

Land use in LCA of biomaterials

Daniel Garraín, Rosario Vidal, Vicente Franco
GID, Engineering Design Group, Dpt. MEC, Universitat Jaume I Castellón
Av. Sos Baynat s/n, 12071 Castellón (Spain)
garrain@uji.es

Keywords: Land use, LCA, biodiversity, life support functions, biomaterials

ABSTRACT

When assessing biodegradable materials, all of the environmental impacts associated along its life cycle should be taken into account. The replacement of conventional materials by biopolymers entails modifications of environmental impacts which are not always evident or easy to quantify.

Existing Life-Cycle Assessment studies of biopolymers have often neglected the land use impact category. Supposing biodegradable materials become more popular in the near future, it is likely that additional land would have to be transformed into crop fields to obtain raw materials, thus causing land occupation and transformation impacts. There are several methodologies available to assess the impact of land use. In this study, a comparison of these methodologies is carried out.

In order to illustrate the disparity among the existing methods, the impact caused by a one-hectare potato field was assessed. Two areas in Spain possessing different soil characteristics were chosen. These were the Mediterranean forests of the Iberian mountain group and the pastures of the north-western Cantabrian region. Our case study comes to show that no reliable methodologies have yet been developed to assess the impact category of land occupation and transformation, even though this is a crucial impact category given its long-term implications on soil quality.

Introduction

Interest in biodegradable materials has developed as a consequence of increasing social awareness of environmental degradation and the possibilities of reducing it by selecting more environmentally-friendly products.

Some authors [1-4] have remarked that biodegradable materials can be, in some cases, less “ecological” than conventional ones. This is -among other reasons- due to the high degree of optimization of conventional industries; biopolymers obtained from renewable sources are still in an incipient state of development as compared to petroleum-derived plastics. Even though the environmental impact of biopolymers is higher nowadays, they should not be rejected because of this. Instead, further research on their optimization towards their environmental improvement should be conducted [5].

When assessing biodegradable materials, all of the environmental impacts associated along its life cycle -“from cradle to grave”- should be taken into account. The replacement of conventional materials by biopolymers entails modifications of environmental impacts which are not always evident or easy to quantify.

Existing Life-Cycle Assessments performed on biopolymers have often neglected the land use impact category, with exceptions like the study conducted by Müller-Sämman et al. [6], which advocates the development of new indicators related to land demand. Given that the organic fraction of biodegradable products often comes from agricultural waste, several environmental issues concerning the impact of crops arise, namely land occupation and transformation.

There are several methodologies available to assess the impact of land use. In earlier LCAs, land use impacts were related to the area of land used, generally in combination with the time required to produce a certain output. These data were combined with qualifications of the land type changed or under use [7]. This is how the concept of physical land use and its impacts -occupation and transformation- came about. This concept is used as a starting point for including land use impacts in LCA studies.

Subsequent studies have focused on a series of methods to present indicators to measure the decrease of biodiversity and impairment of life support functions due to land use. Among all the methods developed we cite those by Köllner [8-9], Goedkoop & Spriensma [10], Vogtländer et al. [11] and Müller-Wenk [12], for the assessment of land use impacts on biodiversity-; those by Milà i Canals [13] and Cowell & Clift [14], to assess impacts on life support functions-; and those by Mattsson et al. [15], Cowell [16], Lindeijer et al. [17-18] and Weidema & Lindeijer [19], to assess both impacts on biodiversity and life support functions.

On the other hand, some authors [20-21] have developed methods to evaluate the impact of land use within LCAs based on the measurement of an ecosystem’s capacity of dissipating solar exergy.

Other authors have made qualitative comparisons of the methods that take into account biodiversity and life support, like van der Voet [22], and have applied some of them to case studies of construction materials [23], greenhouses [24] or vegetable oil crops [15].

In our study, various data sources were used in an application of some of these methodologies to assess the quality impacts on land use caused by the production of biomaterials.

A widespread use of biopolymers would entail the expansion of land areas dedicated to crops, thus causing land occupation and transformation impacts. In order to illustrate the disparity among the existing methods for assessing the impact on land use, the impact caused by the substitution of a certain type of land for a one-hectare crop (e.g. a potato field) was assessed. Two areas in Spain possessing different soil characteristics were chosen. These were the Mediterranean forests of the Iberian mountain group and the pastures of the north-western Cantabrian region.

The methods selected to assess the aforementioned impacts were those by Köllner [8], Goedkoop & Spriensma [10], Vogtländer et al. [11], Weidema & Lindeijer [19] and Lindeijer [18].

