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Published in:
Proceedings Sardinia 2015

Publication date:
2015

Document Version
Publisher's PDF, also known as Version of record

CHALLENGES IN PLASTICS RECYCLING

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SUMMARY: Recycling of waste plastics still remains a challenging area in the waste management sector. The current and potential goals proposed on EU or regional levels are difficult to achieve, and even to partially fullfil them the improvements in collection and sorting should be considerable. A study was undertaken to investigate the factors affecting quality in plastics recycling. The preliminary results showed factors primarily influencing quality of plastics recycling to be polymer cross contamination, presence of additives, non-polymer impurities, and polymer degradation. Deprivation of plastics quality, with respect to recycling, has been shown to happen throughout the plastics value chain, but steps where improvements may happen have been preliminary identified. Example of Cr in plastic samples analysed showed potential spreading and accumulation of chemicals ending up in the waste plastics. In order to assure a functional recycling scheme and maintain consumer and market acceptance of recycled plastics, transparency in data on quality of plastics and better monitoring should be induced.

1. INTRODUCTION

Plastics are one of the important materials that shaped our society in the 20th century (Thompson et al., 2009). Conventional plastics are mostly produced from non-renewable sources of fossil hydrocarbons as oil and gas. They constitute nearly 9% of the world's oil and gas production, 5% as feedstock (PlasticsEurope, 2012) and around 4% for the energy consumed in production (Hopewell et al., 2009). These figures, in relation with increasing concerns due to plastics waste presence in the environment, have led to continuous discussions of better management of plastics waste.

Currently 74 % of post consumer plastic waste in Europe is either incinerated or landfilled (PlasticsEurope, 2015). Hence recycling, applied with a great success to other waste materials (e.g. aluminium, paper), is promoted also for plastics. Although quantitative targets are set on both regional and EU levels, they often do not take into account the quality of the recycled material.

Even a clear definition of quality in plastics recycling is lacking, leading to sometimes contradicting interpretations. Recycled plastics are substituting products otherwise produced from virgin materials, and the quality of the recyclates governs the substitution ratio. The lower the quality of the recycled plastics is, the lower will be the substitution ratio, and the smaller will be the benefits from their recycling (Lazarevic et al., 2010). Plastics materials can be recycled both mechanically and chemically (Al-Salem et al., 2009). Mechanical recycling is a relatively well-established technology used by the industry, primarily due to higher costs associated with chemical recycling. Although being constantly developed, chemical recycling of plastics still faces variety of challenges and full-scale plants are rather seldom encountered. Hence, chemical recycling or

Proceedings Sardinia 2015, Fifteenth International Waste Management and Landfill Symposium
S. Margherita di Pula, Cagliari, Italy; 5 – 9 October 2015

feedstock recycling was not considered in the present work.

Consumer plastics are composed of a variety of common polymers (e.g. PP, PET, PS, etc.) and their recycling potential, as well as resilience to contamination, may differ significantly. The availability of data on quality showed knowledge gaps with respect to all the potential barriers limiting plastics quality recycling (Jakobsen, 2015). In particular, the chemical contamination (either from directly/intentionally used additives or from indirectly/non-intentionally added contamination) is in need of further research, as its influence on the quality of recycled materials and the fate of chemicals in the recycling process are not well documented (e.g. Sax, 2010).

The main goal of the work was to identify the "weak" points in assuring quality plastics recycling, pointing out the factors with significant influence, and show the variations in chemical composition of plastics on the example of Cr. The results can be used as a support tool for recommendations for optimizing the plastic recycling loop with respect to the quality of products and potential recycling goals. The study presents preliminary results of the work in progress.

2. MATERIAL AND METHODS

2.1 Scenario analysis

In order to gain a better understanding of the current and potential recycling efficiencies on the example of household waste plastics in Denmark, a set of scenarios was assessed. The time range covered by the scenarios was between years 2014 and 2025, where Denmark is to reach the potential long-term plastics recycling targets.

