

Systematic Generation and Evaluation of Waste-to-Resource Alternatives

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Abstract

Circular economy appears to be the only suitable approach for closing the materials loop and so to make sustainable current development levels. In this work, a procedure to systematically generate a list of potential waste-to-resource alternatives, using a semi-automatic ontological framework, is presented. The generated alternatives are then analysed and sorted according to different indicators of their economic performance, environmental impact and technological maturity. The approach is illustrated through its application to the management of a residue composed by a mixture of plastic materials.

Keywords: Circular Economy, Product Transformation, Waste-to-Resource, Ontology, Chemical Recycling.

1. Introduction

There is a raising awareness on the need to convert waste into valuable materials suitable for other uses, therefore reducing both, the waste disposal problem and the use of fresh raw materials. In order to deal with such issue, circular economy principles should be developed and applied to the current business and production industries, waste production should be ideally eliminated, hence creating the so called cradle to cradle scheme. In order to do so, systematic tools should be developed to undertake the generation of processing alternatives that promote resource upcycling. The purpose of this work is the development of a method to obtain a set of waste-to-resource transformation processes and select the best process paths, attending to economic and environmental considerations.

The approach hereby adopted is based on knowledge modelling. The use of ontologies for the development of engineering systems provides knowledge management tools in a semantical environment which, as shown by previous research, is applicable to circular economy and industrial symbiosis (Zhou et al., 2018, Cecelja et al., 2015, Rafaat et al., 2013).

2. Methodology

The proposed methodology is built through two main steps:

Process matching and list creation

An ontological framework is used to characterize resources, wastes and intermediate materials, in view of their composition and other relevant properties and specifications, as well as the considered transformation technologies and the significant relations that may be established between them. This framework is first filled with information about processes retrieved through a systematic study of available scientific and technical documentation.

Then, using a process matching method based on linking consecutive processes in a building-blocks approach, the available waste materials are connected to tentative demanded products, creating process paths, which can be modelled as a chain of 1, 2, 3 or even more process steps. Finally, a list is generated, including the identified feasible paths linking waste materials and marketable products, along with all the corresponding process specifications.

Sorting and classification of process paths

The list generated in the first step is then analysed and, for each one of the process paths, different performance indicators (KPIs) are determined, such as economic profit, environmental impact monetized profit and TRL (maturity or technology readiness level as defined by the European Commission, 2014). From them, a set of weighting factors are calculated (Eq. 1), and used to obtain an objective function (Eq. 2). This objective function may be used as global indicator to sort the selected process paths from the most to the less suitable.

$$f_{eco,j} = \frac{P_{eco,j} - \min_j \{P_{eco,j}\}}{\max_j \{P_{eco,j}\} - \min_j \{P_{eco,j}\}} \quad f_{env,j} = \frac{P_{env,j} - \min_j \{P_{env,j}\}}{\max_j \{P_{env,j}\} - \min_j \{P_{env,j}\}} \quad f_{TRL,j} = \frac{TRL_j}{\max_j \{TRL_j\}} \quad (1)$$

$$OF_j = (P_{eco,j} + P_{env,j}) \cdot f_{eco,j} \cdot f_{env,j} \cdot f_{TRL,j} \quad (2)$$

3. Case study

In order to illustrate the application of the proposed methodology, the treatment of a mixed plastic waste input, mainly composed by polyethylene, polypropylene, polystyrene and polyethylene terephthalate has been studied:

First, a list of applicable transformation steps has been obtained from technical literature, leading to a long list of combined processes which may be initially classified in 4 main groups: direct mechanical recycling, down-cycling, landfilling and incineration. This list has been extended to also include recent transformation steps focused on material upcycling. The most relevant treatment paths resulting from this analysis are schematized in Figure 1.

