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Environmental and economic life cycle assessment of polymers and polymer matrix composites: a review

C.A. Bernardo[a,c*], Carla L. Simões[a,c], Lígia M. Costa Pinto[b]

[a]Institute of Polymers and Composites/I3N, Minho University, Guimarães, Portugal

[b]NIMA - Department of Economics, Minho University, Campus de Gualtar, 4710-057 Braga, Portugal

[c]PIEP - Innovation in Polymer Engineering, Minho University, 4800-058 Guimarães, Portugal

Abstract

The present work reviews studies on the use of the Life Cycle Assessment (LCA) and Life Cycle Costing (LCC) methodologies for evaluating environmental and economic impacts of polymers and polymer composites. Current publications were reviewed and differences in methods and results discussed. It was concluded that literature results on LCA of polymers and polymer composites are generally consistent, showing that indicators, such as Global Warming Potential (GWP) and Total Energy Use (TEU) are generally lower than those of alternative materials. On the other hand, the economic literature is not so extensive and standard methods still need to be adopted, since different economic analysis methodologies were used in the studies reviewed.

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Keywords: polymers; composites; environment; life cycle assessment; life cycle costing.

1. Introduction

In the last few years, rising plastic consumption worldwide has led to increasing amounts of plastic waste. Approximately 50% of plastics are used for single-use disposable applications, such as packaging and agricultural films. Only 20-25% of plastics are used in long-term infrastructure items, such as pipes, cable coatings and structural materials. The remainder is used for intermediate lifespan consumer applications, such as electronic goods, furniture and vehicles components [1]. Disposal of plastic waste poses significant difficulties, in part due to the fact that plastic products have small service lifespans. In some applications, such as plastic packaging, it can be less than one month [2]. The problem is enhanced by the fact that plastics have low density, and are often used in hollow products (thus, with very little apparent density) and consequently are highly visible in the waste streams. In fact, although the volume weight fraction of plastics in municipal solid waste (MSW) can represent 20-30%, its mass is only 7-9% of the total MSW mass [3]. In some streams, however, like those from the manufacturing and service industries, plastic waste can appear in much higher proportions. Another aggravating factor is that plastics usually are non-biodegradable, and thus tend to remain in nature for a long time. Considering all types of waste, plastic mass fraction has increased from less than 1% in 1960 to 12% in 2006 [4], of which thermoplastic represent 78% [2]. This ubiquitous presence has caused increased public concern about the potential environmental impact of plastics usage. Public concern, on its turn, has induced multiple studies, namely Life Cycle Assessments (LCA), aimed at evaluating the impact of plastic products throughout their Life Cycle. More recently, economic assessments have complemented those studies.

* Corresponding author.

E-mail address: cbernardo@dep.uminho.pt (C.A. Bernardo)

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The aim of the present work is to review recent LCA and Life Cycle Costing (LCC) studies evaluating the environmental and economic impacts of polymers and polymer composites.

2. LCA of polymers and polymer composites

In the pursuit to eliminate all that is not "green", plastics seem to be a natural target. The focus is usually placed on their high energy content and on the ubiquity of their presence as litter in the environment. This bias, however, is seldom supported by quantitative studies found in recent literature. In fact, when studies assessing the environmental and economic impact of alternative materials are made, plastics often present quite positive life cycle (LC) profiles. Table 1 summarizes published LCA studies comparing the environmental performance of polymers and polymer composites, essentially thermoplastic, with other materials with respect to Global Warming Potential (GWP) and Total Energy Use (TEU). These environmental impact categories were selected since almost all studies consider them, due to the current importance of greenhouse gases enhancement. Some studies also report data on other environmental impact categories, such as Ozone layer depletion potential, Photochemical oxidation, Acidification and Eutrophication, but, as this is not a general feature, they were not included in Table 1.

The results show that, in most cases, and contrarily to public perceptions, the use of conventional polymers generates lower (or, at most, similar) GWP and TEU environmental impacts than other materials. It is also evident that reuse, avoiding the consumption of non-renewable resources, minimises the environmental impact in both indicators. The few conflicting data present in Table 1, like those of references [5] and [17], may be explained by factors such as type of use phase, system boundary, type of End of Life (EoL) treatment, and use of recycled materials. For example, a given phase can generate a higher relative impact, even though this may not be true when the whole Life Cycle is considered. Or distinct systems boundaries can lead to substantial differences in the overall environmental impact. Also, recycled polymers are normally preferable to virgin ones, since their use saves resources and reduces emissions. This beneficial effect of polymers is obtained in spite of the energy consumption and potential gaseous emissions that are necessarily associated to the recycling process.

Table 1. LCA studies comparing traditional materials and polymers.

Material	Global Warming Potential	Total Energy Use
W(su); CB(su); P(r) [5][1]	P(r)≈W(su)<CB(su)	P(r)≈W(su)<CB(su)
G; P [6][1]	P<G	P<G
G; P [7][1]	P<G	P<G
PET; rPET [8][2]	rPET<PET	-
S; HDPE [9][3]	-	HDPE<S
CB(su); PP(r) [10][1]	CB(su)<PP(su)	
S; A; PPC [11][3, a]	PPC≈<A<S	-
Current P version; Prototype version	Prototype<Current	-
PE; PP; PVC [13][4]	PE<PP<PVC	-
A; PPC[14][4, c]	PPC<A[d] A<PPC[e]	-
CB(su); PP(r) [15][1]	PP(r)<CB(su)	PP(r)<CB(su)
EPS; CB [16][1]	CB<EPS[d] EPS<CB[e]	-
rPaper; PS [17][1]	rPaper<PS	-

Applications: [1]Packaging; [2]Construction; [3]Automotive; [4]Consumable product.

[a]Clay reinforced virgin PP; [b]Prototype plastic version based on compatible and recyclable polyolefin; [c]PP composite with virgin PP and recycled tyres' rubber granulate; [d]System boundary up to the manufacture stage, "cradle-to-gate" analysis; [e]System boundary up to the EoL stage, "cradle-to-grave" analysis.

Key - A: aluminium; CB: cardboard; EPS: expanded polystyrene; G: glass; HDPE: high density polyethylene; P: plastic; PE: polyethylene; PET: polyethylene terephthalate; PP: polypropylene; PPC: polypropylene composite; PS: polystyrene; PVC: polyvinyl chloride; r: reused; rPaper: recycled paper; rPET: recycled polyethylene terephthalate; S: steel; SS: stainless steel; su: single-use; W: wood

3. LCC of polymers and polymer composites

According to the Society of Environmental Toxicology and Chemistry (SETAC) working group on LCC, there are three different types of LCC [18]: conventional LCC, environmental LCC and societal LCC. An overall vision of this taxonomy is depicted in Figure 1, together with the corresponding economic aspects. Conventional LCC, to a large extent the historic and current practice of many practitioners, including governments and firms, is based on a purely economic evaluation. It considers the costs associated with a product that are born directly by a given actor, but often neglects external costs. Environmental LCC summarizes all costs associated to a product LC that are directly covered by one, or more, of the actors involved in its LC. It includes the externalities that are anticipated to be internalized in the decision-relevant future. Societal LCC uses an expanded macro-economic system and incorporates a larger set of costs,

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