The following scenarios for Danish household waste plastics were developed:

- *Baseline scenario*
  The scenario assumes no major improvements in the current recycling practices. Collection rates are slowly increasing, while collected waste plastics are sent abroad for centralised sorting and recycling.
- *Forecasting scenario 1*
  The scenario assumes higher increase in collection efficiency rates, while sorting efficiencies are also growing. The first part reflects increasing effort from municipalities to optimise the current waste plastics collection schemes through better information to the general public.
- *Forecasting scenario 2*
  The scenario assumes higher increase in sorting efficiencies when compared to forecasting scenario 1, achieved through establishment of state-of-the-art plastics recovering facilities in Denmark. Collection efficiency remains comparable to the one in forecasting scenario 1.
- *Backcasting scenario*
  The scenario applies a backcasting approach, in which Denmark achieves both mid-term (45 %) and long-term (60 %) targets proposed by EU (European Commission, 2014). Similarly to the forecasting scenario 2, Denmark is assumed to establish efficient plastics recovery facilities. Collection efficiencies remain unknown and are calculated from the remaining two defined parameters.

The recycling efficiency (calculated in baseline and forecast scenarios) is defined as shown in the Eq. 1, where it is a product of collection and sorting efficiencies. Thus, collection efficiency (calculated in the backcasting scenario) can be calculated from Eq. (2).

$$\eta_{Recycling} = \eta_{Collection} \bullet \eta_{Sorting} \tag{1}$$

$$\eta_{Collection} = \frac{\eta_{Recycling}}{\eta_{Sorting}} \tag{2}$$

2.2 Plastic samples

Samples of plastics were collected from a variety of sources. In total 48 samples were collected and Table 1 summarises the details of the samples. Processed plastics, both virgin and recycled, were collected directly from producers. Waste plastics were collected from a Danish municipality and represent both source-segregated fractions and fractions manually sorted out from residual waste.

Table 1. Overview of the plastic samples used in the present study.

	Form	*Polymer types*	*Number of samples*
Virgin	Granulate	PET, HDPE, LDPE, LLDPE, PP, PS	8
Waste plastics	Plastic items	PET, HDPE, LDPE; PP, PS, exp. PS, ABS, and other	20
Recycled (HHW*)	Flakes, pellets, granules, plastic items	PET, HDPE, LDPE, PP, PO	10
Recycled (IW*)	Flakes, pellets, granules	PET, HDPE, LDPE, PP, PS	10

* HHW: Household Waste; IW: Industrial Waste.

2.2.1 Sample pre-treatment

Samples of virgin, recycled household and industrial plastics were used in the form they very obtained from the respective producers (granulate, flakes, pellets, etc.). On the other hand, waste plastic samples collected from Danish household waste had to be pre-treated to be analysed.

After being sorted into different polymer types, samples were first coarsely shredded, followed by a fine shredding down to particle size <1 mm. Shredded samples were stored in individual plastic containers before being analysed. The influence of particle size on the metal recovery was not assessed in the present study.

2.2.2 Sample analysis

The metal analysis was performed in accordance with the US EPA 3052 method. In brief, 0.25 g of plastics were digested in an acid mix containing HNO3, HCl and HF (3:1:1, by volume). The microwave-assisted digestion took place at 180 ^{0}C, for 10 minutes. After being diluted, samples were analysed using Inductively Coupled Plasma Mass Spectrometer (ICP-MS).

Each sample was analysed in triplicates. As an example, results for Cr are reported in the present work. Relative recovery, resulted from methods comparison (see Götze & Astrup (2015) for details), achieved for Cr was 93 %.

3. 2. RESULTS AND DISCUSSION

3.1 Scenario analysis

The initial collection efficiency for the year 2014, was assumed to be 12 %, which is a 1.5 % increase from the year 2011 as reported by the Danish Plastics Industry (2014) for Danish household waste plastics. The sorting efficiency was based on the assessment of five centralized material sorting facilities (Plastic Zero, 2014). The average sorting efficiency resulted was 39 %, which was used as the starting figure across all the scenarios. This value is in agreement with the figures provided by JRC (2009) for the whole of plastics waste across Europe.