Prior to the application of these methods, some considerations regarding the nomenclature of land types need to be made. In the case of methods by Köllner [9], Goedkoop & Spriensma [10] and Vogtländer et al. [11], the chosen areas were classified according to the list of CORINE Land Cover (CLC) classes (table 1).

Table 1: Correspondence of land types of studied areas in Spain with CLC [25].

Area of Spain	CORINE Land Cover Classes (Code)
Iberian mountain group forest	Broad-leaved forest (3.1.1)
Cantabrian region pastures	Less intensive meadows (2.3.1.2)
Conventional crop fields	Conventional arable (2.2.1.1)

In the method Weidema & Lindeijer [19], the geographical characteristics of the studied areas need to be considered as well, as indicated in table 2.

Table 2: Geographical characteristics of studied areas in Spain [19].

	Cantabrian region	Iberian mountain group	Conventional crop
Type of land	Grassland	Mixed forest	Cultivated and permanent crop
Altitude (m)	0-1000	1000-3000	-
Latitude (°)	approx. 40	approx. 40	-

Land use impacts on biodiversity

For the assessment of the impact on biodiversity, the methods by Köllner [8], Goedkoop & Spriensma [10], Vogtländer et al. [11] and Weidema & Lindeijer [19] were applied. The methodologies that we will apply to include land use in LCA measure the number of vascular plant species to calculate a biodiversity indicator, as these plants are deemed representative of general species diversity. The results of the application of these methods are given in table 3 as the calculated indicator values. The ratio between indicator values for each area is also provided.

Table 3: Results of impact of land use (biodiversity), by methodology.

Indicator	Units	Iberian mountain group	Cantabrian region	Ratio
ΔD_{tr} [8] (Ecological Potential Damage of Transformation)	m ² -year	78333	10000	7,8
EQ _{conv} [10] (Ecosystem Quality of Conversion)	m ² -year	309000	30000	10,3
ΔSRI [11] (Species Richness Indicator)	m ² eq.	1566	200	7,8
I _{occ,bio} [19] (Occupation Impact)	Person-eq.	68	24	2,8

From these results, it can be stated that, for a given change in land use, the impact on biodiversity is greater on the Iberian forests, because they are home to a higher number of vascular plant species. In the first three methods [8, 10, 11], the ratios between the impacts caused when placing a crop field in one area and the other are similar, the impact on Iberian forest being greater by a factor of approximately 8 (figure 1). This is because all three methods share common methodological bases. However, the application of the method by Weidema & Lindeijer [19] yields a considerably different ratio, now being approximately 3. The reason for this difference could be attributable to the use of different data sources, and to the fact that the method uses other variables to assess impact, such as the inherent ecosystem scarcity and ecosystem vulnerability.

Land use impacts on life support functions

To assess the impact on life support functions, the methods by Weidema & Lindeijer [19] and Lindeijer [18] were applied, using various data sources.

Life support functions are those ecological structures and processes that sustain the productivity, adaptability and capacity for renewal of lands, water or the biosphere as a whole. The free net primary production (fNPP) was chosen as a measure of the contribution to life support. This is the amount of biomass (quantity of carbon per area and time) which nature can freely apply for its own development, when human consumption of biomass (NCP) is subtracted from the net produced biomass (NPP), as in forestry and agriculture [18]. For the sake of simplicity, only NPP values were applied to the aforementioned methods. Table 4 shows the results of the application of these methods.

Table 4: Results of impact of land use (life support functions), by methodology.

Indicator	Units	Cantabrian region	Iberian mountain group
I _{occ,prod} [19] (Occupation Impact)	Person-eq.	23	-17
EC _{LS} [18] (Ecosystem Change)	kg C/ year	1150	-650

The results in terms of productivity reflect that soils occupied by potato fields are more productive than forests - as predicted by the authors [19]- in cases where human intervention raises NPP value. This increase in productivity is attributable to the use of fertilizers, irrigation, etc. However, when a pasture is replaced by a potato field, there is a negative impact on productivity. These results are inverted regarding biodiversity. Nevertheless, the results could significantly vary depending on the source of data used for obtaining NPP. Considering the NPP values given by Romano [26], opposite results are obtained (Table 5).

Table 5: Impact on land of one-hectare potato field, by NPP data source

Source of data	$I_{occ,prod}$ [19] (person-eq.)		EC_{LS} [18] (kg C/year)	
	Cantabrian	Iberian mountain	Cantabrian	Iberian mountain
	region	group	region	group
Weidema & Lindeijer [26]	23	-17	1150	-650
Romano ^a [35]	38	66	1881	2538
Romano ^b [35]	-33	-26	-1649	-992

^a NPP data (potential and actual) as extracted from Vitousek et al. [27].

