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A REVIEW OF LIFE CYCLE ASSESSMENT: AGROPRODUCTS MODELING

REVISIÓN SOBRE LA EVALUACIÓN DEL CICLO DE VIDA: MODELAMIENTO EN AGROPRODUCTOS

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Resumen

El Análisis de Ciclo de Vida es una metodología ampliamente usada con el fin de evaluar los impactos ambientales y sociales asociados a un ciclo productivo completo, en una visión "de la Cuna a la Tumba" o de una nueva "de la Cuna a la Cuna" la cual toma en cuenta también el reciclaje de productos y subproductos, intentando tener en cuenta cada uno de los componentes de estos impactos, o al menos casi todos. En particular, esta revisión bibliográfica considera que; las cadenas agro-productiva tienen componentes y consideraciones específicas, que deben ser tomados en cuenta en el proceso de evaluación de ciclos de vida. Estas consideraciones han sido comentadas en el texto y algunas consideraciones de cálculo fueron citadas.

Palabras claves: ACV, producción agrícola, impactos sociales impactos ambientales.

Abstract

Life Cycle Assessment is a trendsetter methodology in order to assess environmental and social impacts associated to an entire productive cycle in a vision "Cradle to Grave" or in a further vision "Cradle to Cradle" that considers the reuse of product wastes and side products, trying to take in count every single component of these impacts or almost all of them. In particular, this review considers that agro-productive chains have unique components and considerations, which need to be counted in the assessment process. These have been commented in the text and some calculation considerations were cited.

Keywords: LCA, agro-production, social impacts, environmental impacts.

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1 Introduction

Life cycle assessments (LCA), until now, have generally been used to analyze the effects that a product, process or services will have on the environment. Results of an LCA study will let companies and people in general know which aspects of their production are efficient, and where they can improve efficiency to reduce environmental and social impacts. All stages in the life cycle of the product are considered in a LCA, from the mining and extraction of its raw materials, to the shipping, right on to the landfill. Data are not only considered for the initial product, but also for the full life cycles of other materials that are used in the making of the product. Social (S-LCA) and socio-economic life cycle assessments add extra dimensions of impact analysis, valuable information for those who seek to produce or purchase responsibly (Dreyer *et al.*, 2010; Unep Setac Life Cycle Initiative, 2009).

One of the complexities of LCA is that it has been applied to different types of decisions, ranging from single products to large scale policy decisions such as whether or not to build a particular power plant instead a biorefinery (Gasol, 2009; Menichetti and Otto, 2009). Although LCA was developed for single products, in recent years there has been a distinct shift in applying it to such larger scale decision contexts (Menichetti and Otto, 2009; Ramachandran *et al.*, 2007). Part of the reason for this shift has been the argument that since LCA is useful for determining the environmental impacts of a product, surely it is useful for determining the environmental impacts of a "product" like a power plant.

This shift in perspective from "conventional" to "unconventional" products has been described as two separate types of LCA:

i. Attributional life cycle assessment (focuses on describing the environmentally relevant physical flows to and from a product or process emit).

ii. Consequential life cycle assessment (describes how relevant environmental flows will change in response to possible decisions).

Ultimately, the differences between attributional and consequential LCA are the result of the choices made in the aim and scope definition of steps of the LCA process (Brander *et al.*, 2008; European Commission Institute for Environment and Sustainability, 2010; Thomassen *et al.*, 2008).

In consequential LCA, the system boundaries are defined to include the activities contributing to the environmental consequence of the change–regardless of whether or not these changes are within or outside of the cradle-to-grave system being investigated (D'Avino *et al.*, 2015; Schmidt, 2008). As a result, the process of system expansion (to avoid or deal with the allocation problem in multi-product systems) is an inherent part of consequential LCA studies. In consequence, consequential LCA includes additional economic concepts like marginal production costs, elasticity of supply and demand, dynamic models (instead of the linear and static models of traditional LCA), etc.(European Environment Agency, 2012; Gasol, 2009). It is typically more conceptually complex and the results obtained are highly sensitive to assumptions made. The failure to identify inadequate implicit assumptions will led to a poor analysis.

