sup>3</sup> per year as show in Figure 3. This is because of PS is not degraded under real landfill and composting conditions (Khoo and Tan, 2010; Suwanmanee, 2010). The results from Figure 2 clearly showed that PLA'' with scenario 2 was the best option with negative value of GWP impact of  $-5.53 \times 10^4$  t CO<sub>2</sub> equivalent per year. It can be noted that increasing composting rate up to 50% in MSW, reduced the GWP value in PLA' and PLA'' by 0.41 to 0.42% and accounting as  $1.516 \times 10^2$  to  $2.265 \times 10^2$  t CO<sub>2</sub> equivalent per year. The obtained results show that

GWP impact whole the life cycle of PLA derived from corn (PLA'') is  $9.095 \times 10^4$  to  $9.132 \times 10^4$  t CO<sub>2</sub> equivalent per year lower than that of PLA derived from sugarcane (PLA'). The photosynthesis during corn plantation could greatly reduce GWP impact of 102.2% or about  $-3.671 \times 10^4$  t CO<sub>2</sub> equivalent per year.

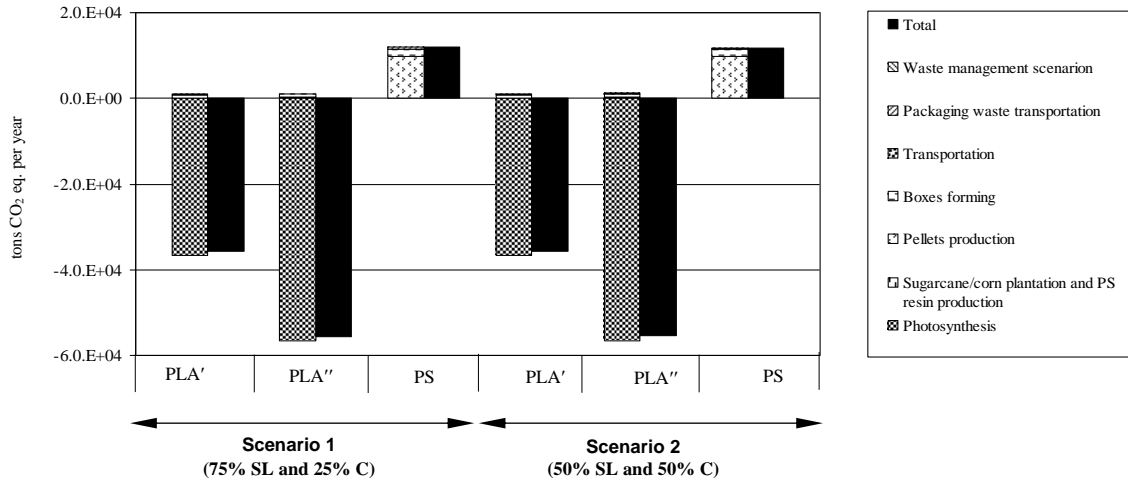


Figure 2: The GWP impact of PLA', PLA'' and PS boxes with waste management

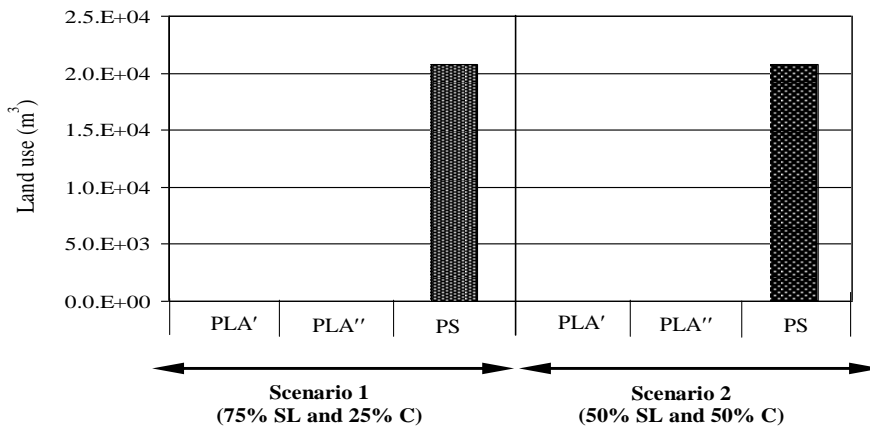


Figure 3: Land use capacity (m<sup>3</sup>) of PLA', PLA'' and PS boxes with waste management

