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Recovery of aged plastics from waste stored in bales

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Abstract: Since 1994, baled waste has symbolized the waste management crisis in the Campania Region (Italy). In response to the long-term environmental burden caused by their storage, a regional strategy was launched in 2015, leading to the construction of two dedicated treatment facilities in Caivano and Giugliano municipalities.
This study focuses on the recovery and recycling potential of plastic fractions obtained from the treatment of these bales. Through comprehensive chemical-physical and mechanical analyses, the work aims to evaluate the quality, degradation, and recyclability of different types of plastics (PET, PE, PP) considering end-of-waste criteria and circular economy targets. The results provide insights into the feasibility of valorizing plastic waste streams via mechanical recycling.

Keywords: circular economy, recovery, recycling, urban mining, waste management.

1. Introduction

The need to transition from a linear to a circular economy has led to the exploration of innovative strategies for waste management, particularly in regions historically affected by poor waste infrastructure (Sauvé et al. 2016). The circular economy is based on business models which reject the linear "take-make-waste" approach. It aims to: (i) maintain products in use for a longer time by reusing and repairing them, reducing waste generation, and (ii) use more secondary raw materials in production cycles, creating new growth and job opportunities (Cossu and Williams 2015). Environmental legislation in the European Union (EU) aims to bolster the transition towards circular economy (Agovino et al. 2024) through Directive (2018)/850/EU which ushered in new regulations to further reduce the share of landfilled waste.
Among these strategies, urban mining has emerged as a promising approach for the recovery of resources from waste, including long-term stored bales. As highlighted by a previous study (Belgiorno and Cesaro, 2017), urban mining aims to reclaim materials from complex waste matrices, offering both environmental and economic benefits. This approach has been implemented as practical application in the treatment of approximately 4,5 million tons of waste bales accumulated from 2001 to 2008 in Campania Region (Alessandra Cesaro and Belgiorno 2020).

In response to this ongoing challenge, the Campania Region developed a strategy in 2015, that was based on three key pillars (A. Cesaro et al. 2018):

- transport of the untreated bales outside the region;
- realization of a plant to produce Solid Recovered Fuel (SRF) for energy plants;
- realization of a plant for the selection and recovery materials contained in the bales.

As part of this strategy, the Giugliano and Caivano plants were built in Campania. The Caivano plant, operational since June 2021, is primarily focused on the production of SRF, while Giugliano plant, operational since 2022, is designed to maximize on the recovery of plastics and metals from waste bales.
This paper presents the outcomes of these urban mining approaches, with a specific focus on the critical issues related to the plastic fractions derived from the mechanical-biological treatment of baled waste. Particular attention is given to the chemical-physical characterization of plastics and the assessment of their recyclability potential, considering the current end-of-waste criteria and the market assets and requirements.

2. Material and methods

2.1. MBT plants

The Giugliano plant, operational since 2022, treats up to 250,000 tons/years of baled waste, yielding around 50% secondary solid fuel (SRF), 25% recyclable materials (mainly plastics and metals), and 25% residual waste for landfilling. Among the plastic materials recovered, 7.6% is polyethylene terephthalate (PET), 1.1% is polyethylene (PE), and 1.1% is polypropylene (PP).

2.2. Analytical set up

As part of the characterization of plastic fractions from the mechanical-biological treatment (MBT) plant of Giugliano in Campania, representative samples are be collected from the mechanical sorting process, following the procedure outlined in Technical Standard UNI 10802:2023.
The samples analyzed in the laboratory are taken from the outgoing fractions of the plant, which correspond to each type of plastic separated within the plant. The types of plastics analyzed in this study are:

- polyethylene (PE) (mainly film, bags, and packaging);

- polyethylene terephthalate (PET) (packaging);
- polypropylene (PP) (packaging).

The plastics samples are analyzed chemically to determine their compositional, structural, and mechanical properties, to assess their potential for recycling.

The planned analyses entail innovative and conventional analysis:

- advanced spectroscopic analyses using NMR and FT-IR to investigate the microstructural characteristics and to evaluate the oxidation and aging of polymer chains (Peez et al. 2019);
- conventional thermal analyses (TGA), performed in accordance with ISO 11358-1:2022 and ASTM E1131, to determine the thermal behavior of the polymers (Corcione and Frigione 2012);
- conventional mechanical tests according to ASTM D638, to assess the tensile strength and elongation at break of the polymeric materials (Kuhn and Medlin 2000).

3. Results and conclusions

This study outlines the methodological approach adopted to evaluate the quality and recyclability potential of plastic fractions (PET, PE, PP) obtained from long-term stored waste bales treated at the Giugliano MBT plant. The integration of conventional mechanical and thermal analyses with advanced spectroscopic techniques, such as FT-IR and NRM, is expected to offer a comprehensive understanding of the degradation state of the polymers and their suitability for mechanical recycling. This methodological innovation could represent a valuable tool to support the classification of secondary raw materials according to end-of-waste criteria. COREPLA's quality thresholds, particularly regarding contaminants, composition, and purity PET, PE and PP fractions (**Table 1**), will be used as benchmarks for assessing recyclability. Although these criteria are defined for plastics from separate collection, they will provide a reference framework for evaluating materials derived from mixed waste sources.

Table 1. Minimum quality requirements for PET, PE and PP according to COREPLA

Parameters	PET mix	PE	PP
PVC containers (%)	0.5	1	-
Transparent PET containers (%)	10	1	-
Polyolefin (PE/PP) containers (%)	6.5	10	9
Other materials (%)	6	1.5	10
Metals (g)	150	150	150
Contaminations	low	low	low

The ongoing analyses will help assess the feasibility of valorizing plastics derived from complex residual waste streams, thereby supporting circular economy objectives and urban mining strategies.

Among the techniques employed, Nuclear Magnetic Resonance (NMR) stands out for its innovative ability to provide detailed insights into the molecular structures of polymers.

As highlighted by Zhou et al. (2025), NMR allows the detection of specific nuclei (those with a non-zero spin) by placing them in a static magnetic field and exposing them, to electromagnetic radiation. The resulting signals offer valuable information on the chemical environment and degradation state of the polymers under study.

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