While attributional LCA uses average data (*i.e.*, data representing the average environmental burden for producing a unit of the good or service in the system), consequential LCA uses marginal data representing the effects of a small change in the output of goods and/or services. Focusing on marginal data narrows the set of data required, since indicators that do not change because of the intervention do not have to be known–which is not the case in attributional LCA (Brander *et al.*, 2008; Schmidt, 2008; Thomassen *et al.*, 2008). Instead, the challenge in consequential LCA is thoroughly justifying that particular indicators will not be impacted and thus can be ignored in the analysis.

Taking an example in order to explain properly LCA. Let us imagine that "XY Inc"–a hypothetical retailer–has requested a LCA of their latest product: a package of colorless shirts. XY Inc. wants to know how this new item will affect its environmental footprint (E-LCA) as a corporation as well as what sort of improvements they can make to the production of the shirts that will reduce emissions and other harmful environmental outputs. Furthermore, "XY Inc" wants to know what sort of social and socio-economic effects these shirts will have on their workers and on the communities where they have shirt factories. As an already established company, XY is legally held to minimum benchmarks for things like workers' rights but they want to take their social responsibility further and need guidance on how to proceed.

The label "Fair Trade" is limited in scope and ignores huge sections of the life cycle reducing its feasibility (Jørgensen, 2013; Weidema, 2005). While the making of shirts may be ethical, the company wants to know if this can be true for "Cradle to Grave" or further "Cradle to Cradle" analysis of production (Braungart *et al.*, 2007), including phases like shipping, disposal and so on. These specifications and questions will help the analysts focus on finding data relevant to the goals of "XY Inc". They will work in cooperation with the analysts to determine what sort of data will be required to do the study. What kind of emissions to the air, water, or land will the study take into account? The list of chemicals released into nature during the production of the shirts, some more potent and detrimental than others. Special attention will probably be paid to outputs like carbon dioxide, nitrogen dioxides and other greenhouse gases. Furthermore, the analysts will inform the stakeholders on which phases of the life cycle of the product might have the greatest share of worker hours and moreover, for which phases of the life cycle the social impacts may be the most important, using additional data (Dreyer *et al.*, 2010; Grießhammer *et al.*, 2006).

The analyst will consider all the data found on the shirts, taking into account each and every piece and process involved in the making of the product, as much as can be acquired. The impacts of the gathering and shipment of raw cotton to a textile company, of refining that cotton into a fabric that can be seen into shirts, the dyeing of the fabric, the stitching, the printing and addition of those uncomfortable tags that go on the necks of the shirts that say "XY Inc" in little letters-each part is factored in. However, this is just the first step. Analysts then need to consider the impacts of the life cycles of the dyes, threads, and nylon label tags up until the point at which they enter the life cycle of the shirt itself. By the end of the study, analysts will have data that can tell them exactly how much carbon dioxide is produced for each shirt they make. As much as they can, the analysts will also try to find the information on the location where each of the inputs were made and how they were transported. But that is just the easy part. Environmental impacts are much more easily standardized and quantified tan social and socio-economic ones, for obvious reasons (Hauschild *et al.*, 2008; Jørgensen, 2013; Unep Setac Life Cycle Initiative, 2009). Emissions, for example, can be readily measured and given numerical data that can be used over and over. However, Social Life Cycle Assessments (S-LCA) are surely as important as environmental ones (Menichetti and Otto, 2009; Unep Setac Life Cycle Initiative, 2009; Weidema, 2005). That being said, how can we proceed to conduct an S-LCA? How do we collect the data? How can we begin to assess and measure the social effects of a T-shirt? How do we define a socially responsible company or practice? How do we bring the results for every phases of the life cycle together? These questions must be answered.

One of the most important issues with S-LCA is keeping consistency among the standards between studies. Even, if its standards can eventually become more or less similar in criteria, differences among studies will always occur. Generally, practitioners of S-LCA will need to incorporate a large share of qualitative data, since numeric information will be less capable of addressing the issues at hand. When numeric data is useful additional data will still be needed to address its meaning: compliance with minimum wage laws does not always mean the wages are livable. Often, data may have to be collected on the spot, since databases for specific social and socio-economic impacts are at a minimum. As one might guess, the current limitations of S-LCA are many.