^b NPP data as extracted from Vitousek et al. [27] (potential) and Margalef [28] (actual).

Conclusions

Further development is needed in the methodologies aimed at assessing environmental impact of land use. The results of our case study come to show that no reliable methodologies have yet been developed to assess the impact category of land occupation and transformation, even though this is a crucial impact category given its long-term implications on soil quality.

The *Expert Workshop on Definition of Best Indicators for Biodiversity and Soil Quality for Life Cycle Assessment* [29] concluded that there was no clear consensus on the preference for species [8, 10, 11] versus ecosystem level indicators [19]. It has been shown that the application of both types of methods to the evaluation of equal situations can lead to dissimilar results.

The application of the method by Weidema & Lindeijer [19] yielded confusing results: a change in land use can have greater impact on life support functions in one area, whereas biodiversity could be more significantly damaged if the same change were to take place in a different area. Therefore, further development is needed in the field of indicators that take into account impacts on both biodiversity and life support functions through the application of multicriteria approaches. Furthermore, the disparity currently available data –as illustrated by the example involving NPP values- comes to show that every effort should be made to gather comprehensive, consistent data on land characteristics for the development of such indicators.

An important aspect of the increased use of land is that environmental impact depends on where the change in land use takes place. Thus, it would be necessary to standardise methods for the assessment of land use impacts associated. To that avail, it would be useful to take steps towards identifying land-use indicators at local and regional levels. The results could then be extrapolated to higher levels.

As a final remark, we advocate giving consideration to less frequently used impact categories (land use; but also aesthetic impact, noise, odour, etc.), which can be applied to the environmental assessment of any type of material.

Acknowledgements

This work has been developed as a part of this projects:

- National Environmental Science and Technology Programme of the R&D National Programme 2004-2007 (Ministry of the Environment of Spain): Reference 566/2006/1-2.4. “*Análisis del ciclo de vida de residuos de materiales biodegradables y biocompuestos, como alternativa a los polímeros convencionales (Life cycle assessment of the waste of biodegradable materials and biocomposites, as an alternative to conventional polymers)*”.
- National Means of Transport and Construction Programme of the Scientific Research, Development and Technological Innovation National Programme 2004-2007 (Ministry of Public Works of Spain): Order 2251/2006. “*Desarrollo de categorías de impacto aplicadas a materiales cerámicos usando la metodología del análisis de ciclo de vida (Development of impact categories applied to ceramic materials using the life cycle assessment)*”.