### 3.2 Life cycle impact assessment: part 2

The second objective was to assess the GWP impact and land use capacity of PLA-based boxes from cradle to grave based on 10% of total plastics waste or  $2.22 \times 10^5$  t per year and disposal in scenario 2. Figures 4(a) and 4(b) showed the comparison of total GWP impact and land use capacity of PLA-based and PS boxes. The results showed that GWP and land use impact of PLA-based boxes were lower than those of PS box in scenario 1 about  $5.530 \times 10^5$  t CO<sub>2</sub> equivalent per year and  $2.075 \times 10^6$  m<sup>3</sup> per year or 4.63 % and 10% of total impacts respectively.

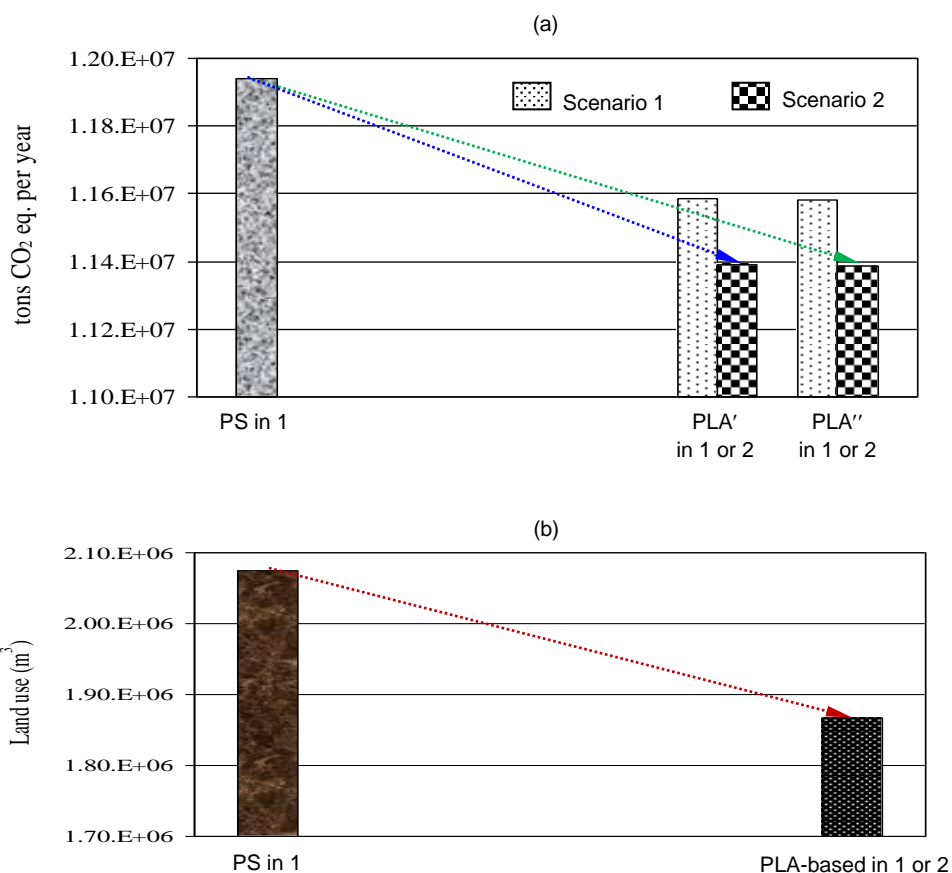


Figure 4: The GWP impact of PLA', PLA'' and PS boxes and disposal in scenario 2 based on  $2.22 \times 10^5$  ts per year: a) GWP impact and b) land use capacity.

