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Life cycle assessment of end-of-life treatments for plastic film waste

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A B S T R A C T

Plastic film waste can cause a variety of environmental impacts and pose a significant challenge for the consumer product industry. Understanding the environmental tradeoffs of various end-of-life strategies for plastic film waste is thus important for developing and deploying appropriate sustainable solutions. In this paper, we use life cycle assessment (LCA) to assess the environmental impacts of various plastic film waste treatment systems. We consider four different waste treatment scenarios for plastic films: landfill disposal of mixed waste; incineration of mixed waste; recycling of mixed waste; and recycling of recyclable waste. The results demonstrate a considerable advantage of recycling over landfill disposal or incineration. The main environmental benefit is from the recycle of plastics that can substitute for the production of plastics from virgin materials. From a sensitivity analysis, five key parameters are identified that affect the aggregate environmental impact including mass fraction of films in the waste, recycling rate, utilization rate, waste-to-energy conversion rate, and the type of energy can be substituted by the recovered energy from incineration.

1. Introduction

Film-based packaging, also known as flexible packaging, refers to any package or portion of a package for which the shape can be easily changed, including bags, pouches, labels, liners, wraps, rollstock, or other flexible products (Flexible Packaging Association, 2016). Flexible packaging utilizes the best qualities of materials such as plastic, paper, and aluminum foil to deliver a wide range of protective functions within the smallest possible amount of material (Flexible Packaging Association, 2016). Each flexible package is produced with particular film that has a unique combination of attributes for a specific application. For example, low-density polyethylene (LDPE) films have high clarity and moderate stretch ability, which can be used as bread bags. Conversely, high-density polyethylene (HDPE) films have certain degree of opacity and low stretch ability, which can be used as grocery bags and air cushions for packaging.

Owing to its adaptability and capability for conserving resources, the production of flexible packaging has been steadily growing over the past 10 years. In 2016, annual sales of flexible packaging in the U.S. were about $30.2 billion, comprising 19% of the $164 billion U.S. packaging industry and its second largest segment (Flexible Packaging Association, 2017).

The scale of plastic film production causes significant environmental impacts. After entering the marine environment, plastic waste is ingested by 44% of seabird species, and at least 267 species of marine organisms are affected by plastic waste around the world (Moore, 2008). Most film waste is currently disposed with other municipal waste. Landfill disposal, the conventional approach for municipal waste management, requires a large amount of space, and has been identified as one of the major sources of methane emissions contributing to climate change (Kumar et al., 2004). Incineration reduces the need for landfill disposal and can recover energy from combustion of waste. However, hazardous air pollutants are generated and released during incineration (Wiles, 1996). Recycling meanwhile is generally recognized for its environmental benefit of allowing the reuse of discarded materials. Recycled plastic films can be used to make various new products, such as composite lumber, crates, and bags (The Association of Plastic Recyclers, 2018). Nonetheless, a survey of programs in 2010 shows that curbside sites for bag and film recycling are only accessible to 10.8% of the U.S. population (Moore Recycling

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Associates, 2012). Only few curbside collection programs accept plastic films because post-consumer films must be clean and dry to be recycled and films can clog sorting machines at materials recovery facilities (MRF) (The Association of Plastic Recyclers, 2018). Moreover, the collection and transportation of recyclable waste also consume energy and resources, the amounts of which vary and depend on the location and type of waste. Given these considerations, an analysis is presented herein of the environmental burdens and benefits of various end-of-life treatments for plastic film waste.

Life cycle assessment (LCA) is a method to assess the holistic environmental impacts of a product or process in all of its life cycle stages, including resource extraction, materials processing, manufacturing, transport, use, and end-of-life disposal. Because it encompasses all stages of a product's life cycle and a wide range of environmental impacts, LCA can help direct policy and technology development to avoid environmental burden shifting among different stages and types of impacts. Since the 1990s, researchers have conducted various LCA studies on waste management strategies (Mølgaard, 1995; Barton et al., 1996; Craighill and Powell, 1996). Björklund and Finnveden (2005) reviewed 40 LCA case studies and found that recycling is, in most cases, preferable to landfill disposal or incineration with respect to life cycle energy use and global warming potential. Laurent et al. (2014) reviewed 222 LCA studies of solid waste management systems and concluded that the LCA results largely depend upon local attributes.

