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Is there an environmentally optimal separate collection rate?

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ABSTRACT

Material recycling often leads to environmental benefits when compared to thermal treatments or landfilling and is therefore positioned in the waste hierarchy as the third priority after waste prevention and reuse. To assess the environmental impacts of recycling and the related substitution of primary material, linear steady-state models of physical flows are typically used. In reality, the environmental burdens of collection and recycling are likely to be a non-linear function of the collection rate. This short communication aims at raising awareness of the non-linear effects in separate collection systems and presents the first non-linear quantitative model for PET bottle recycling. The influence of collection rates on the material quality and the transport network is analyzed based on the data collected from industrial partners. The results highlight that in the present Swiss recycling system a very high collection rate close to 100% yields optimum environmental benefits with respect to global warming. The empirical data, however, provided indications for a decrease in the marginal environmental benefit of recycling. This can be seen as an indication that tipping points may exist for other recycling systems, in which the environmental benefits from substituting primary materials are less pronounced than they are for PET.

1. Introduction

Recycling is seen as a key player when moving towards a Circular Economy and indeed often leads to environmental benefits when compared to thermal treatments or landfilling (e.g. review by Laurent et al. (2014)). The life cycle assessment (LCA) models used to analyze these environmental benefits, however, are typically linear steady-state models of physical flows (Guinée, 2002). In reality, the environmental burdens of collection and recycling are likely to be a non-linear function of the collection rate (Ekvall et al., 2007). Recycling rates close to 100%, for example, may lead to extra transports and prohibitive sorting efforts, which results in increased fuel consumption and emissions. Non-linearity in material recycling has previously been shown for metal recycling, e.g. from end-of-life vehicles (Ignatenko et al., 2008; Reuter et al., 2013), but these studies focused on the technological aspects in the recycling process. When examining the influence of the collection behavior of individuals, a previous qualitative study (Bunge, 2015) put forward the hypothesis that the environmentally optimal recycling rate is below 100%. Hence, for countries with very high collection rates (e.g. Switzerland), non-linearities need to be examined. Data availability is low, however, and modelling the correlation of collection rate, the collection purity, and the related environmental benefit and impact of recycling has not been done previously.

Currently, the target system for waste management relies completely on collection and recycling rates, as stated in the European Waste Directive and in Swiss regulations (EC, 2015, 2008; USG, 2016). When these targets are set, it is assumed that recycling is environmentally favorable regardless of the collection and recycling rate. A decreasing marginal benefit of increased collection and recycling could, therefore, have a substantial influence on policy making and priority setting in waste management. Especially when targeting high recycling rates, as is done for example in the Circular Economy Action Plan of the European Commission (2015), the effects of increased collection on the environmental performance of recycling of the individual fractions should be examined. Using completely linear LCA models impede the inclusion of these additional efforts when evaluating different waste management strategies and may lead to erroneous conclusions.

In Switzerland, the PET Recycling Switzerland (PRS) association is responsible for the logistics of the source separated collection and the sorting of PET bottles from beverages. Both PET bottle recycling in Switzerland and the PRS association were launched in 1990. In the last 27 years, the collection rate has increased to 87%, a very high level compared to other countries (Haupt et al.,

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2017a; Welle, 2011). Today, the network of PRS is responsible for around 95% of the PET bottles collected in Switzerland (Haupt et al., 2017a). PRS collects a large number of data around the collection and sorting of PET bottles, the residues in the collection, and the logistic network.

This study aims at raising awareness of the non-linear effects in separate collection systems and presents the first quantitative model for PET bottle recycling. For this, the influence of collection rates on the material quality and the transport network is analyzed based on the industrial data collected from PRS. This allows for the calculation of the environmental benefits as a function of the collection rate. Hence, the results are expected to support policy makers when setting targets for national waste management systems.

2. Methodology

PET bottle recycling in Switzerland is voluntary with no deposit system in place. The collection system is well established with collection points in public spaces, at retailers and at municipal collection centers. The majority of the collected material is sorted in five sorting centers in Switzerland, while a minor share is directly exported for recycling. After sorting out the residues and color-sorting, the material enters either the open-loop recycling (multi-colored PET), e.g. to PET fibres, or the closed-loop recycling (blue and transparent PET). The distribution of recyclables into these processes was based on Haupt et al. (2017a). The industrial data on the collection system includes the separate collection and the sorting and allows for modelling the correlation of the collection rates with (i) the transport distances for the collection and (ii) the purity of the collected material. Here, purity is defined as the share of PET material contained in the collection, as opposed to other materials (PE bottle caps, paper) and other wastes (e.g. liquids in discarded bottles) that need to be sorted out. The analysis below is based on the assumption that the material collected is always sorted to the same quality necessary for the later recycling process. Since the sorting processes of PET are very efficient and recycling processes request a defined quality level for recyclable inputs (for open-loop and closed-loop recycling systems), this assumption is assumed to be valid. Contamination of recyclables with potential chemical pollutants could not be taken into account due to the lack of data.