2 Enviromental life cycle assessment

The International Organization for Standardization identifies four phases for conducting a LCA, those are showed in Figure 1 (International Organization for Standardization, 2007; Weidema, 2005):

- Goal and Scope (functional unit), where the reasons for carrying out the study and its intended use are described and where details are given on the approach taken to conduct the study.
- Life Cycle Inventory (LCI), where the product system and its constituent unit processes are described, and exchanges between the product system and the environment are compiled and evaluated. These are called elementary flows; include inputs from nature (*e.g.* extracted raw materials, land used, raw materials and so on) and outputs to nature (*e.g.* emissions to air, water and soil). The amounts of elementary flows exchanged by the product

system and the environment are in reference to one functional unit, as defined in the Goal and Scope phase.

- Life Cycle Impact Assessment (LCIA), where the magnitude and significance of environmental impacts associated with the elementary flows compiled. This is done by associating the life cycle inventory results with environmental impact categories and category indicators. LCI results, other than elementary flows, are identified and their relationship to corresponding category indicators is determined. LCIA has a number of mandatory elements: selection of impact categories, category indicators, and characterization models as well as assignment of the LCI results to the various impact categories (classification) and calculation of category indicator results (characterization).

- Life Cycle Interpretation, where the findings of the previous two phases are combined with the defined goal and scope in order to reach conclusions or recommendations. It is important to note that Environmental-LCA provides an assessment of potential impacts based on a chosen functional unit.

3 Social life cycle assessment

In short, S-LCA can be understood as a methodology for providing decision support about the social impacts related to cradle to grave point of view. Including, potentially, the entire product life cycle in the assessment, the S-LCA has a more holistic perspective on the impacts of products than other social assessment tools. This more holistic assessment among others allows the decision maker to compare decision alternatives with regard to a more complete account of the social impacts of products than other. For providing this holistic assessment of social impacts of a product, S-LCA needs to include an

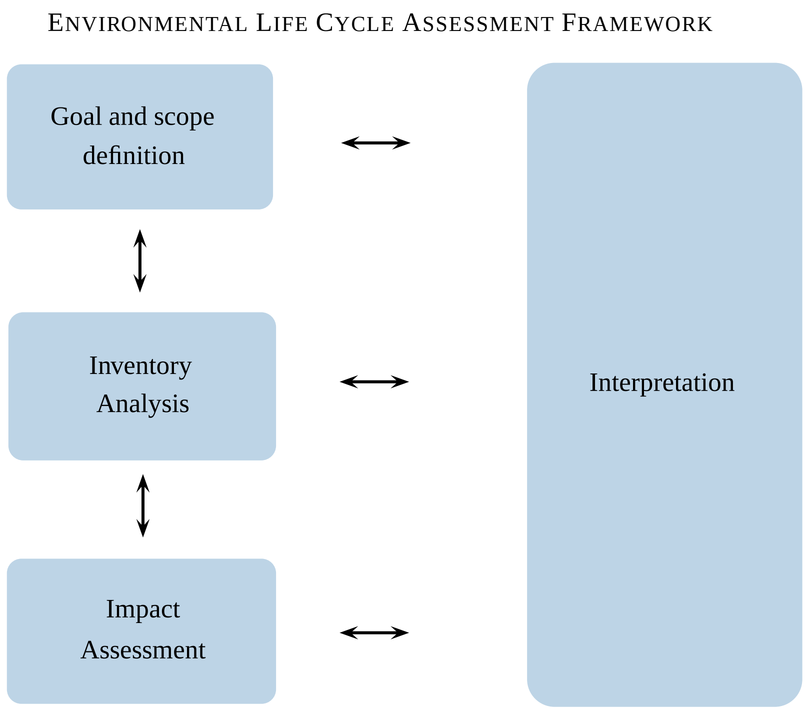

Figure 1. Life Cycle Assessment, shown as a dynamic cycle.

