HOW TO DEAL WITH THE END-OF-LIFE OF BIO-BASED PLASTICS IN A LCA: CURRENT CHALLENGES AND PROPOSALS

Antonio Dobon, Anne-Sophie Le Meur, Mercedes Hortal. Packaging, Transport and Logistics Research Center (ITENE), Spain. *Parque Tecnológico, C/ Albert Einstein, 1. 46980 Paterna, Valencia (Spain). E: adobon@itene.com*

Keywords: bio-based plastics, LCA, end-of-life, modeling, uncertainty.

ABSTRACT

Bio-based plastics are gaining market share and forecasts shows that the demand of these materials will rise up to 178% in Europe by 2015. In case of biodegradable bio-based plastics there is an increasing concern about the different end-of-life options, since there are still not specific routes and these materials may affect other end-of-life schemes. Furthermore, discussions on the end-of-life regulations of bio-based plastics in the EU are becoming a matter of interest. Moreover the end-of-life LCA data about most of the bio-based plastics is based on estimations and even unavailable, being a challenge for LCA practitioners. This study explores the current end-of-life routes on a life cycle perspective and provides proposals to ensure a proper modeling for bio-based plastics.

INTRODUCTION

Among bio-based materials, the development of biodegradable packaging materials based on renewable resources has received increasing attention, particularly in EU countries (Davis 2006). This has driven to an increase of bio-based packaging applications (Davis, 2006) especially for single use/disposable applications. In spite of such interest, almost all the environmental impact information on bio-based materials (including bio-based plastics) is concentrated in the production stage although relatively little data about their waste treatment is available (Hermann, 2011) (Madival, 2009). There are many life cycle assessments of bio-based and biodegradable materials where the post-consumer waste treatment phase is deliberately neglected because of a lack of consistent data (Hermann, 2011), even though the end-of-life (EOL) may strongly influence the conclusions (Madival, 2009) (Patel, 2005) (Guo, 2012). One reason is that such materials have not been produced on a large scale yet or if so only for a short time. However, taking decisions with LCA implies a wider point of view and therefore there is a real need to expand the systems to include, or at least to estimate, what would happen with bio-based plastics when introduced in common EOL waste treatments.

METHODS

Main scientific literature has been reviewed, including also grey literature. Several approaches for dealing with the end-of-life were found. For instance, Hermann (2011) developed probably the widest analysis performed to date on the EOL of bio-based materials. The work of Hermann (2011) was partially based on the use of analogies as the best option to create estimated scenarios for the EOL, as he made for starch, PLA, starch/polycaprolactone and PHA. On the other hand, Madival (2009) has suggested the use of generic 100% mixed plastic waste inventory data for the EOL of PLA, whereas surprisingly only incineration, recycling and landfilling were considered and composting was directly omitted due to the lack of data. Furthermore, Madival (2009) has recognized that most of the EOL scenarios in its study considered were hypothetical. On the contrary Khoo (2010) suggests the use of site-dependent impacts of the EOL stage in order to make the results more meaningful. Guo (2013) has tried to overcome such drawbacks by considering meta-data analysis of literature of EOL options combined with lab tests and some industrial data, although his outcomes only applied to starch-PVOH blends derived from maize, potato and wheat. The literature review performed has led us to the conclusion that there is a lack of reliable data related to the EOL of bio-based plastics and several key issues were identified which are discussed below.

RESULTS & DISCUSSION

The influence of the thickness and the limitations for certain EOL waste treatments

When bio-based plastics are considered one should take into account that the thickness of the material influences the behavior of the material in waste treatments with the exception of incineration processes (Hermann, 2011). Therefore, the biodegradability of materials depends on the chemical composition of the materials considered as well as on the final product (Nampoothiri, 2010). Bio-based plastics products have also certain limitations to some kinds of waste-treatment processes. That's the case of recycling, where for biodegadable bio-based plastics the biodegradation process has been triggered during service life or in the waste stream (Davis, 2006). There are some exceptions like the bio-based PE, PET and PP which deliver a plastic material with identical physical and chemical properties to their fossil counterparts, giving an identical EOL behavior (European Bioplastics, 2013) (Shen, 2009). Several positions have been found in the literature in the discussion around if the biodegradable plastics (most of them bio-based) either harm or not the plastics recycling industry. Davis (2006) said that this argument is unfounded, at least in the UK, although clarified that suitable mechanisms for clear and unambiguous labeling of biodegradable packaging together with infrastructure for certification and joint collection of biodegradable packaging with organic waste are necessary. On the other hand Plastics Europe (2012) stresses that "the benefits of biodegradability can only be obtained in appropriate composting facilities". Song (2009) stated that plastics that enter the municipal waste stream may add complications for existing plastic recycling systems.

