STUDY OF THE INCLUSION OF LIFE CYCLE ASSESSMENT IMPACT CATEGORIES IN ECOLOGICAL FOOTPRINT CALCULATION

Vanesa Lo Iacono Ferreira

Juan IgnacioTorregrosa López

Jaime Lora García

María José Bastante-Ceca

Salvador F. Capuz-Rizo

Universitat Politècnica de València

Abstract

The Ecological Footprint (EF) has been compared to a simplified version of a Life Cycle Assessment (LCA) (Finkbeiner, 2009) (Weideman et al., 2008). This simplification allows a simpler calculation method and a more intuitive result, at the expense of rigor in the calculation. This loss of rigor has been criticized by many experts. To improve these shortcomings, EF could pick up either in the calculation of productive land needed for the activity, either by calculating the land required to absorb the environmental impact, the effect of inclusion of the different impact categories of GWP. In this paper, the way of including others impact categories of LCA in EF calculation will be study, especially its influence on:
The calculation of the productive footprint
The calculation of land area needed to absorb global impact activity.

Keywords: *Life Cycle Assessment; Ecological Footprint; Resource category; Ecosystem quality*

Resumen

La Huella Ecológica (HE) ha sido comparada con una versión simplificada de un Análisis del Ciclo de Vida (ACV) (Finkbeiner M. , 2009) (Weideman et al., 2008). Esta simplificación permite disponer de una metodología de cálculo más simple y un resultado intuitivo, a costa de perder rigor en el cálculo. Esta pérdida de rigor ha sido muy criticada por diversos expertos. Con objeto de mejorar esas deficiencias, la HE podría recoger, bien en el cálculo del terreno productivo necesario para realizar la actividad, bien mediante el cálculo del terreno necesario para absorber el impacto ambiental, el efecto de la inclusión de otras categorías de impacto diferentes de GWP. En esta comunicación se analizará de qué manera se podrían traducir otras categorías de impacto propias del ACV en el cálculo de la HE, en especial su incidencia sobre:

. El cálculo de la huella productiva.

. El cálculo de la superficie de terreno necesario para asimilar el impacto global de la actividad.

Palabras clave: Análisis de Ciclo de Vida; Huella Ecológica; Categoría de recursos; Calidad del ecosistema

1. Introduction

LCA is a high-level mechanism, strongly based, that helps humanity understand and analyses products and activity impacts for health and environment.

To consider EF as a simplified version of LCA (Finkbeiner, 2009) (Weideman et al., 2008) benefit interpretation of LCA results. Although rigor might be lost, understandable and measurable are the two essential characteristics of EF. Including LCA categories in EF analyses can improve rigor results and enrich this instructive indicator.

To analyse how LCA impact categories influence EF, a review of each tool is made.

1.1 Life Cycle Assessment (LCA)

As is defined in UNE-EN ISO 14040 (AENOR, 2006), LCA is a technic developed to evaluate impacts associated to a product. Four objectives can be distinguished in LCA application:

Identify opportunities to improve productive cycle of the product.

Detect as much information as possible to assist in decision making.

Select pertinent environmental indicators and it measure technics.

Produce marketing.

LCA goal is to analysed potential environmental impacts and environmental aspects along the entire life cycle of the product. A material and energy flow analysis has to be made.

Four phases are needed to define LCA methodology, although they are closely related as can be seen in

Figure 1.

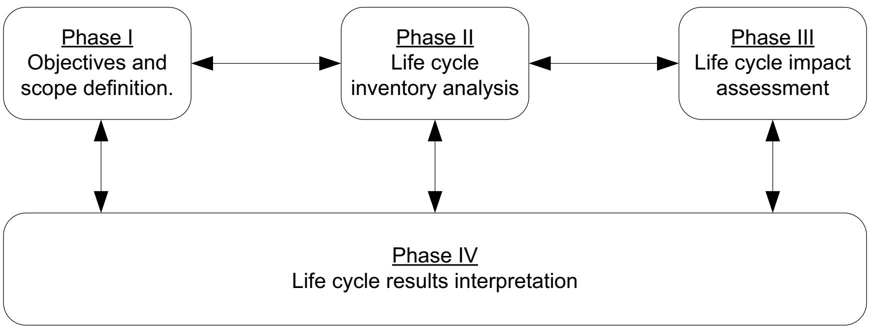
Phase I: Objectives and scope definition.

Phase II: Life cycle inventory analysis (LCI).

Phase III: Life cycle impact assessment (LCIA).

Phase IV: Life cycle results interpretation.

Figure 1: LCA phases



Requirements and guidelines for LCA analysis are defined by standard (UNE-EN ISO 14044, 2006).