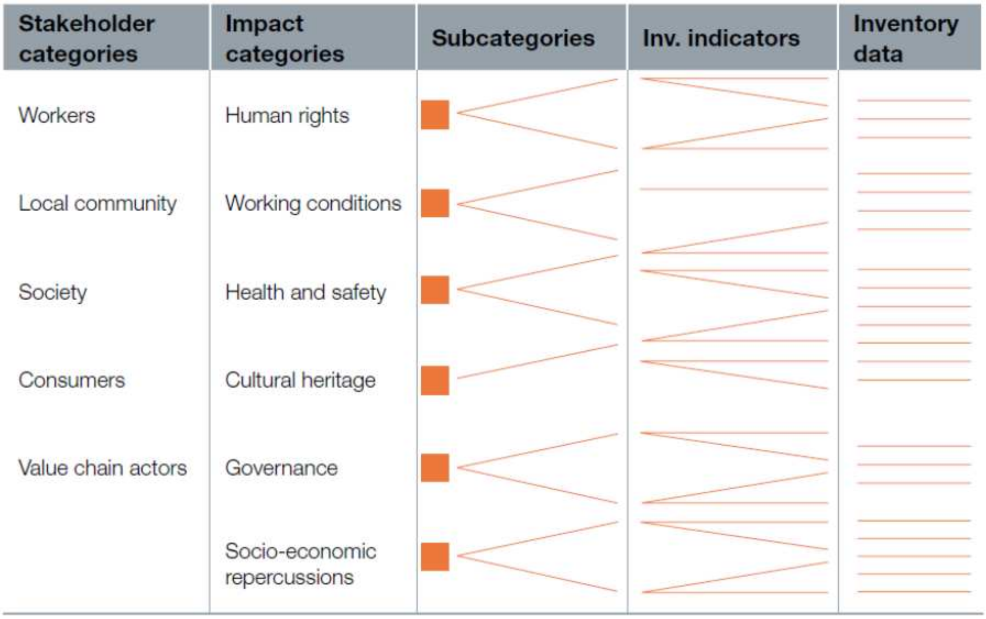

Figure 2. Assessment system from categories refereed to a unit of measurement. Modified from (Benoit *et al.*, 2007).

assessment of, at least, the most significant parts of the product life cycle. Even though it has been discussed what the significant parts of the life cycle actually amounts to (Dreyer *et al.*, 2006; Grießhammer *et al.*, 2006; Weidema, B. P, 2005), it will in most cases include several arrows in the life cycle, meaning that an assessment of the social impacts related to one life cycle stage will rarely be enough (Figure 2).

So, what a social impact is?. According to Society of Environmental Toxicology and Chemistry (SETAC), social impacts are consequences of positive or negative pressures on social endpoints (*i.e.* well-being of stakeholders). Social impacts are understood to be consequences of social interactions weaved in the context of an activity (production, consumption or disposal) and/or engendered by it and/or by preventive or reinforcing actions taken by stakeholders (ex. enforcing safety measures in a facility). When referring to the causes of social impacts, this generally implies three dimensions:

i. **Behaviors:** social impacts are those caused by a specific behavior or decision. (*e.g.* forbidding employees to form unions, allowing illegal child labor, and seizing employees' identity papers);

ii. **Socio-economic processes:** social impacts are the downstream effect of socio-economic decisions. The question arises "What is chosen, both at the macro and micro level?" (*e.g.* an investment decision in a sector to build infrastructure in a community) and

iii. **Capitals**, human, social, cultural social impacts relate to the original context, attributes possessed by an individual, a group, a society (*e.g.*, education level). They can be either positive or negative. For example, the human capital might suffer from a high percentage of individuals being HIV positive. In this case, a negative social impact may strike harder in this specific context or a positive may be of higher value. In order to make clear this fig one illustrates how to collect data according to stakeholder's categories.

4 Life cycle assessment modelling for agroproductive chains

It is important to estimate environmental and social impacts of these activities in order to make it more affordable throughout technology changes and

