Strategies to enhance the circularity of PET thermoformed packaging waste based on material characterisation

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Nowadays, the concern to reduce the environmental pressures associated with the use of plastic packaging is growing worldwide. Polyethylene terephthalate (PET) is the most widely used polymer in packaging applications. Within Europe roughly 70% of PET packages are bottles, 20% are trays, 7% films and 3% is miscellaneous. Roughly 60% of the European PET bottles are collected and sorted for recycling (Eunomia, 2022). PET trays are PET in form of thermoformed sheet used for food packaging, which can be composed of mono-layer PET used for fresh fruits and vegetables, or multilayer PET and other polymers used to preserve meat, fish and cheese (Thoden van Velzen and Santomasi, 2022). In some European countries, PET trays are started to be sorted from the plastic waste fraction into appropriate output streams. The share of PET trays varies between countries, with rates of 2-3% in Italy (Gadaleta et al., 2023) or 4% in Belgium (Kleinhans et al., 2021) to 15%-20% in the Netherlands (Brouwer et al., 2018, 2019).

The presence of multi-material trays, adhesives, films and the brittleness of the material add to the challenges of maintaining a high-quality circular model for this packaging (Eunomia, 2022). The complexity of PET trays can largely be attributed to their crucial role in preserving food products (Delva et al., 2019). However, when it comes to end-of-life management, the multilayer structure presents challenges in efficiently recovering the entire sorted PET tray waste stream through mechanical recycling. Nevertheless, the recycling of PET trays holds promise, since the main material of the trays (PET) can in principle also be closed-loop recycled to food-grade recycled PET (rPET).

This study aims to investigate criticalities concerning the recycling of PET trays. This research goes a step further than the current literature (Roosen et al., 2020; Seier et al., 2022; Thoden van Velzen et al., 2020) by conducting an intricate and deep examination of the material composition, seeking to pinpoint critical issues and detect challenges that may be incongruent with current recycling technologies.

In particular, experimental laboratory investigation has been carried out on PET tray waste from a collection agency and a sorting facility to shed light on specific hurdles and areas for improvement in chemical and mechanical recycling processes. This was achieved by comparing different types of PET trays, whose composition is heterogeneous and complex. Thus, this points to, among the different configurations, the best and feasible solutions (into the guidelines for design-for-recycling) capable of maintaining good characteristics during the life phase as packaging and characteristics suitable with the considered recycling processes. The main steps of the research regarding:

i) categorisation of PET trays in 16 different types linked to their use and composition;
ii) definition of the heterogeneous and complex composition in terms of packaging elements, polymers, contaminants present in the waste stream;
iii) recyclability assessment of each category, considering mechanical and chemical recycling practices.

The material composition of trays was determined through a combination of thermal and chemical analysis techniques (e.g., ATR-FTIR spectroscopy, DSC, saponification, etc.). Based on this data the average material composition of the sorted PET tray sample was approximated (Table 1).

Table 1. Average material composition of the sorted PET tray waste

PET [%]	PE [%]	PP [%]	PS [%]	PVC [%]	Other plastics [%]	Paper [%]	Metal [%]	Glass [%]	Undefinable [%]
79.2 ± 15.2	8.6 ± 3.1	2.6 ± 0.8	1.1 ± 1.5	1.1 ± 0.0	1.8 ± 1.1	4.4 ± 0.3	0.3 ± 0.2	0.6 ± 0.0	0.2 ± 0.3

Afterwards, the recyclability of the various categories of PET trays was assessed based on their material build-up. For the scope, the material composition of all sixteen categories of PET trays were compared to defined mechanical and chemical design-for-recycling guidelines (Fig.1).

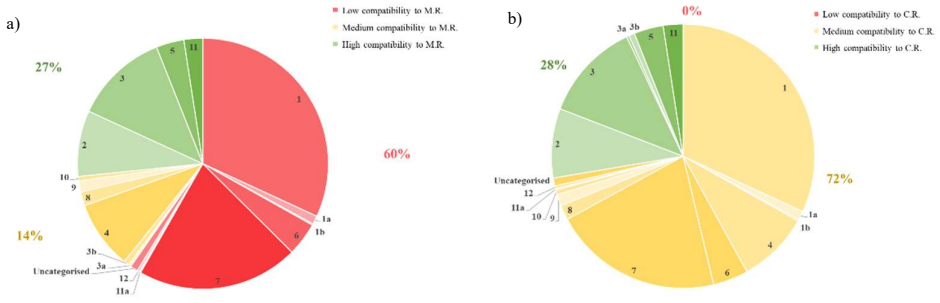

Figure 1. Weight percentage per category found in sorted product samples and colour classification in low, medium and high compatibility to a) mechanical recycling (M.R.) and b) chemical recycling (C.R.)

The most ubiquitous PET trays were only found to be suitable to produce opaque recycled PET with mechanical recycling processes; only some more uncommon PET trays to produce transparent recycled PET (Figure 1).

Depolymerisation processes hold more promise as the PET in these trays is easily accessible. Mechanical recycling is environmentally and economically sustainable (Schyns and Shaver, 2021), also it reduces fossil fuel consumption, carbon dioxide emissions (Ragaert et al., 2017). Anyway, the efficiency of recycling treatment (in terms of degree of degradation, mechanical properties and quality of recycled products) depends directly on the composition of the source stream, especially for mechanical recycling. Indeed, it is essential to optimise all stages of recycling from collection to sorting, but also to intervene in the design of the packaging itself. For the scope, some design aspects of the PET trays that improve the quality of the recycled PET were suggested in this work, giving a solution to reduce the impact of this plastic packaging stream.

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