Phase I, objectives and scope definition, allows defining information and specifications required for LCA study.

Environmental effects generated by the product are analysed in LCI, phase II. All environmental loads and effects generated by the activity or product analysed must be take into account. The amount of substances, radiation, noises or vibrations emitted to or removed from the surroundings must be considered. Parameters identify must be quantifiable. Raw materials, energy consumption, air emissions, waste, water emissions, etc. can be included. As said before, a material flow analyses is essential to perform phase II.

Completed LCI, LCIA can be executed, the quantification of impacts associated to each aspect defined at phase II. Different kind of impacts might be taken into account, but there is no standard that rules how to establish impact categories and its indicators, just suggestions and examples (Udo de Haes et al., 1999).

Different methodologies have been design to carry on with LCIA and can be grouped by Weighting methods – single index approaches – and Damage oriented method.

Single index approaches can be in three lines: monetary methods, sustainability and target methods and social and expert method; Eco-indicator 95 is an example.

Eco-indicator 99 (Goedkoop & Spriensma, 2001), a damage oriented method is analysed in order to carry out the goal of this paper. Descriptions of other methodologies can be found in Sonnemman (2004).

A critical review must be included in LCA report, as well as the relationship between different phases and the terms of use of value judgments and optional elements. Limitations of study must be described over the critical review. Non indications are given in standard procedures about measurement units for LCA.

1.2 Ecological Footprint (EF)

EF was defined by Wackernagel & Rees (Wackernagel & Rees, 1996) as "the area of ecologically productive land needed to produce the resources used and assimilate the waste produce by a given population with a specific lifestyle indefinitely". Main goal of it development was to evaluate how dependent is the objective analysed on resources and territory.

Global hectares (gha) are used to measure EF, the average bioproductivity of productive world hectares.

EF methodology, design by Wackernagel & Rees (Wackernagel et al., 2010), considerate 6 different categories or items:

- Carbon Footprint
- Built-up land
- Forest land
- Cropland
- Grazing land
- Fishing grounds

Carbon Footprint (CF) evaluates greenhouse gas emissions (GHG) as equivalent CO_2 emissions by the activity or organization analysed, although exact reach depend on factor. Energy used emissions within the process are considered.

Using global average absorption factor, emissions are converted to land needed to absorb them. Standard PAS 2050 (British Standard Institute, 2008) specify how to assess life cycle GHG of goods and services.

Built-up land, Forest land, Cropland, Grazing land and Fishing grounds represents land needed, Productive Footprint (PF), to obtain necessary resources to carry out with the activity of the organization evaluated.

Results are obtained in hectares; a unit easily interpreted as the land occupied by a football camp: a hectare.

Sustainability degree can be evaluated comparing land on property by the organization with EF. Although conclusions has to be taken with care, considering activities performed by the organization.

Improve sustainability is main objectives when EF is analysed. Process and sub-process most relevant for EF are distinguished and weak and strong points are established for the sake of reducing EF and it components. Even though neutralization has to be last option, neutralization mechanism are developed and standardized; standard PAS 2060 (British Standard Institute, 2010) specify how to neutralize impact associated to CF.

2. Analysis

Although LCA was designed for product analysis, nowadays is applied also for activity analyses.

As seen before, categories identify in LCA analyses depend on LCIA definition and the methodology used in it. For this study Eco-indicator 99 (Goedkoop & Spriensma, 2001)is used as LCIA tool.

Eco-indicator 99 distinguishes three main categories that contained 11 different aspects as shown in Table 1.

Table 1: Eco-indicator 99 structure. (Goedkoop & Spriensma, 2001)

Category	Aspects
Mineral and fossil resources	Mineral
	Fossil
Ecosystem quality	Ecotoxicity
	Eutrophication
	Acidification
	Land use
Human Health	Climate change
	Ozone layer depletion
	Carcinogenesis
	Ionising radiation
	Respiratory effects

Table 2 summarize an analysis of each Eco-indicator 99 aspect and it consideration in EF traditional methodology conducted by authors of this paper. EF aspect is related with an Eco-indicator 99 aspect.

Those Eco-indicator 99 aspects that are included, in a certain way, in traditional EF methodology are identified with Wackernagel & Rees reference.

- In grey, Eco-indicator 99 aspects that are not included but exists studies that gives a clue to introduce them, or an alternative methodologies to evaluate them in an EF compatible way. References are assigned.
- With an X, aspects that have no sense in EF assessment.
- In white, relations that are no needed.

A LCA Human Health category aspect is represented in EF, Climate Change. Indeed, a valid alternative to evaluate CF is by LCA Climate Change category. Ozone layer depletion, carcinogenesis, ionising radiation and respiratory effects are not contemplated in EF.