#### 4. Conclusions

This study assessed and evaluated GWP and land use capacity of bio-based boxes, PLA' and PLA'', and petroleum-based, PS box. It was found that the PS with scenario 1 showed the highest GWP impact and land use capacity of  $1.194 \times 10^4$  t CO<sub>2</sub> equivalent per year and  $2.073 \times 10^6$  m<sup>3</sup> per year. PLA' and PLA'' with scenario 2 showed the lowest GWP impact and land use capacity. The second objective was to assess the GWP impact and land use capacity of all studied boxes from cradle to grave based on 10% of total plastics waste or  $2.22 \times 10^5$  t per year and disposal in scenario 2. It was found that total GWP impact and land use capacity of PLA-based boxes in scenario 2 were lower than those of PS in scenario 1 of 4.63% and 10% respectively.

#### Acknowledgments

This work has been supported by the Thai Research Fund (MRG6180218) and Srinakharinwirot University Fund (SWU 686/2563).

#### References

- Department of Highway, 2020, Distance between provinces in Thailand <<http://map-server.doh.go.th>> accessed 10.12.2021.
- European Bioplastic, 2017, Bioplastics market data 2017, <[http://docs.european-bioplastics.org/publications/market\\_data/2017/](http://docs.european-bioplastics.org/publications/market_data/2017/)> accessed 10.12.2021.
- Ganjyal G.M., Weber R., Hanna M.A., 2007. Laboratory composting of extruded starch acetate and polylactic acid blended foams. *Bioresource Technology*, 98, 3176 – 3179.

- ISO 14040, 2006, Environmental management – Life cycle assessment – Principles and framework, International Organization for Standardization, Geneva, Switzerland.
- ISO 14044, 2006, Environmental management – Life cycle assessment – Requirement and guidelines, International Organization for Standardization, Geneva, Switzerland.
- Norddahl B., 2021. Chemical product design in a sustainable environment, *Chemical Engineering Transactions*, 86, 1339–1344.
- Office of Agricultural Economics, 2020, Agricultural economic report 2020, <<https://www.oae.go.th/assets/portals/1/fileups/prcaidata/files/maize%20province%20dit%2062.pdf>> accessed 10.12.2021.
- Pollution Control Department, 2012, Information and services solid waste generation in Thailand 2012, <<http://www.pcd.go.th>> accessed 10.12.2021.
- Pollution Control Department, 2020, Information and services solid waste generation in Thailand 2020, <<http://www.pcd.go.th>> accessed 10.12.2021.
- Razza F., Fieschi M., Innocenti F.D., Bastioli C., 2009. Compostable cutlery and waste management: An LCA approach, *Waste Manage*, 29, 1424 – 1433.
- Stramarkou M., Boukouvalas C., Eleni P., Karalekas D., Krokida M., Comparative life cycle assessment of polyethylene terephthalate (PET) and multilayer Tetra Pak juice packaging systems, *Chemical Engineering Transactions*, 87, 103–108.
- Suwanmanee U., 2010. Modeling and life cycle environmental assessment of conventional and degradable plastic packages. PhD Thesis, Kasetsart University, Thailand.
- Suwanmanee U., Varabuntoonvit V., Chaiwutthinan P., Tajan M., Muncharoen T., Leejarkpai T., 2012. Life cycle assessment of single use thermoform boxes made from polystyrene (PS), polylactic acid (PLA) and PLA/starch: cradle to consumer gate, *Int J Life Cycle Assess.* Doi 10.1007/s11367-012-0479-7.
- Thailand Board of Investment, 2020, Thailand' s bioeconomy, < [https://www.boi.go.th/upload/content/BOI\\_brochure\\_BioEconomy.pdf](https://www.boi.go.th/upload/content/BOI_brochure_BioEconomy.pdf)> accessed 10.12.2021.