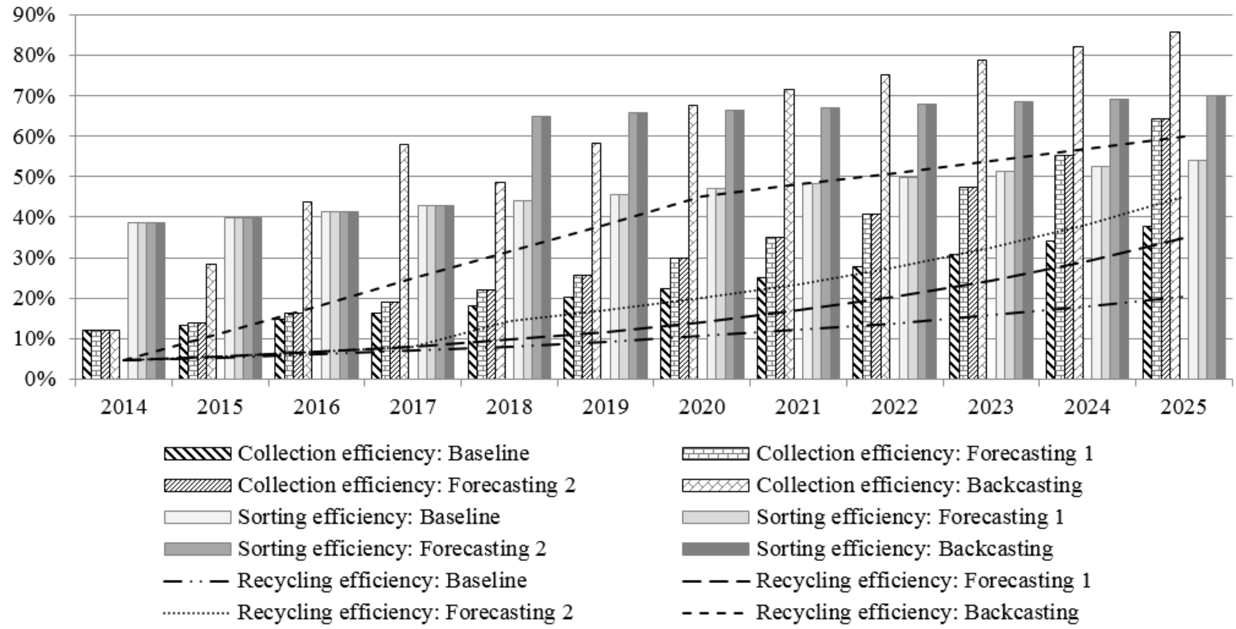

Figure 1. Collection, sorting and recycling efficiencies of the scenarios assessed.

The initial recycling efficiency in all four scenarios was 4.6 %, reaching in the baseline scenario 11 % in 2020 and 20 % in 2025. The results of the scenario analysis showed that none, among baseline and forecasting scenarios, reached the potentially proposed targets. For the two forecasting scenarios the recycling efficiencies reached were 14 % and 24 %, and 35 % and 45 % for the years 2020 and 2025, respectively. The results showed that the long-term targets (year 2025) can be achieved to a greater extend when compared to the mid-term targets (year 2020).

The results for the backcasting scenario showed that for the recycling targets to be achieved, the collection efficiencies of 68 % and 86 % have to be established in 2020 and 2025, respectively.

The overall results of the scenario analysis suggest that the potential recycling targets might be difficult to meet in a Danish reality. The backcasting scenario suggested collection rates close to that of paper and glass (Miljøstyrelsen, 2013), which were allowed a significantly broader timeframe to be achieved, in order to fulfill the targets.

3.2 Limitations in plastics recycling

Table 2 presents the main sources of contamination and whether potential impovements can be applied accross the plastics value chain (see Jakobsen (2015) for details). Additives and degradation were the main contmination sources which can vary from one polymer to another. Addition of additives (kinds and amounts) will depend on the type of polymer and intended applications, while degradation will be different depending on the chemical structure of a polymer. As evident from

Table 2, contamination and potential improvements can take place in all the steps of the plastics value chain, except for extraction where potential contamination is expected to be limited. Most of the contmination of a polymer occurs in the manufacturing step (including the plastics product design and labeling), but potential improvements are also considerable in this step. As an example, better design of plastics items in order to reduce the physical (e.g. multiple polymers) and chemical (less or better choice of additives) complexity will reduce the contamination and can potentially improve the quality of recycled plastics. Nevertheless, assuring quality of recycling will require attention from the whole value chain.

Table 2 Sources of contamination (C) and potential for improvement (I) for the four main limitations across the plastics value chain.