The limits of biodegradation of bio-based plastics

A key factor when creating EOL LCA scenarios is that not every bio-based plastic can be treated by composting and/or digestion. One common example is PLA, which is only capable to biodegrade under certain industrial composting conditions with temperatures of 60ºC and above (Shah, 2008), being inadequate for home composting (Davis, 2006) (Hermann, 2011). Furthermore, process conditions for composting (temperature, humidity, oxygen, etc.) must be strictly controlled to produce suitable compost (Gironi, 2011). Therefore LCA practitioners should take into account such limitations whenever an EOL scenario is created. Furthermore, bio-based biodegradable plastics are generally unsuitable for landfilling (Davis, 2006). In case landfilling of biodegradable plastics is considered, Häkkinen (2010) suggests assumed that

PLA behaves similarly to lignin, or polyesters such as PET, and does not degrade in well-engineered landfills where there is little moisture or warmth.

Carbon storage, avoided impact and credits

During biological waste treatment, the materials are metabolized, so a part of their embodied carbon is emitted into air and the remainder is stored as compost or digestate (Hermann, 2011). Theoretically long-term carbon sequestration from compost can be calculated by laboratory assays, even though these results are uncertain since the extraction of humic substances from soil is difficult (Hermann, 2011). Indeed, carbon credits can considerably affect the results (Hermann, 2011) (Pawelzik, 2013), but there are significant uncertainties in how they are calculated. Guo (2011, 2012, 2013) has decided to use a carbon counting approach based on carbon stoichiometry. The compost or digestate can replace soil conditioners supporting humus formation (Hermann, 2011). In fact, the common practice is to assume that the compost produced substitute peat or straw, fertilizers as well as act as a way for carbon sequestration in soil (Razza, 2009) (Hermann, 2011). Furthermore, several authors have stated that not all the N in compost is available for plants considering ranges between 10 to 35% (Hansen, 2006) (Hermann, 2011). Therefore, variations due to avoided impacts and credits strongly depend on the methodological choices considered by the LCA practitioner as it was recognized by Madival (2009). In the absence of bio-based plastics specific data for composting, it seems scientifically sound the approach suggested by Hermann (2011) which is based process emissions from existing industrial composting processes of vegetable, fruit and garden waste and material-specific biodegradation levels. However, LCA practitioners should be aware of the large differences about biodegradation rates for some bio-based plastics declared by several authors as well as the variations on the composting technologies which affects mainly to the amount of C as CH_4 (Hermann, 2011).

Table 1. State-of-the art of data sources & assumptions in selected LCA of bio-based plastics.

Author	Area	Bio-based plastic	Industrial composting	Home composting	Landfilling	Inci-neration	Recycling	Anaerobic digestion
(Razza, 2009)**	IT	Mater-Bi	a)					
(Madival, 2009)	US	PLA			b)	b)		
(Häkkinen, 2010)	EU	PLA						
(Leceta, 2013)	EU?	Chitosan						
(Guo, 2011)*	UK	Starch-PVOH blends						
(Guo, 2012)* (Guo, 2013)*	UK	Starch-PVOH blend						
(Khoo, 2010)**	SG	PHA						
(Gironi, 2011)	EU?	Mater-Bi	Not specified					
(Edwards, 2012)***	UK	Starch-polyester			b)	b)		
(Liptow, 2012)	BR+EU	Bio-PE						

Database | Literature | Own calculation | Theoretical calc. | Lab scale results | Ind. scale results | Meta-data analysis | Not specified