Land use, an aspect of Ecosystem quality is represented by Built-up land, Forest land, cropland, Grazing land and Fishing ground EF aspects.

Ecotoxicity, Eutrophication or Acidification are not considered categories in current EF methodology.

Fossil impact is also partial considered, by the fraction of fossil fuels that are involved in energy use inside CF calculation.

No mineral impact are considered in EF, but other resources as cropland, forest, grazing land and fishing grounds needed to perform activity organization are considered as part of PF.

Table 2: Summary Eco-indicator 99 EF relation

Aspects			Ecological Footprint					
			Built-up land	Forest land	Cropland	Grazing land	Fishing ground	Carbon footprint
Life Cycle Assessment	**Resources**	**Mineral**	Nguyen methodology (Nguyen et al, 2005)					
		Fossil	Nguyen methodology (Nguyen et al, 2005)					
	Ecosystem quality	**Ecotoxicity**		Natural attenuation analysis (Röling & van Verseveld, 2002) (Jim & Chen, 2008)				
		Eutrophication		Natural attenuation analysis (Röling & van Verseveld, 2002) (Jim & Chen, 2008)				
		Acidification		Natural attenuation analysis (Röling & van Verseveld, 2002) (Jim & Chen, 2008)				
		Land use	EF traditional methodology (Wackernagel & Rees, 1996)					
	Human health	**Climate change**						EF traditional methodology (Wackernagel & Rees, 1996)
		Ozone layer depletion	X	X	X	X	X	X
		Carcinogenesis	X	X	X	X	X	X
		Ionising radiation	X	X	X	X	X	X
		Respiratory effects	X	X	X	X	X	X

2.1 Including Resource category: Minerals and Fossil

Eco-indicator 99 resource category emphasizes impact in quality of ores and fossil material sources, taking into account long-term trends of lowering resource quality. Proposed methodology assumes that effort to extract remaining resources increases when resource quality is reduced. Depending if damage to mineral or to fossil is being analysed, concentration and effort to extract varies it relevance. In case of mineral source, concentration is the most relevant parameter; reducing concentration implicates a grate increase in effort to extract. However, for fossil fuels, concentration is not considered significant as the effort needed to extract the resource.

Weak and strong points of Eco-indicator 99 method proposal are mentioned by its authors (Goedkoop & Spriensma, 2001) (see a summary at Table 3). Model establishes de decrease of concentration as a result of the extraction.

Table 3: Weak and strong points of Eco-indicator 99

Weak points	There will be no sudden and discontinuous changes in the gradual decrease of resource quality. All mineral resource is considered to be of equal importance to mankind. No substitution of mineral by another compound is taken into account.	**Strong points**	*Model is not directly dependent on estimates of future annual consumption.* The expected increase in the effort to extract resources seems to reflect a real concern of mankind.

Surplus Energy is the unit applied to measure resource damage by this methodology. Surplus energy represents the difference between energy needed to extract a resource in the present and energy that will be needed to extract it in the future, assuming a possible link between depletion of abiotic resources and Human Health category (Nguyen et al, 2005). This attribution does not represent a problem for LCA but can introduce more laxity into EF.

Nguyen (2005) propose an alternative methodology to quantify abiotic resources as to include it in EF analysis, *exergy loss* parameter ΔE_x. Exergy evolves as world entropy increased, is not conserved as mass or energy and does not depend on Human health or eco-system quality directly. Math development of this parameter can be seen in Nguyen's paper.

Exergy loss considered mining, milling and smelting process of ore. Nguyen provides complete equations for analysis and a study of exergy loss for seven materials in a period of 50 years from now on (Table 4).

Table 4: Exergy loss values according to Nguyen

Material	ΔE_x **[MJ /ton]**	**Abiotic factor (Af) [gha/ton]**
Aluminium	3.94E+03	2.12
Chromium	2.73E+02	0.15
Copper	1.65E+05	88.72
Iron	2.88E+01	0.02
Molybdenum	4.26E+04	22.98
Nickel	3.43E+04	18.51
Zinc	3.19E+03	1.72

When converting exergy loss in gha units, temporal period has to be taken into account; abiotic factor analysis presented in Table 4 are evaluated for 50 years and was estimated using the exergy loss of the material and the vegetation area needed to absorbed equivalent solar exergy. Equation 1 express Required Abiotic Area (AA_R) in gha, where Af_i represents de Abiotic factor for (i) material and M_i quantity of M material consumption.

Equation 1

$$AA_R = \sum_i^n Af_i \cdot M_i$$

A linear relationship between traditional methods was found by Nguyen. Equation 2 represents the relationship with

Table 5 statistic values and Table 6 properties. Equation 2 application has to be meditated considering is a regression of countries EF values.