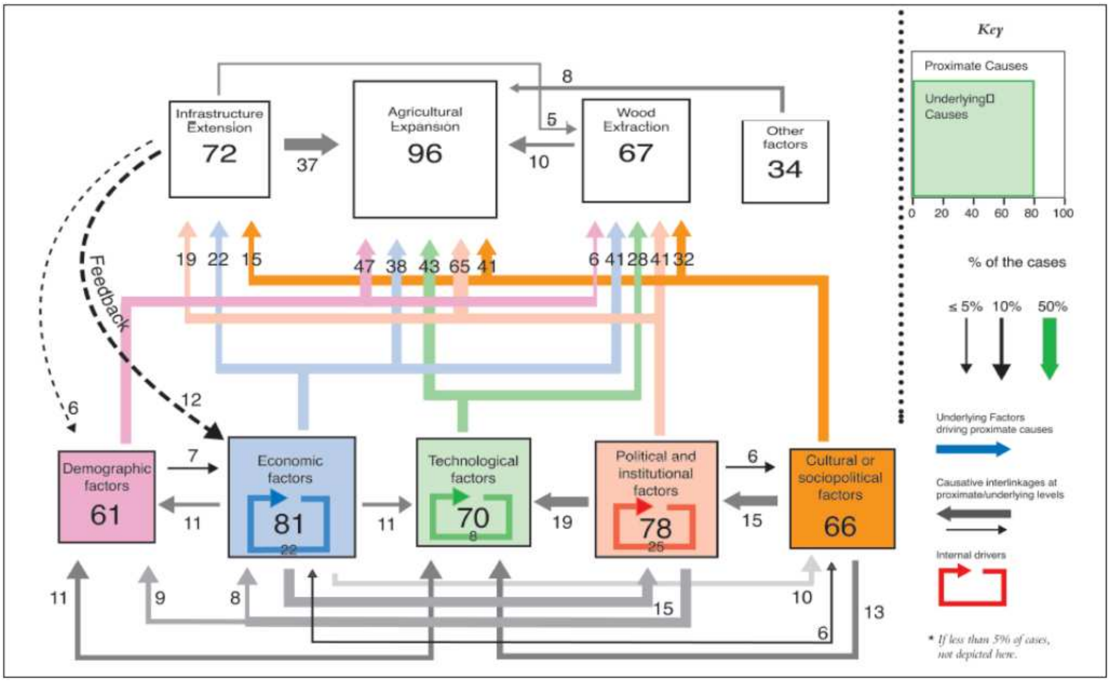

Figure 3. Patterns of tropical deforestation. Taken from (Lambin *et al.*, 2001).

improvements. However, to make it possible some particular consideration should be taken.

An estimated 18 % of global Green House Gases (GHG) emissions arise from land use change and forestry. These estimates are uncertain and emission estimates range from 2,899 Mt of carbon dioxide to 8,601 Mt (20 % of carbon dioxide emissions) (Gallejones *et al.*, 2015; Rebitzer *et al.*, 2004; Schmidt, 2008). Deforestation is by far the largest component of land use changes emissions and in particular, the land use of tropical forest has changed (Figure 3). Drawing on FAO statistics 19, 58 % of the deforestation has been influenced by commercial agriculture. The agriculture as a driver can be complex with interaction with other drivers such as road building, logging, primary extraction and population growth.

Most public debate about food and deforestation is focused in direct links between land use change and the food system. Considering the dominance of the tropics in land use change (Lambin *et al.*, 2001), this focuses attention on produce from these regions, particularly soy and beef from South America and palm oil from South-east Asia. This approach to the problem regards deforestation as attributable to USA and EU food consumption when world's consumed food is grown on recently converted land.

5 Life cycle inventory (LCI) modelling for agroproducts

For operations, we have to take into account

Production and maintenance of farm machinery. It is commonly suggested in agricultural LCA that the production of machinery and other capital equipment should be included in the inventory because they can have a relevant share of the overall impacts (Acero *et al.*, 2014). According to the project, scoping, site-specific data have been collected from farms in the selected place, while more generic data have been used for upstream production of farm inputs and downstream activities. Site-specific data on machinery use (use per year, expected lifetime, weight, etc.) have been collected from the studied farms in order to allocate the impacts of machinery production to the studied crops (Cardone *et al.*, 2003; Gallejones *et* *al.*, 2015; Lapola *et al.*, 2010). The method selected is generally followed in the ecoinvent[1] database using software tools as openLCA or SimaPro to process information, where it has been implemented with a more sophisticated model (specific study of machinery production related emissions; detailed materials composition and so on). The assumptions and data conversions for the different life cycle stages of machinery considered in this study are explained in the following sections;

Manufacture Energy consumption and materials composition are representative of different agricultural machines, and have therefore been used as they appear in ecoinvent (Emissions from manufacture are included in ecoinvent). However, the reference flow for machinery datasets is a kg of machine, and this has been changed to hours or hectares to reflect the data collected in the inventory. When doing so, site-specific data on machinery weight, lifespan and yearly usage have been used to parameterize the ecoinvent data in the following way where the first element represents the flows recorded in the ecoinvent datasets (Canals *et al.*, 2007; Dreyer *et al.*, 2010). The allocation to the total units (hours or hectares) used in the machine's lifetime is done in the ecoinvent datasets for field work processes, and thus needs to be removed from there once it has been done in the machine's manufacture.

