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The recyclability benefit rate of closed-loop and open-loop systems: A case study on plastic recycling in Flanders

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ABSTRACT

Over the last few years, waste management strategies are shifting from waste disposal to recycling and recovery and are considering waste as a potential new resource. To monitor the progress in these waste management strategies, governmental policies have developed a wide range of indicators. In this study, we analyzed the concept of the recyclability benefit rate indicator, which expresses the potential environmental savings that can be achieved from recycling the product over the environmental burdens of virgin production followed by disposal. This indicator is therefore, based on estimated environmental impact values obtained through Life Cycle Assessment (LCA) practices. We quantify the environmental impact in terms of resource consumption using the Cumulative Exergy Extraction from the Natural Environment method. This research applied this indicator to two cases of plastic waste recycling in Flanders: closed-loop recycling (case A) and open-loop recycling (case B). Each case is compared to an incineration scenario and a landfilling scenario. The considered plastic waste originates from small domestic appliances and household waste other than plastic bottles. However, the existing recyclability benefit rate indicator does not consider the potential substitution of different materials occurring in open-loop recycling. To address this issue, we further developed the indicator for open-loop recycling and cascaded use. Overall, the results show that both closed-loop and open-loop recycling are more resource efficient than landfilling and incineration with energy recovery.

1. Introduction

Our society has grown through the extraction and usage of natural resources. Nonetheless, for many natural resources on earth, the available supply is at risk (Boryczko et al., 2014). If our current rate of natural resource use persists, then we will require more than one planet to sustain our consumption and production patterns (Footprintnetwerk, 2014). To balance economic growth and natural resource consumption, our society has to utilize resources more efficiently, or in other words, drastically increase its resource efficiency (BIO-SEC-SERI, 2012).

Apart from finding more efficient processes, a better management of waste represents the most apparent potential to increase resource efficiency (BIO-SEC-SERI, 2012). This management can be achieved by preventing waste or by reusing, recovering energy from or recycling the waste (Directive 2008/98/EC, 2008). Instead of focusing on waste disposal, waste materials can be considered as potential new resources, so-called 'waste-as-resources'. This change in mindset from waste disposal to waste-as-resources is becoming increasingly implemented in the waste management strategies of governmental policies. To ensure the progress in waste management, several institutions have been developing a wide range of indicators to provide quantitative information on the current status and to communicate results. Through these indicators, the existing status can be evaluated and future policy directions for waste prevention, reuse, energy recovery and recycling can be developed. A framework for the classification of these resource efficiency indicators at different levels can be found in the work of Huysman et al. (2015).

One of the leading governmental organizations in the field of developing and applying waste-as-resources indicators is the European Union. Various waste-as-resources indicators have been developed by the European Commission's Joint Research Centre (JRC) (Ardente and Mathieux, 2014; EC-JRC, 2012a,b). One of these indicators is the Recyclability Benefit Rate (RBR), expressing the potential environmental savings related to the recycling of a

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product over the environmental burdens of virgin production followed by disposal. This indicator is generally calculated using environmental impact values obtained through Life Cycle Assessment (LCA) (ISO, 2006a,b). The intended application of this indicator is to support the European Commission with the integration of measures aiming at improving resource efficiency in European product policies (Ardente and Mathieux, 2014).

The first objective of this paper is to explore the applicability of the recyclability benefit rate indicator concept in two cases of plastic waste treatment in Flanders: closed-loop recycling (case A) and open-loop recycling (case B). In closed-loop recycling, the inherent properties of the recycled material are not considerably different from those of the virgin material. The recycled material can thus substitute the virgin material and be used in the identical type of products as before. In open-loop recycling, the inherent properties of the recycled material differ from those of the virgin material in a way that it is only usable for other product applications, mostly substituting other materials (Nakatani, 2014; Williams et al., 2010; Wolf and Chomkhamsri, 2014). Based on these two cases, the indicator is further developed for open-loop recycling and cascaded use.

The considered plastic waste originates from small domestic appliances (e.g., radios, vacuum cleaners) and household plastics other than plastic bottles (e.g., foils, bags). Given the indispensable role of plastics in our modern society, these products provide a relevant case study. In 2012, the global production of plastics was 288 million tons (Plastics Europe, 2013). The development of synthetic polymers used to make these plastics consumes almost 8% of the global crude oil production (Nkwachukwu et al., 2013). However, after use, plastics become a major waste management challenge. Because the degradation of plastics in the environment takes a considerable amount of time, plastics impose risks to human health and the natural environment (Nkwachukwu et al., 2013).

These environmental concerns, combined with the impending supply risk of crude oil, are important incentives to stimulate the recovery of plastics. To compare different plastic waste treatments, several LCA studies have been performed in the literature. Comprehensive reviews can be found in the work of Lazarevic et al. (2010) and Laurent et al. (2014). In all of these studies, the environmental impact assessment is largely focused on the emissions and to a lesser extent on resources, the latter by using the abiotic depletion potential as an indicator. However, a good analysis focusing on the full asset of natural resources (Swart et al., 2015) in combination with resource efficiency indicators is still missing.

