Techno-economic sustainability criteria and indicators for End-of-Life options of bio-based plastics

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While analyzing the different alternative scenarios of EoL options for post-consumer and post-industrial bio-based plastics, several questions are raised concerning the critical parameters that affect the applicability of each scenario. The scope of this paper is to identify the factors that determine the feasibility and sustainability of alternative EoL options and consequently to define the relevant criteria and indicators that can be used to evaluate the techno-economic sustainability of the alternative EoL treatments of bio-based products.

The boundary for the Techno-Economic Sustainability Analysis (TESA) criteria for the processing of the feedstock raw material to the final product and the boundary of the alternative EoL options of post-consumer and post-industrial bio-based products are shown in Figure 1. Between the processing boundary and the EoL boundary there is the market and use stage. Then the stage of the post-consumer and post-industrial bio-based plastics waste management follows. The market and use and the waste management stages are not included in the TESA analysis of the alternative EoL options. The waste management stage in particular, is an independent and very complicated stage that includes all kinds of municipal and industrial wastes, including plastics for recycling, and many different wastes management systems. These systems are analyzed extensively in the literature and are applicable also to bio-based plastics, unless separate collection is organized (e.g. for bio-based, biodegradable plastic packaging).

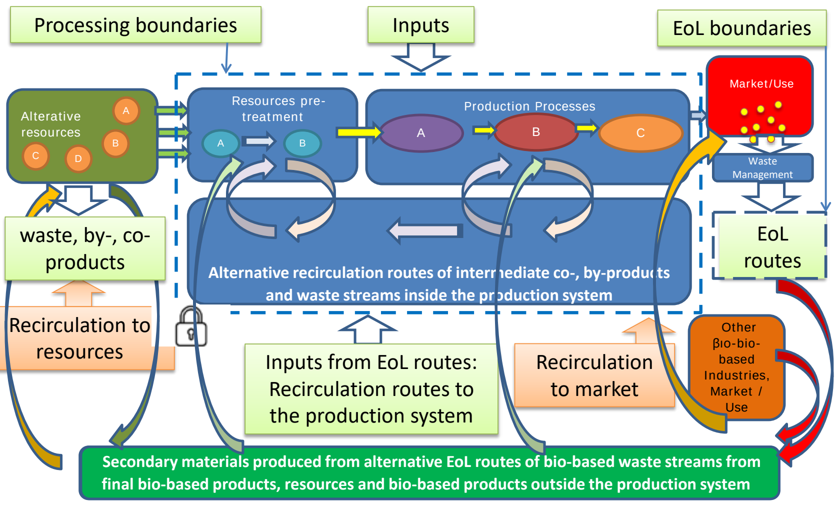

Figure 1. Alternative recirculation routes from EoL options outside the production system boundaries

The alternative EoL boundaries for the present techno-economic sustainability analysis start from the entrance of the collected and sorted post-consumer and post-industrial bio-based plastics to the EoL facility and ends at the final recovered material product (e.g. recyclate, compost) and/or energy recovery. The recirculation and valorization of the recovered materials/energy is not included in the TESA analysis of EoL options but it is analysed separately as it represents a challenging and complicated emerging process of the Bio-economy bringing the gap of the Circular Economy between processing and EoL options.

Mechanical recycling of bio-based plastics: Mechanical recycling follows the “reuse” option at the top of the hierarchy of the waste management alternatives of the Directive 2008/98/EC (WFD) [[1]] and the new Circular Economy Package (CEP) [[23]]. The CEP directive has set new higher targets for recycling by2030: 70% for all packaging waste and 55% for plastic packaging waste while all plastics packaging should be recyclable.

The proposed criteria are based on extensive literature review of the main factors affecting mechanical recycling of bio-based plastics and they are grouped into 3 integrated TESA Criteria: Recyclability, Recirculation potential and Economic viability. The proposed indicators are directly related to the main factors of the TESA criteria as shown in Table 1 (only the techno-economic sustainability criteria and indicators for mechanical recycling are briefly presented as an illustrative example.). Common techno-economic –

environmental criteria (e.g. mass recovery efficiency, utilities efficiency and waste – emissions impact on sustainability) are analysed separately along with their proposed indicators.

Table 1. TESA criteria and indicators for industrial scrap and post-consumer bio-based plastics.

Criteria	Indicators	Units
Recyclability	**Biodegradability**	**Yes/No**
	Sorting efficiency	η_{sort} *(%)* = kg of sorted (dry weight) X100/ kg of the collected post consumer specific bio-based plastic (dry weight)
	Compatibility	η_{comp} *(%)* = kg of compatible polymer x 100 / kg of the sorted post-consumer specific bio-based plastic (dry weight)
	Thermal degradation characteristics	η_{TD} *(%)* = Elongation at break of recyclate (Rεbr) x100 / Elongation at break of sorted post consumer plastic (PCεbr)
	Physical characteristics limiting recyclability	**Yes/No**
Recirculation potential	**Maximum number of possible reprocessing cycles**	**Number of cycles**
	Characterization according to standards for recyclates	**Yes/No**
	Traceability scheme for the product cycles	**Yes/No**
	Recirculation potential of the recyclate	**Yes/No**
Economic viability	**Availability of mechanical recycling facilities**	**Yes/No**
	Availability of collected and sorted industrial/post-consumer bio-based plastics	**Material** *(kt/an)* = kt of collected and sorted bio-based plastic waste available per year
	Market of bio-based recyclates	**Relative value** (%)=price of recyclate (*€/kg recyclate)*/price of virgin *(€/kg Virgin material)*
	Financial feasibility	**Return On Investment (ROI)** **Net Present Value (NPV)**

Chemical recycling of bio-based plastics: If mechanical recycling is technically and/or economically not a viable option (e.g. the process is sensitive to contaminants, polymer is seriously degraded etc.), chemical recycling may be considered as the next recommended alternative. The CEP directive does not distinguish between mechanical and chemical recycling concerning the new higher targets for recycling by 2030: 70% for all packaging waste and 55% for plastic packaging waste while all plastics packaging should be recyclable.

Organic recycling - aerobic industrial composting and anaerobic digestions of bio-based plastics: In the cases when reuse or material recovery options ranking higher on the waste hierarchy, i.e. mechanical or chemical recycling, are not feasible, then organic recycling is the next desirable pathway for the treatment of post-consumer bio-based plastics []. This is especially suggested for the case when biodegradable plastic items are mixed with biowaste. Organic recycling comprises an alternative recovery option for biodegradable bio-based products difficult to recycle because of the contamination by organic waste (e.g. food packaging, food service ware).

The proposed techno-economic and common environmental – techno-economic criteria sustainability criteria and indicators represent a safe guide to preferred and feasibly technically and economically viable alternative EoL routes for post-consumer and post-industrial bio-based plastics .

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References

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