Maintenance and repairs the considerations done in ecoinvent for maintenance (change of tyres, mineral oil, filters, batteries, etc.) are considered valid for this project. In the case of repairs, an increase of the manufacture materials is considered depending on the machine type (Nemecek *et al.*, 2001; Spugnoli and Dainelli, 2013) . For tillage machines this is considered to be 45% extra material (steel); as specific data on this materials is easily collected in the farms (representing the frequency of change of tillage components such as harrow tines), this will be used instead (Enrique *et al.*, 2014; Van Der Werf, 2004). Therefore, the steel input in the ecoinvent datasets for tillage machines is reduced by 45% and then increased by the calculated site-specific amount. The data collected from farmers actually shows quite dramatic increases in steel consumption when calculated like this, with e.g. increases of 200-264% (instead of the suggested 45%) for repairs in ploughs and power harrows.

Land use associated to farm buildings. Nemecek *et al.* offer data on space requirements for different machines (Nemecek *et al.*, 2004). It has been assumed that a shed is available in all farms to shelter all machines, and that a space equivalent to the requirement of each machine is provided all year-long. Therefore, the data in m^2 offered by ecoinvent are directly converted to m^2/year for each machine. The m^2/year are then allocated to the functional output of the machine during one year. Area occupied by farm sheds is classified as 'Occupation, urban, discontinuously built' in ecoinvent. A similar approach has been used for the other buildings in the farm used for the studied vegetables. The area used by these buildings has been obtained from the farmers and classified as 'Occupation, urban, discontinuously built'. Specific data for land use by farm buildings are provided in LCA reports for the different farms studied.

Use of agricultural machinery (field works). Fuel consumption for the different operations has been assessed specifically for the studied farms. This figure has then substituted the figures reported in ecoinvent, plus all subsequent emissions related to fuel consumption. The same sources used in ecoinvent for fuel emissions in agricultural machinery have been used, specifically for CO, HC (expressed as NMVOC) and NOx in Table A10 of (Nemecek *et al.*, 2004), which differ substantially respect road vehicles. The emissions of CO, HC, NOx are expressed in g/h, Table A10 of (Nemecek *et al.*, 2004), depending on each different operation; these emissions are re-calculated with the duration of the operations obtained from the farmers using the parameter rate_h (dividing the duration in hours/ha obtained from the farmers by the duration expressed in ecoinvent, Table A9 of (Nemecek *et al.*, 2004). To update fuel-related emissions (CO_2, SO_2, Pb, methane...), Table 7.1 of (Nemecek *et al.*, 2004), the parameter

[1] For further information, please visit: http://www.ecoinvent.org/database/database.html.

rate_fuel (fuel consumption per ha in RELU divided by fuel consumption per hectare in ecoinvent) is created and used for multiplying inputs (fuel consumption) and outputs related to fuel (most air emissions).

Completely representative: duration of operation lies within $\pm 20\%$ of that reported in ecoinvent_ Partly representative: duration of operation lies within $\pm 21 - 50\%$ of that reported in ecoinvent_ Not representative: duration of operation over 50 %.

Consideration of manual labor. With very few exceptions the environmental impacts associated with human labor have systematically been excluded from LCA studies. The reason most often argued for this is that labor-force maintenance-related environmental impacts (*e.g.* food consumption by workers; energy use for shelter; etc.) would occur regardless of the studied system (Piringer, G. and Steinberg L, 2006). *i.e.* that person would still eat (and possibly work elsewhere) if the studied system was not in place. Piringer and Steinberg (2006) assess the energy costs of labor in wheat production in the USA, concluding that this is of minor importance. According to their findings, labor-related energy would represent maximum 7.1 % of energy use for wheat if the highest estimate for labor energy use is compared to the best estimates (*i.e.* not highest values) for the other items of the energy bill. It should be noted that there is a huge uncertainty in this value. In any case, it could be argued that 'in terms of energy efficiency at least, it would be a little unfair to compare the energy balance of non-mechanized or partly mechanized systems with fully mechanized ones without accounting for human labor input's (Shabbir Gheewala, 19.06.2007 e-mail communication in LCA forum). In this study we have considered that impacts of maintaining humans are not affected by the studied system (*i.e.* food consumption, housing, etc. are excluded from the study), but that work-related transportation is increased by the studied system. Hence, an estimation of labor related transport has been done for labor-intensive operations. The nature of labor force in agricultural sector varies widely between the assessed countries, and so the way in which these impacts have been assessed also varies. In any case, the attempts done in this study have to be seen only as a first try to assess the relevance of labor transport-related impacts, and not as an exhaustive absolute statement of environmental impacts related to agricultural human labor in different countries.

