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Carbon footprint calculation for thermoformed starch-filled polypropylene biobased materials

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ABSTRACT

Thermoformed trays made from biobased materials were prepared from agricultural waste (seeds or tubers), plasticizer and polypropylene (PP). A talc-filled PP thermoformed tray was used for comparison. The carbon footprint of the thermoformed trays was calculated according to PAS 2050. System boundaries were established according to a business-to-business approach, based on data collected regarding the raw material production, transportation and processing. Biobased trays yield a lower carbon footprint than talc-filled polypropylene trays as a result of renewable resource input, a lower processing temperature and shorter thermoforming cycle. The carbon footprint reduction could be achieved through optimization of the thermoforming process and the use of low-footprint raw materials.

1. Introduction

The increasing concentration of greenhouse gases (GHGs) enhances heat trapping in the atmosphere, leading to an increase in global temperatures, also known as global warming. Carbon dioxide (CO_2) is one of the primary GHGs that are contributing to the climate change. The atmospheric concentration of CO_2 has increased since 1800 from approximately 275 ppm–390 ppm in 2011 (Kutilek, 2011). It is released into the atmosphere as a by-product of fossil fuel combustion and land-use changes (Moriarty and Honnery, 2008).

Malaysia is a developing country and is not legally bound by the Kyoto Protocol agreement to reduce its GHG emissions (UNFCCC, 2011). However, the Malaysian government has voluntarily committed to a 40% reduction of its 2005 gross domestic product (GDP) emissions intensity levels by 2020 and, under these conditions, receives assistance from developed countries (The Star, 2009). United Nations Statistics show that Malaysia's CO_2 emissions in 2005 stood at 183 million metric tons, or 7.0 metric tons per capita. In comparison, that same year, the neighboring countries of Singapore and Indonesia produced 11.6 and 1.5 metric tons per capita, respectively (United Nations Statistics, 2012). One approach to cut down the carbon emissions in Malaysia is by encouraging the use of biobased products.

According to the American Society for Testing and Materials (ASTM), a biobased material is an organic material containing carbon that has been derived from a renewable resource via a biological process. Renewable resources are available on a recurring basis, such as starch and grass. A biobased product can be fully or partially made from renewable resources. The starch-filled PP prepared here is considered a biobased material. The use of biobased plastics (e.g., PLA and thermoplastic starch) can reduce the dependency on fossil fuels, and these materials' production process may be more energy efficient than petroleum-based plastics processing (Álvarez-Chávez et al., 2012). A previous study by Madival et al. (2009) reported that the CO_2 emission during the production of a PLA clamshell (extrusion and thermoforming) was 7–9% lower than that of polyethylene terephthalate (PET).

Determining a product's carbon footprint involves the quantification of all GHGs released during all or part of it life cycle, expressed as CO_2 equivalents (CO_2eq) (Yuttitham et al., 2011). Publicly Available Specification (PAS) 2050 is the first standard method developed to measure product carbon footprint (PAS, 2050, 2008; Whittaker et al., 2011). This methodology accounts for emissions of six types of GHGs, including CO_2, nitrous oxide (N_2O), methane (CH_4) and the hydrofluorocarbon (HFC) and perfluorocarbon (PFC) families of gases. PAS 2050 has proven to be practical and scientifically robust for business implementation regardless of

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company size or sector. Many researchers have also adopted PAS 2050 in their product carbon footprint studies; for example, Iribarren et al. (2010) used PAS 2050 to investigate the carbon footprint of a canned mussel according to a business-to-customer basis. Dormer et al. (2013) reported that a food tray made from 85% recycled PET showed 58% carbon footprint reduction compared to a 100% virgin PET tray. Dias and Arroja (2012) reported that the use of three different methodologies (ISO 14040/14044, PAS, 2050 and the CEPI framework) to assess the carbon footprint of A4 paper gave different results, but all methodologies were able to identify the major emission hot spots.

The aim of this work is to study the carbon footprint of thermoformed trays, specifically trays made from biobased materials versus talc-filled polypropylene (PP) trays. The biobased materials were prepared using starch-containing agricultural waste (seeds or tubers), premixed with plasticizer and then melt blended with PP. Talc-filled PP was most likely the first commercialized filled polymer for thermoforming application (Throne, 1999). The homopolymer PP is difficult to process by thermoforming due to its narrow thermoforming window, so it is frequently formed just a few degrees below the melting temperature. Additionally, semi-crystalline PP tends to shrink more than the amorphous polymer (O'Connor et al., 2010). The inclusion of an inorganic filler (talc) into PP can improve the dimension stability, as filled resins shrink less than unfilled resins. Moreover, the talc-filled PP tray output is expected to increase because talc-filled PP has a higher thermal conductivity than unfilled PP (Weidenfeller et al., 2004). Both the biobased and talc-filled PP compounds were shaped through sheet extrusion and vacuum thermoforming into a tray product. The calculation of a product's carbon footprint is important, as this can help the manufacturer understand the key carbon-intense areas that have the greatest impact on the overall footprint and prioritize areas for emission reduction.

