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Short Communication

Quality of resources: A typology for supporting transitions towards resource efficiency using the single-use plastic bottle as an example

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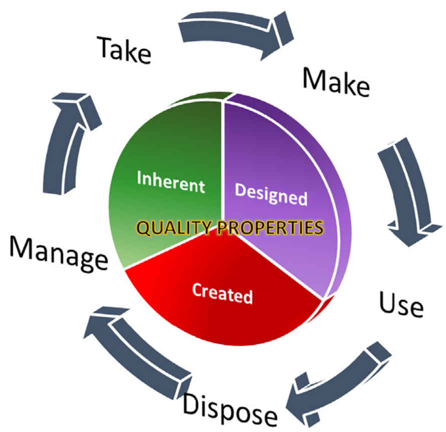
HIGHLIGHTS

- Perceived low quality of wasted resources prevents their circularity.
- A typology of quality properties was developed to promote circularity of resources.
- Inherent, designed and created characteristics of resources determine their quality.
- Designed and created plastic bottle characteristics affect their recyclability.
- Quality changes during resources lifecycle determine systemic interventions needed.

GRAPHICAL ABSTRACT



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ABSTRACT

The growing British waste management sector has consistently voiced the need to improve the quality of waste streams and thus the value of secondary resources produced, in order to achieve higher reprocessing rates. Mismanagement of wastes that may lead to contamination and degradation of the recyclate feedstock constitutes one of the main barriers in the pathway to a circular economy. The sector has also repeatedly called upon manufacturers to collaborate in designing materials, components and products (MCPs) with properties that aid recovery, refurbishing, repair and recycling (e.g. separabilty of materials, clear labelling), as waste managers recognise the value of early engagement well before MCPs enter the supply chain (i.e. before MCPs are produced and distributed to the end user). Nonetheless, progress has been slow with regard to improved design for promoting components and products longevity and segregation at source when they reach their end-of-use or end-of-life stage in order to promote circularity. China's ban on imports of low quality recyclates at the end of 2017 marked the beginning of a new era in waste management. It drew attention to UK's dependence on export of low-value secondary resources, placing 'quality' in the spotlight. This article delves into the notion of quality; how quality is understood and assessed at different parts of the MCPs lifecycle, and how it might be systematically measured. A typology to distinguish avoidable and unavoidable designed and created characteristics at all stages of MCPs lifecycle is proposed to provide industry with a tool to design wastes out of the economy. The typology's application is demonstrated using the single-use plastic bottles as an example.

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1. Introduction

Quality of wastes and secondary materials is perceived to be one of the main barriers to the greater recovery of resources from waste, including municipal solid waste, construction and demolition, and commercial and industrial wastes. Yet, quality is an elusive notion. Traditional definitions such as "*the standard of something as measured against other things of a similar kind; the degree of excellence of something*" or "*a distinctive attribute or characteristic possessed by something*" (Oxford Dictionary of English (3 Ed.), 2015) do not reflect that in reality, the quality of materials, components, and products (MCPs) produced, and those recovered from wastes, is defined and perceived differently by each stakeholder in the system. This disparity is driven by a number of factors: the intended use of MCPs, which depends on the properties/characteristics and original purpose (for a designer/manufacturer); existing regulations/specifications (for a specifier); cultural mind-sets and attitudes towards resources recovered from wastes such as resistance to repairing, remanufacturing, reuse, recovery and recycling (for recyclers, reprocessors and manufacturers, but also end-users); and marketability and aesthetic aspects (for manufacturers, retailers, end-users and clients).

Quality measurements vary across different sectors and MCPs. These measurements are often imposed by existing regulations, legislation and standards, and other quality assurance and testing protocols, or they are arbitrarily defined based on a combination of stakeholder expectations regarding what properties quality should reflect. Quality in the latter category is often determined qualitatively "on-sight", based on the visual appearance of MCPs, or by interpreting the way different discarded MCPs are separated at source. For example, large amounts of fruits and vegetables that are not the 'right' shape or size are thrown away because retailers do not consider these to be up to the 'high-quality' standard demanded by consumers, leading to perfectly edible food being wasted (The Guardian, 2013); large amounts of non-target (often unrecyclable) MCPs being placed in the wrong recycling receptacles can cause entire loads of recyclable MCPs to be rejected because the overall quality might be compromised due to contamination (edie.NET, 2016). Rejection of this type can also occur at material recovery facilities (MRFs); but when materials such as paper, glass, metals and plastics are eventually sorted for further processing the quality definition changes. This is because recyclate quality, as in the case of plastics, is often categorised by colour (e.g. translucent and clear plastics are considered of better quality) or type (e.g. polyethylene terephthalate (PET) and high-density polyethylene (HDPE) are considered to be high-value streams and thus, are always targeted for sorting); other plastic materials may only be considered as contaminants even though it may be technically possible for them to be recycled.