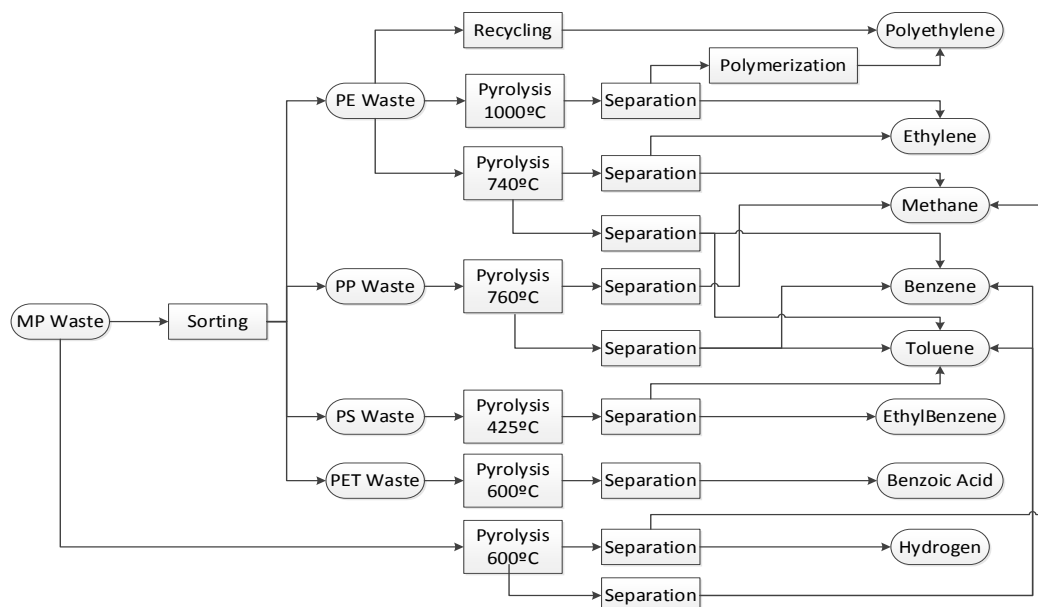


Figure 1: Tentative treatment paths for mixed plastic waste recycling.

Second, different scenarios have been proposed in order to assess the matching between generated process and current requirements. After this matching step, a total of 32 different paths or alternatives are finally assessed and, therefore, economic and environmental profit, as well as the corresponding TRL and weighting factors (Eq. 1), have been calculated. Then the process paths are sorted (Table 1), showing the potential advantages and inconveniences of the considered processes. To simplify, only the 4 first and last processing alternatives are shown. As presented below, chemical recycling is a very promising way of treating plastic waste followed by direct downcycling and mechanical recycling. In contrast, among the less suitable alternatives are landfilling and incineration.

Table 1. Results and weighting parameters for the different process paths.

Process path	Profit (€/t)	Economic factor	E.I. Profit (€/t)	E.I. factor	TRL	O.F.	Global Position
PE pyrolysis 740°C + Sep.	173.88	0.98	199,63	1,00	7	1041,90	1
PE pyr. 1000°C + Sep. +Poly.	81.35	0.89	66,97	0,64	7	510,35	2
MPW direct downcycling	0.00	0.82	0,00	0,46	9	376,03	3
MPW direct mech. recycling	113.39	0.92	-27,04	0,39	8	344,85	4
...
MPW incineration	15.79	0.83	-94.48	0.21	9	157.86	29
Landfill	-403.53	0.45	-66.66	0.28	9	66.13	30
MPW pyrolysis 425°C + Sep.	-396.89	0.45	-99.71	0.19	8	38.68	31
MPW pyrolysis 760°C + Sep.	-834.92	0.05	-161.82	0.02	8	0.00	32

4. Conclusions

The assessment of novel methods and technologies should consider many uncertain factors. Their fair comparison in front of other well established procedures must consider technology combinations and different working scenarios, and this requires in depth optimization and superstructure analysis of a complex combinatorial situation, which in practice must be limited to a manageable list of technologies and scenarios.

The proposed framework combines the systematic generation of alternative routes with KPIs analysis, contemplating flexible working scenarios, to support decision-makers to identify the most economically and environmentally beneficial solutions.

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