2.1. Transport vs. collection rates

Increasing the recycling rate requires a more widely spread collection system for recyclables. In the case of PET bottle recycling in Switzerland, over 60,000 collection points were opened in the last 27 years. These collection points are grouped into four categories: Collection in municipalities, at retailers, from distributers, and at so called facultative sites (schools, train stations, parks, etc.). During the last ten years, the number of collection points has increased by over 60% while the amount collected has increased by 20% (Fig. 1). In particular, there is a strong increase for the number of collection points at facultative sites. These are collection points that are established to improve consumer separate collection convenience and, therefore, increase the collection rate.

Comparing the collection rates of the last 10 years, which are based on primary industrial data, to the number of installed collection points, and assuming that at a collection rate of zero corresponds to no installed collection points, an exponential curve can be fitted to the data (Fig. 2). A larger number of collection points, however, might also indicate that longer transport distances are required. As the collection at facultative sites (which are typically correlated with smaller collection volumes) increased (Fig. 1), there is a risk of increasing transport distance per kg of material.

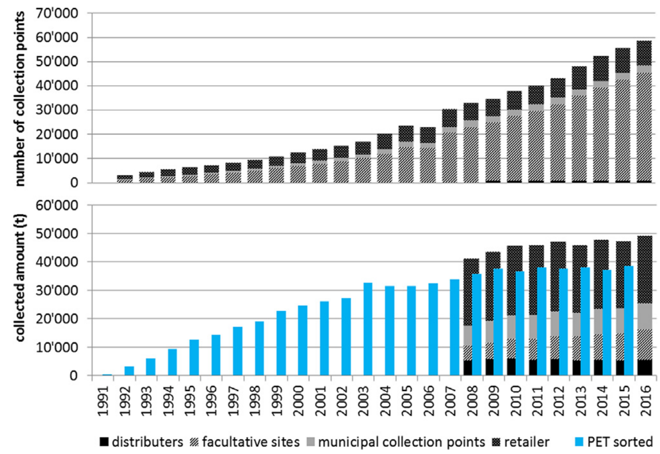

Fig. 1. Historic development of collection points. Number of collection points in the four collection routes (above) and the respective amounts of PET sorted (as reported by the Swiss Federal Office of the Environment, FOEN (2017)) and collected in the four collection channels (below). The amount of PET collected is only available from 2008 to 2016. Supplementary interactive plot data available online.

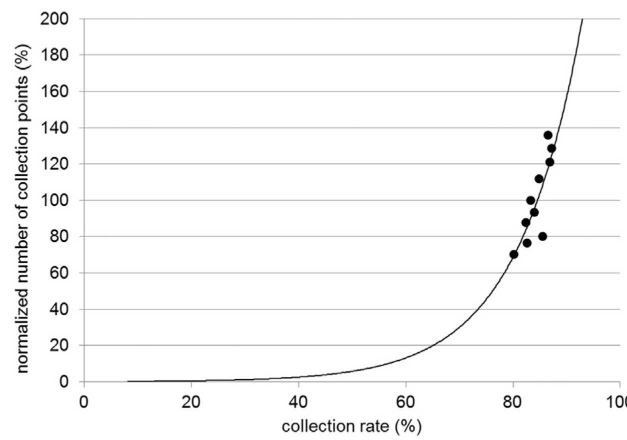

Fig. 2. Collection rate vs. number of collection points. Correlation of collection rates and number of collection points for the PET bottle recycling in Switzerland (measured points) and the resulting trendline (solid line). The number of collection points was normalized for 2012. Supplementary interactive plot data available online.

Two scenarios are developed to investigate the effect of the transport on the environmental performance of the PET bottle recycling. Both scenarios are related to the collection effort in 2016, which displayed 137 tkm of road transport and 1.25 tkm rail transport, on average, and further includes the collection infrastructure (Haupt et al., in press). In a first scenario, the transport effort per tonne of material is assumed to increase at the same rate as the number of collection points. In the second scenario, a denser network of collection sites is assumed to not substantially increase the transport effort per kilogram of PET bottles collected. The environmental impact was quantified for both scenarios to test the sensitivity of the overall performance on the transport distance.

2.2. Collection rate vs. purity of collection

In addition to the transport, the purity of the PET collection, i.e. the amount of sorted PET per kg of material collected (PET incl. residues), is expected to be influenced by the collection rate. The data was, therefore, statistically analyzed for its correlation. Fig. 3 shows the relationship between collection rate and purity