2. Materials and methodology

2.1. Materials

The starch-containing agricultural wastes used in this study, agricultural waste seed (AWS) and agricultural waste tuber (AWT), were supplied by Texchem Material Sdn Bhd, Malaysia. The AWS and AWT were derived from local agricultural waste sources with starch compositions of 43 wt% and 50 wt%, respectively. They were cleaned, ground into powder and sieved to obtain an average particle size of 6.5 μm and 27.7 μm, respectively. Polypropylene (PP) and glycerin-based plasticizer were also supplied by Texchem Material Sdn Bhd. The melt flow index (MFI) and density of PP were 3.16 g/10 min (190°C/2.16 kg) and 0.90 g/cm^3, respectively. The glycerin-based plasticizer had a density of 1 g/cm^3, an acid value of $<$3% and moisture $<$0.2%. The talc powder (325 mesh) was obtained from Euro Chemo-Pharma, Malaysia.

2.2. Goals of the study

The objectives of the study were as follows:

- To calculate the carbon footprint of thermoformed trays made from starch-filled PP biobased materials and talc-filled PP.
- To identify the key carbon footprint contributors and to determine actions for emission reduction.

2.3. Functional unit

The functional unit used to express the GHG emissions for the raw materials being investigated is defined as kg CO_2eq/kg raw material. All inputs and outputs of analysis are related to the functional unit (kg CO_2eq/kg tray in this study) in order to allow emission estimation for thermoformed tray production.

2.4. System definition and boundary

The thermoformed tray carbon footprint was calculated according to the PAS 2050 methodology using a business-to-business approach, more popularly known as cradle-to-gate (Mungkung et al., 2012). The exclusion of end-of-life emissions was due to the high uncertainty of the use phase and disposal phase of the tray. The tray is designed as primary packaging to hold and protect consumer products during shipping to the global market. The uncertainty arose because details of the delivery to the consumer product manufacturer and the end consumer are unknown, and there is a lack of accurate data on the disposal options (such as reuse, recycle, landfill or incineration). Moreover, each city and country has different recycling infrastructures and preferred waste management options.

Thus, this study assessment focuses on the areas in which we can initiate improvements, particularly for operation in the Texchem Polymer factory, such as compounding, sheet extrusion and thermoforming processes. The system boundary of the tray product involved three major stages, starting from the production of the raw materials (AWS, AWT, plasticizer, PP and talc), transportation of the raw materials into the Texchem Polymer factory and the processing steps to convert them into the tray product. Both the AWS and AWT are discarded agricultural by-products, and they are not grown exclusively for making biobased trays. Thus, the cradle stage of the AWT and AWS does not include plant cultivation-related emissions, but is instead defined from the stage of the conversion factory to the pulverization of the waste. The overall system boundaries for the production of the biobased (AWS/PP and AWT/PP) and talc-filled PP trays can be observed in Figs. 1–3.

2.5. Other exclusions

The GHG emissions arising from the production of capital goods, such as machinery use, factory building and employee transportation to and from the work site, have been excluded from the system boundary. The human inputs to processes are also excluded from the boundary.

2.6. GHGs and global warming potential

The defined system boundary reveals that the GHGs emitted in this study are mainly CO_2, particularly for activities in the Texchem Polymer factory. CO_2 has a global warming potential (GWP) of 1,

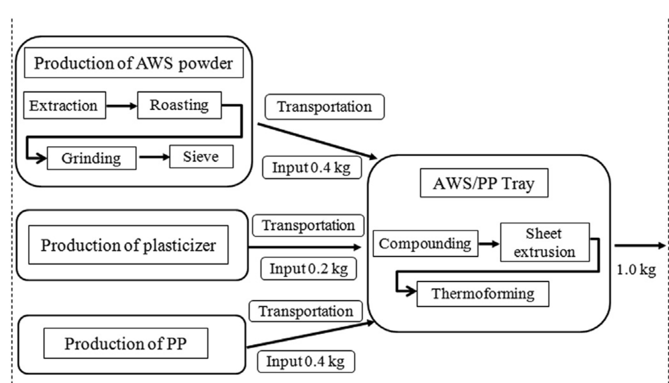

Fig. 1. System boundary for the AWS/PP tray using the business-to-business approach.

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