The majority of the reviewed studies focused on solid waste management in Europe, with only a few addressing solid waste management in North America. Morris (2005) concluded that for most conventionally recoverable materials, recycling consumes less energy and imposes lower environmental burdens than landfill disposal or incineration. Cabaraban et al. (2008) determined that bioreactor landfill disposal is favored over in-vessel composting in terms of energy use, cost, and airborne and waterborne emissions. To balance environmental impacts and costs, Thorneloe et al. (2007) used a municipal solid waste decision support tool to assess options for waste management. Kaplan et al. (2009) applied an optimization model and showed that the most cost-effective option for solid waste management is to implement curbside recycling for only a portion of the population. Overall, these previous studies have mainly focused on conventional recoverable materials, such as cardboard, mixed paper, aluminum cans, and plastic bottles. The life cycle environmental impacts of plastic film waste have not been investigated. In this research, we evaluate the life cycle environmental impacts of three end-of-life treatments for post-consumer plastic films: recycling, landfill disposal, and incineration. Our results consider the tradeoffs between these options and identify processes within the waste management system that significantly contribute to environmental impacts. These insights are intended help guide the development of waste management strategies for post-consumer plastic films.

2. Material and methods

This study is conducted according to the standard four-step LCA procedure of ISO14040/14044 (ISO, 2006), as outlined in the following sections.

2.1. Goal and scope definition

The overall goal of the study is to compare the life cycle environmental impacts of several end-of-life treatments for post-consumer plastic films. Specific goals are to: (1) evaluate and compare environmental impacts of different end-of-life treatments under various collection and waste composition scenarios; (2) identify key parameters affecting the environmental impacts of film waste treatments; and (3) inform film waste management decisions.

The functional unit is chosen to be the film waste contained within one metric ton of either recyclable waste or mixed waste. Following Pressley et al. (2015), the mass fraction of plastic films is assumed to be 0.6% and 2% in recyclable waste and mixed waste, respectively.

The system boundary is defined as spanning from post-consumption to end-of-life (Fig. 1). After a packaged product has been used, its plastic film packaging, or any portion of the product that contains a plastic film, is discarded into either a mixed waste or a recyclable waste stream. Mixed waste is collected by trucks and sent to either a landfill site, an incinerator for energy recovery, or a materials recovery facility (MRF) for recycling. Recyclable waste is

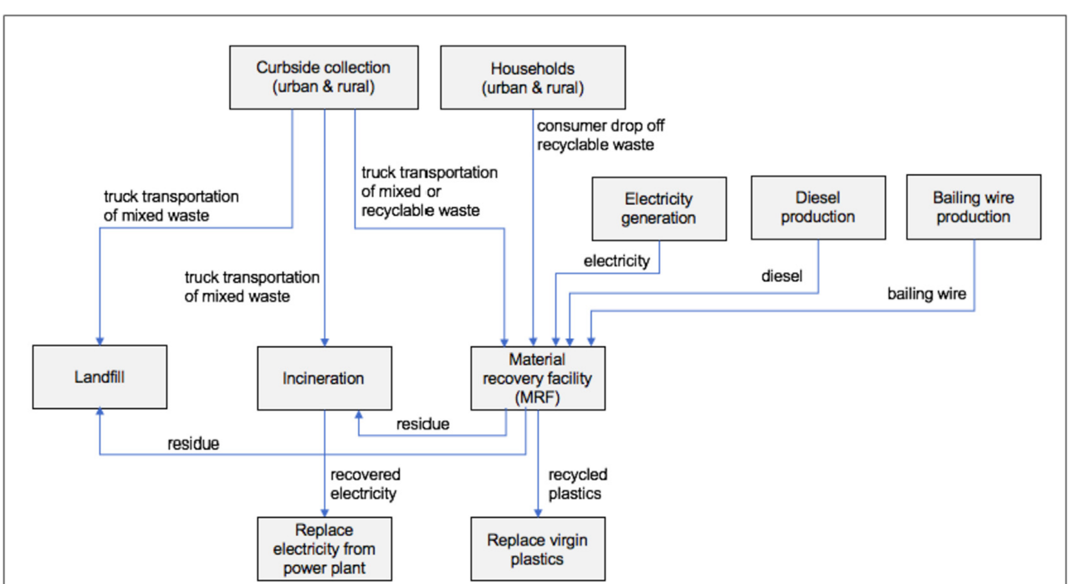

Fig. 1. Process flow diagram of the post-consumer plastic film treatment system.