	Extraction	*Production*	*Manufacture, incl. design*	*Use*	*Segregation*	*Collection*	*Sorting*	*Re-processing, incl. upgrading*
Polymer cross contamination			C + I		C + I	C	C + I	I
Additives		C + I	C + I					
Non-polymer impurities			C + I	C	C + I		I	
Degradation			C	C				C + I

3.3 Cr in plastics

Chemicals in polymers can be the result of their direct addition (additives) or indirect addition through contamination (non-polymer impurities). The concentration of Cr in the plastic samples analysed are presented in Figure 2, where the results are grouped into virgin, waste, and recycled plastics. It is evident that virgin plastics was a minor source of Cr, as the concentrations found were the lowest (approx. 0.6 mg/kg) and presented low variation.

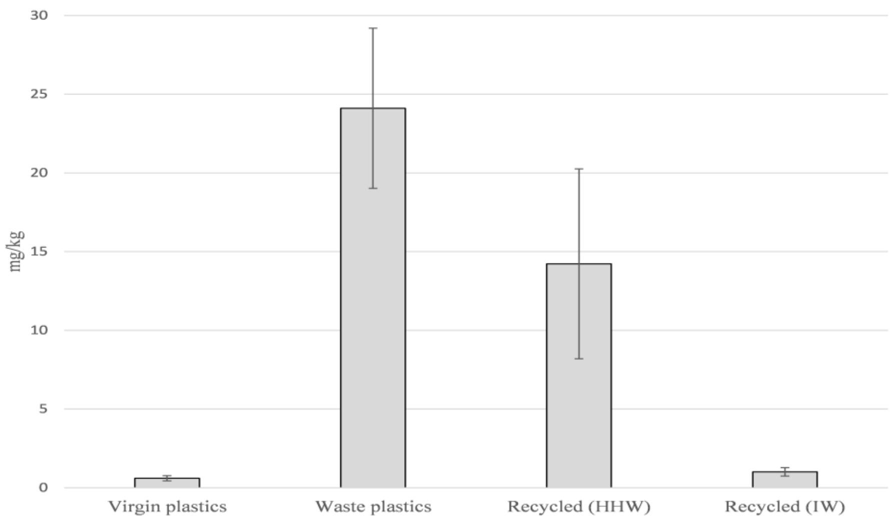

Figure 2. Measured concentration of Cr (mg/kg) in virgin, waste and recycled plastics; HHW: Household waste; IW: Industrial waste.

Recycled industrial waste plastics also showed low Cr concentrations (approx. 1 mg/kg), in levels comparable to that of virgin plastics. Waste and recycled household plastics had significantly higher Cr concentrations (average of 24 and 14 mg/kg, respectively), comparable to the ones found in the literature (e.g. Cossu et al., 2012). Increase in Cr from household plastics, when compared to virgin or recycled IW samples, could indicate use or waste collection phases as the main Cr source in plastics. However, this indicates an additional knowledge gap, as quite often the sources of potential contamination are not known and might be difficult to predict.

The difference between household waste and recycled plastics was shown to be insignificant ($p>0.05$), indicating inefficient removal of Cr in plastics recycling. Thus, potentially attributing to spreading or accumulation of Cr in products based on recycled plastics as raw material.

4. CONCLUSIONS

Plastics' recycling remains a challenging task in waste management. A generic scenario analysis showed that achieving significant improvements in plastics recycling, fulfilling potential quantity goals, might be challenging. A backcasting scenario showed that significant improvements in waste plastics collection and sorting would be required.

Quality of plastics recycling is of a major concern. The main aspects influencing it were identified to be the following four: polymer cross contamination, additives, non-polymer impurities, and degradation. It appeared that a functional improvement in plastics recycling would require contribution from most of the players across the plastics value chain.

The example of Cr in 48 plastic samples assessed in this work could indicate potential spreading or accumulation of contamination, which might extend beyond Cr. This contamination could result either from direct use of additives, used in plastics post-production phases, or from use or waste collection/management phases. It is evident that information on quality of plastics is sparse and better monitoring of plastics contamination would be required in order to assure the increase and feasibility of their recycling.

AKNOWLEDGEMENTS

The authors would like to thank Sinh Hy Nguyen and Susanne Kruse (Department of Environmental Engineering, Technical University of Denmark) for their assistance with the analysis. The Danish Research Council is acknowledged for its financial support through the 3R Research School and the IRMAR project.

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