Quality measurements based on specific regulations, specifications and testing protocols are particularly pronounced in Europe. For example, the production of packaging intended to come in contact with food and drink (known as food contact materials, FCMs) needs to comply with the EU food contact legislation (*Regulation (EC) No 1935/2004; Regulation (EU) No 10/2011 for plastics*); whereas textiles production must be aligned with the EU *Textile Regulation (EU) No 1007/2011* on fibre names and related labelling and marking of the fibre composition of textile products. Some quality measurements for MCPs recovered from waste follow the same principle, with various regulations, quality protocols and standards controlling their use up to the appropriate levels of environmental and human health protection, safety and hygiene. In the case of solid recovered fuel (SRF), a product derived from waste, quality is measured and regulated via a set of technical criteria outlined in the EN 15359 standard with the (i) net calorific value (NCV) (also known as lower heating value), (ii) total chlorine (Cl) content, and (iii) mercury (Hg) content, being the most critical based on the end use (Iacovidou et al., 2017a). Another product derived from waste is compost. Compost quality is measured via a range of physical and chemical indicators including solids (e.g. glass and non-biodegradable fragments), heavy metals (e.g. Cd, Cr, Cu, Pb, Ni and Zn), humic substances, pH and other organic contaminants (e.g. polycyclic aromatic hydrocarbons (PAHs), polychlorinated dibenzo-p-dioxins/polychlorinated dibenzofurans (PCDD/Fs)). The concentrations of these physical and chemical indicators are outlined in the Compost Quality Protocol and PAS100 (developed as a requirements of end-of-waste criteria set in the Waste Framework Directive 08) according to different applications (Farrell and Jones, 2009). For recyclable materials such as plastic, quality at the reprocessing stage is measured by following a testing protocol that measures additives concentration, viscosity and moisture content, amongst others. It appears that variations in quality measurements may create complexity and/or uncertainty in the system as a result of concurrent variations in the way regulations, standards and/or protocols are applied to different places. This complexity is somewhat essential as it ensures that the MCPs recovered from waste meet the MCP specifications required at the production/application level in which they are going to be used, and which might differ from one place to another; assuring high-level performance and public safety.

In this article, we concluded that if quality is to be measured according to the suitability of the MCPs to continue to be used for the same function or an alternative use, a better definition is needed. Therefore, quality of MCPs is defined here as: *the remaining functionality described* via *the inherent, designed and created characteristics of a recovered MCP that make it suitable for the same or a different application measured against the properties required for assuring good performance and public safety in the specific application*. Based on this definition, the quality of MCPs can be determined and affected by actions at any point in their lifecycle, from their initial design through to their disposal and end-of-life (EoL) management (Hahladakis and Iacovidou, 2018). The objectives of this article are: 1) to provide a description of how each step of the MCPs lifecycle might affect their quality (this would generate insights into the key attributes that must be taken into account when assessing interventions made upstream or downstream of the point where wastes are generated), as shown in Fig. 1 (Iacovidou et al., 2017c) (Section 2); 2) to propose a typology for assessing the type of improvements that could potentially be made for increasing the quality of MCPs recovered from waste (Section 3); and 3) to provide a simple illustrative example of how the typology developed could be used (Section 4). The final section of the article concludes with recommendations for furthering this research.

2. Impact of all stages of materials, components and products (MCPs) lifecycle on their quality

The composition of MCPs is defined here as the complex suite of interacting inherent and designed characteristics (e.g. colour, density, hardness, electrical conductivity, corrosion/oxidation resistance). The inherent characteristics of MCPs are those that either:

- occur naturally (e.g. those of wood, raw foodstuffs, metallic elements, dimensional stone, cotton, gemstones or crude oil); or
- are produced by chemical, thermal and mechanical processes that offer a particular combination of technical properties (corrosion resistance, mechanical properties and service life) relevant to a particular use, and which cannot be changed (e.g. those of polymers, processed foodstuffs, engineered composites or metal alloys); called herein as 'chemically produced' characteristics.

The designed characteristics are those that occur during the fabrication and/or amalgamation of different materials to elicit a particular appearance and 'feel' (e.g. colour in plastics and paper, seasoning in foodstuff, aroma in personal care products, coating in glass and ceramic components, surface finishes in cars), and enhance MCPs performance and reliability (e.g. preservatives in foodstuffs, additives in polymers, paint coating in steel components, multi-layered crisp bags and pill