*Full EOL LCI available. WRATE database used for infrastructure processes
Partial EOL LCI available / * Litter was also considered

a)Italian I-LCA database
b)Ecoinvent

Uncertainty issues and modeling of the EOL of bio-based plastics

Uncertainty is one of the key issues in every LCA, specifically when comparative assertions are considered. For instance, in case of PLA, the uncertainties regarding biodegradation in a landfill have a substantial impact on the estimates of GHG emissions (Patel, 2005) (Hakkinen, 2010). Furthermore such uncertainty is significantly increased when readers look at the assumptions made by many authors to define the EOL scenarios for the assessment of bio-based plastics. For instance, Miller (2013) considered that the anaerobic digestion of PHVB can be assumed as the same process for cellulose. In some cases (Häkkinen, 2010) (Leceta,

2013) (Gironi, 2011), the origin of the data used to model the EOL has not been specified, thus increasing the uncertainty of the LCIA results (Table 1). Guo (2011) has also pointed out the uncertainties of the use of laboratory trials related to anaerobic digestion.

CONCLUSIONS & RECOMMENDATIONS

The main conclusions & recommendations that can be achieved from our research have been: (a) there is not a general rule to take decisions about the use and EOL of bio-based plastics. Our recommendation is to perform a case-by-case analysis since the LCA results are highly sensitive to the different biodegradability behavior/rates of bio-based plastics as well as to the methodological choices; (b) the development of standard/globally accepted procedures for the LCA of bio-based plastics and other bio-based materials should be very useful to define common criteria for EOL modeling, reducing dissimilar and contradictory conclusions; (c) more knowledge about the real behavior of bio-based and biodegradable materials during final disposal and waste management technologies is needed. In fact, for most bio-based plastics this information is unknown and very few LCI datasets are available to date.
Acknowledgements: The research leading to these results has received funding from the European Union Seventh Framework Programme (FP7/2007- 2013) under grant agreement n° 265096: LCA to go project.

REFERENCES

Davis G., Song J.H. (2006) Ind Crop Prod 23: 147–161
Edwards C, Parker G. (2012) A LCA of oxo-biodegradable, compostable and conventional Bags. Intertek report
European Bioplastics (2013). Benefits of biobased rigid packaging. Fact sheet April 2013.
Guo M, Trzcinski AP, Stuckey DC, Murphy RJ. (2011) Bioresource Technol 102: 11137–11146
Guo M, Murphy RJ (2012) J Polym Environ 20: 976–990
Guo M, Stuckey DC, Murphy RJ (2013) Bioresource Technol 127: 256–266
Häkkinen T., Vares S. (2010) J Clean Prod 18: 1458-1463
Hansen TL, Bhander GS, Christensen TH, Bruun S, Jensen KS. (2006) Waste Manage Res 24(2):153-66.
Hermann B.G., Debeer L., De Wilde B., Blok K., Patel M.K. (2011) Polym Degrad Stabil 96 1159-1171
Gironi F, Piemonte V (2011) Energ Source Part A, 33:21, 1949-1959
Khoo HH, Tan RBH (2010) Int J Life Cycle Assess 15: 338–345
Leceta I, Guerrero P, Cabezudo S, de la Caba K. (2013) J Clean Prod 41: 312-318
Liptow C, Tillman AM (2012) J Ind Ecol 16 (3): 420–435
Madival S., Auras R., Singh SP., Narayan R. (2009) J Clean Prod 17, 1183–1194.
Nampoothiri KM, Nair NR, John RP (2010) Bioresource Technol 101: 8493-8501
Miller SA, Billington SL, Lepech MD. (2013) J Clean Prod 40: 190-198
Patel, M., et al (2005). Biopolymers Online DOI: 10.1002/3527600035.bpola014
Pawelzik P., et al (2013) Resour Conserv Recy 73 211– 228
Plastics Europe (2012). Bioplastics - 2012 update. http://www.plasticseurope.org/ (accessed April 2013)
Razza F, Fieschi M, Degli Innocenti F, Bastioli C (2009) Waste Manage 29: 1424–1433
Shah AA, Hasan F, Hameed A, Ahmed S. (2008) Biotechnol Adv 26, 246-265
Shen L, Haufe J, Patel MK (2009) http://www.epnoe.eu/research/Life-Cycle-Analysis (accessed March 2013)
Song JH, Murphy RJ, Narayan R, Davies GBH (2009) Phil. Trans. R. Soc. B 2009 364