Therefore, the second objective of this paper is to perform such an analysis using an impact methodology which accounts for resource consumption: the Cumulative Exergy Extraction from the Natural Environment or CEENE (Dewulf et al., 2007). This methodology is based on the exergy concept, enabling accounting for both the quantity and the quality of a wide range of natural resources (Dewulf et al., 2008).

2. Materials and methods

2.1. Scope definition

The scope of the paper is to evaluate the resource efficiency in two cases of plastic waste treatment in Flanders (see Fig. 1): closed-loop recycling of plastics extracted from electronic waste (case A) and open-loop recycling of plastics from household waste (case B). For each case, three possible scenarios are available: (1) material recovery by closed-loop or open-loop recycling, (2) incineration for

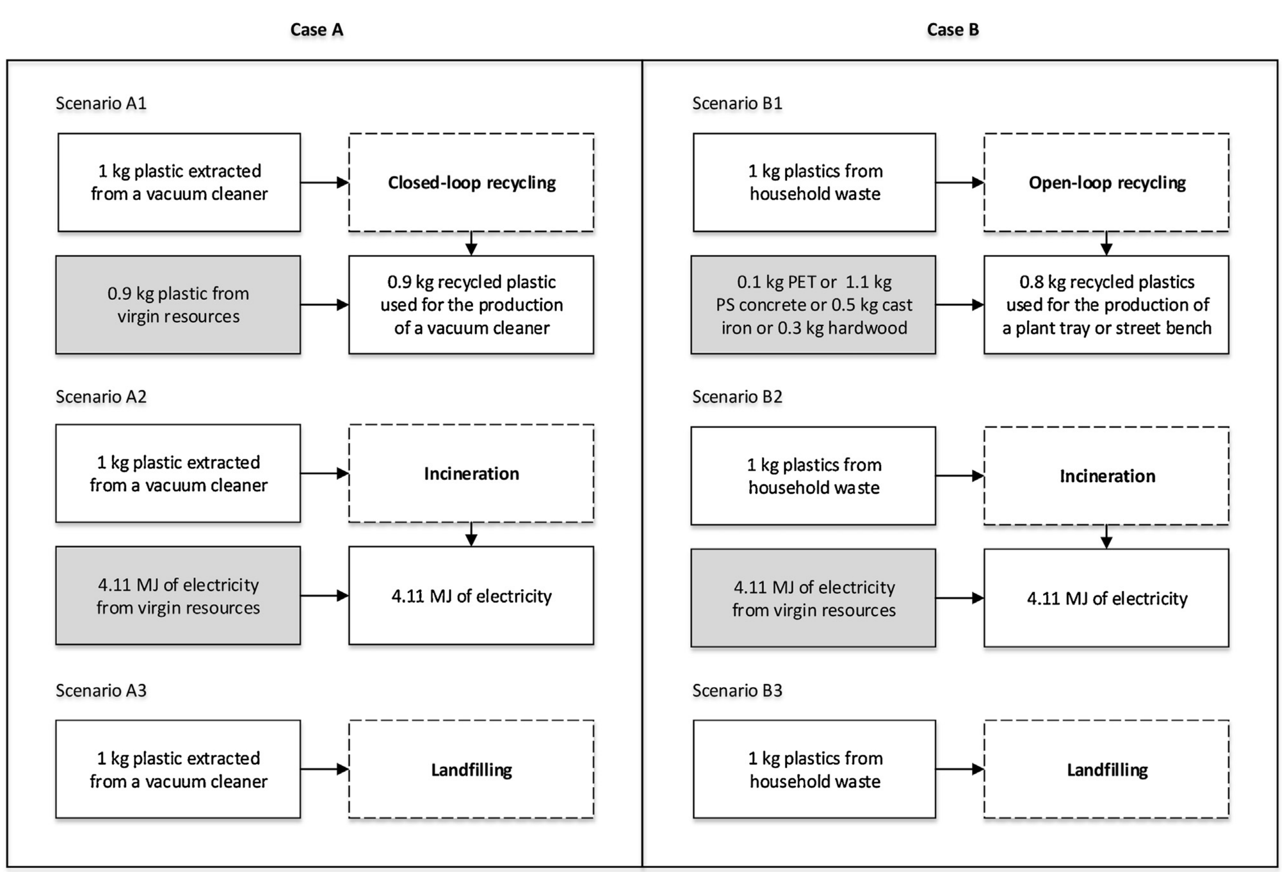

Fig. 1. Presentation of case A and case B. For each case, three possible scenarios are available: closed-loop/open-loop recycling, incineration for electricity recovery and landfilling. The grey colored blocks are the products for which the production from virgin resources ('virgin production') can be avoided.