References

- [1] Gärtner S.O., Reinhardt G.A. Biobased products and their environmental impacts with respect to conventional products. In Proceedings of the 2nd World Conference on Biomass for Energy, Industry and Climate Protection, Rome, 2004.
- [2] Braschkat J., Gärtner S.O., Reinhardt G.A. Environmental impacts of bio-based products in comparison with conventional products. *Agroindustria*, Ed. Ranalli, Bologna, 2004, Vol.2, pp. 53-59.
- [3] Patel M., Bastioli C., Marini L., Würdinger G.E. Life-Cycle Assessment of Bio-Based Polymers and Natural Fibres. *Encyclopedia "Biopolymers"*, 2003 Vol.10, pp. 409-452.
- [4] Scott G. Green polymers. *Polymer degradation and stability*, 2000, 68, pp. 1-7.
- [5] Känzig J., Anex R., Jolliet O. Conference report: International workshop on assessing the sustainability of bio-based products. *International Journal of Life-Cycle Assessment*, 2003, 8 (5), pp. 313-314.
- [6] Müller-Sämann K.M., Reinhardt G.A., Vetter R., Gärtner S.O. *Nachwachsende Rohstoffe in Baden-Württemberg: Identifizierung Vorteilhafter Produktlinien zur stofflichen Nutzung unter Besonderer Berücksichtigung Umweltgerechter Anbauverfahren. Projektabschluss-bericht Forschungszentrum Karlsruhe IfUL Müllheim*, 2003.
- [7] Lindeijer E. Review of land use methodologies. *Journal of Cleaner Production* 8 (2000), pp.273-281.
- [8] Köllner T. Land use in product life cycles and its consequences for ecosystem quality. Dissertation PhD 2519, March 2001, Universität St. Gallen, Switzerland, 2001.
- [9] Köllner T. Species-pool effect potentials (SPEP) as a yardstick to evaluate land-use impacts on biodiversity. *Journal of Cleaner Production*, 8 (2000), pp.293-311.
- [10] Goedkoop M., Spriensma R. The Eco-indicator 99. A damage oriented method for Life Cycle Impact Assessment. Methodology report, Third Edition, PRé Consultants, Amersfoort, The Netherlands, June 2001.
- [11] Vogtländer J.G., Lindeijer E., Witte J.P.M., Hendriks C. Characterizing the change of land-use based on flora: application for EIA and LCA. *Journal of Cleaner Production*, 12 (2004), pp.47-57.
- [12] Müller-Wenk R. Land use - The main threat to species. How to include Land use in LCA. *IWÖ-Diskussionbeitrag n.64, IWÖ, Universität St. Gallen, Switzerland*, 1998.
- [13] Milà i Canals L. Contributions to LCA methodology for agricultural systems. Site-dependency and soil degradation impact assessment. PhD dissertation, Universitat Autònoma de Barcelona, 2003.
- [14] Cowell S.J., Clift R. A methodology for assessing soil quantity and quality in life cycle assessment. *Journal of Cleaner Production*, 8 (2000), pp. 321-331.
- [15] Mattsson B., Cedeberg C., Blix L. Agricultural land use in life cycle assessment (LCA): case studies of three vegetables oil crops. *Journal of Cleaner production*, 8 (2000), pp. 283-292.
- [16] Cowell S.J. Environmental Life Cycle Assessment of agricultural systems: integration into decision making. PhD dissertation, Centre of Environmental Strategy, University of Surrey, Guilford, UK, 1998.
- [17] Lindeijer E., van Kampen M., Fraanje P.J., van Gooben H.F., Nabuurs G.J., Schouwenberg E.P.A.G., Prins A.H., Dankers N., Leopold M.F. Biodiversity and land use indicators for land use impacts in LCA. Ministerie V&W. Publicatiereeks Grondstoffen 1998/07, rapport n. W-DWW-98-059, 1998.
- [18] Lindeijer E. Biodiversity and life support impacts of land use in LCA. *Journal of Cleaner Production*, 8 (2000), pp. 313-319.
- [19] Weidema B., Lindeijer E. Physical impacts of land use in product life cycle assessment. Final report of the EURENVIRON-LCAGAPS sub-project on land use. Department of Manufacturing Engineering and Management, Technical University of Denmark, 2001.
- [20] Muys B., García Quijano J. A new method for Land Use Impact Assessment in LCA based on the ecosystem exergy concept. Internal report, Laboratory for Forest, Nature and Landscape Research, KULeuven, 2002.
- [21] Wagendorp T., Gulinck H., Coppin P., Muys B. Land use impact evaluation in life cycle assessment based on ecosystem thermodynamics. *Energy*, 31 (2006), pp. 112-125.
- [22] van der Voet E. Land use in LCA. CML-SSP Working Paper, Centre of Environmental Science, Leiden University, The Netherlands, 2001.
- [23] Lindeijer E., Kok I., Eggels P., Alferts A. Improving and testing a land use methodology in LCA. Including case-studies on bricks, concrete and wood. Ed: Dutch Ministry of Transport, Public Works

- and Water Management (RWS DWW), 2002.
- [24] Antón A., Castells F., Montero J.I. Land use indicators in life cycle assessment. Case study: The environmental impact of Mediterranean greenhouses. *Journal of Cleaner Production*, 15 (2007), pp. 432-438.
- [25] Available on: <http://terrestrial.eionet.europa.eu/CLC2000/classes>. (Feb. 2007).
- [26] Romano D. Recursos basados en la fotosíntesis. Curso Ecología y Globalización: Flujos monetarios, de energía y de materiales, Sustentabilidad y Globalización. J. Riechmann and J. Nieto, Ed. Germanía, Alzira, Valencia, Spain, 2003.
- [27] Vitousek P.M., Ehrlich P.R., Ehrlich A.H., Matson P.A. Human appropriation of the products of photosynthesis. *Bioscience*, Vol.36, n.6, 1986, pp. 368-373.
- [28] Margalef R. Ecología. ISBN 84-282-0405-5, Ed. Omega, 1998.
- [29] Milà i Canals L., Basson L., Clift R. Müller-Wenk R., Bauer C., Hansen Y., Brandao M. Expert Workshop on Definition of Best Indicators for Biodiversity and Soil Quality for Life Cycle Assessment (LCA). CES Working Paper 02/06, Centre for Environmental Strategy, University of Surrey, UK, ISSN: 1464-8083, June 2006.