Equation 2

$$EF_{Nguyen} = 0.79 \cdot EF_{traditional} + 0.25$$

Table 5: Statistic values for Equation 2

R	0.977
R-sqr	0.955
Standard Error of Estimate	1.261

Table 6: Properties of Equation 2

	y_O	a
Coefficient	0.2515	0.7923
t	0.441	8.494
P	0.6820	0.0011

Although this methodology is developed for traditional EF goals, countries, it can be applied to every kind of organization or product knowing it material consumption.

2.2 Introducing Ecosystem quality: Ecotoxicity, Eutrophication and Acidification

Processes as dilution, dispersion, ion exchange, sorption, transformation and degradation are included in Natural Attenuation concept (Röling & van Verseveld, 2002). Forest, water mass, soil and all natural structure can assimilate, depending on its characteristics, pollutants and balance ecotoxicity, eutrophication and acidification process.

Although no specific investigation reports has been found about land and type of land required to assimilate those impacts, some researcher has already provide knowledge to address conclusive investigations about this aspects.

Röling & van Verseveld (2002) evaluate the capacity for intrinsic bioremediation of subsurface were microorganisms can attenuate pollutants as organic molecules metals, and inorganic nitrogen compounds based on Subsurface Specimen Banking concept. An insight in the natural attenuation of many compounds in a wide variety of subsurface geochemical settings wants to be given but, as it authors express, current knowledge of natural attenuation has to be improved. However, bases and methodologies for research are developed.

Ecosystem services assessments can contribute to ecosystem quality evaluation by natural attenuation concept (Jim & Chen, 2008). This parameter can be evaluated in area units to be included in EF assessment. Jim & Chen (2008) contribute to this cause by investigation urban trees capacity to remove air pollutant. SO_2, NO_x, and Total Suspended Particulates (TSP) are considered as main pollutants in under study region Guangzhou in China.

Parameters and methodology considered to quantify air pollutant removal can be seen in Equation 3.

Equation 3

$$F = \sum_i Vd_i \cdot C_i \cdot A \cdot T$$

Where F is the amount of air pollutants (i) removed by urban trees, Vd_i [$cm^/s$] represents deposition velocity, C_i [g/cm^3] is the concentration of air pollutant I, A [cm^2] is de tree cover in under study region and T [s] is time period considered.

Different situations as emissions of volatile organic compounds, transfer process, flower seasons, dry and wet season where included in Jim & Chen (Jim & Chen, 2008) analysis.

Removals rates obtain by Jim & Chen (2008) are presented in Table 7.

Table 7. Removal rates of air pollutants by land use according to Jim & Chen for Guangzhou city in China.

Land use	**SO_2 removal rate [kg/ha.year]**	**NO_x removal rate [kg/ha.year]**	**TSP removal rate [kg/ha.year]**	**Total removal rate [kg/ha.year]**
Recreational	23.87	24.29	88.79	136.90
Institutional	28.13	24.89	115.18	168.21
Residential	30.55	25.30	99.31	155.16
Transportation	21.18	28.86	110.50	160.55
Industrial	32.74	28.90	132.78	194.42

2.3 Land use consideration

Although land use is included in EF traditional methodology, Lenzen & Murray (Lenzen & Murray, 2001) (Lenzen et al., 2006) make a contribution that deserves to be considered. Deserts and ice caps are included in land use assessment by evaluating its usefulness to area productivity when regions are EF object. In particular, arid and semi-arid lands are included in Australian EF assessment.

3. Conclusions

In opinion of the authors, several categories of Ecoindicator 99 can be transformed into land needed to produce the resources used and assimilate the waste produce by a given population with a specific lifestyle indefinitely:

- Abiotic resources can be transformed into gha through the concept of exergy loss.
- Natural attenuation capacity of the ecosystems could be consider in order to estimate the gha of ecosystems necessary to absorb impacts related to Ecotoxiciy, Eutrophication and Acidification.

Methodologies analysed has specific mathematical method that contributes on rigor to EF. Uncertainty analyses can be performed over these methodologies.

Including Resource and Ecosystem quality LCA categories enrich EF methodology with rigor and comparative capacities between understudy organizations.

Developing methodologies to include Resource and Ecosystem quality categories gives EF indicator the capacity to include quality and biodiversity concepts besides actual view focus on production consumer goods. Whereas, the possibility of evaluates the loss of land that provokes acidification, etherification and ecotoxicity.

Further studies are necessary to evaluate quantitative influence of these new categories on EF assessment. Nowadays, authors are analysing this influence in the EF assessment in Universitat Politècnica de València for the years 2009 and 2010.

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