Labor-intensive operations. First of all, a focus has been placed on those operations that the farmers consider as 'labor intensive'. These are generally all operations that cannot be mechanized, such as harvesting of lettuces, brassica or green beans; hand weeding within rows; installation/removal of irrigation infrastructure; etc. In the UK and Spain most of these operations coincide (with a trend in Spain to perform more operations manually), whereas in Uganda the assessed farms show a much lower degree of mechanization, with use of tractors and machinery being the exception rather than the rule. However, in Uganda most farm workers travel to the field by bike or on foot, and so their transportation impacts have been neglected. The labor intensive operations recorded for the LCA studies do not match the labor costs that could be found in the farm accounting books. As a rule of thumb, all permanent workers would be omitted from the LCA study, because they generally perform operations with high energy use (e.g. mechanized farm operations, where the tractor fuel use will override the fuel use of their private cars) or with low labor input per unit of product (e.g. in a packing plant). On the other hand, it is usually the temporary workers who perform the labor-intensive operations. This study has tried to provide a first estimate of the importance of transportation of temporary workers for some of the studied crops.

Considering the Global Warming Potential and other impact categories is necessary to estimate N_2O production due to N-Fertilizers and residuals during de process using software tools as BioGrace or OpenLCA. Moreover, it is fundamental to determine an allocation factor formula in order to reassign impact to the mainstream (functional unit) and downstream (byproducts) present in agricultural processes (D'Avino *et al.*, 2015; Spugnoli *et al.*, 2012). Energy approach is one of the best (Equation 1):

$$\text{Yield Allocation Factor} = \frac{\text{Yield} \times \text{Grain LHV}}{(\text{Yield} \times \text{Grain LHV}) + (\text{Straw} \times \text{Straw LHV})}, \quad (1)$$

where: the Yield Allocation Factor refers to impacts coefficient and is an adimensional factor; Yield is the mass production referred to the functional unit, expressed in kg; Grain LHV is the energy content or lower hating value (LHV), usually in MJ/kg; Straw is mass of *epigeous* residues, in kg; and Straw LHV is the energy content associated to *epigeous* residues, in MJ/kg. This allocation formula explains how the lower heating value (LHV) is used for the redistribution of the impacts associated to the functional unit in; yield of the crop and, its straw or *epigeous* residues.

However, a mass allocation factor could be useful and its formula is shown in Equation 2.

$$\text{Yield Allocation Factor} = \frac{\text{Yield}}{\text{Yield} + \text{Straw}}. \quad (2)$$

However, allocation method (Allocation factor should be a non-unit value) is not the best choice to reduce or allocate impact in process which has several authors (D'Avino *et al.*, 2015; Li and Mupondwa, 2014) and institution recommends (International Organization for Standardization, 2007) to use system expansion approach instead allocation.

6 Conclusions

For Agro-inputs (i.e. production, including machinery, phytosanitaires and so on) using the ecoinvent database has been used throughout the project to keep consistency, despising software used this database covers virtually every single scenery. However, Country laws and politics could change results and estimations and it should be enhanced to make an accurate assessment. Actually, software tools as Biograce, SimaPro and OpenLCA, are the main informatics supports to use ecoinvent databases, which provide uniformity to the estimation for environmental aspect. However to assess social impacts there is no methodology, only some guide lines.

Environmental information is an essential component of the environmental policy process that accepts the uncertainty in estimations and drivers, it remains clear that land use change is connected to agriculture and this is a significant cause of emissions attributable to the global food economy and other sectors as bioenergy. It is worth noting, that deforestation of the world to supply agricultural land has taken place over long time and much reforestation occurred in the last two centuries.

The associated CO_2 emissions from this historical deforestation have long been assimilated into the Earth's atmosphere. In addition, it is directly related to agriculture and associated processes, not only for the land use change and for the CO_2, CH_4 and N_2O emission to the air, also other contaminants as pesticides emitted to air, water and soil are produced. For these reason is necessary to assess its impacts regarding environmental and social ones.

Bibliography

Acero, A. A. P., C. Rodríguez and A. Ciroth. 2014. LCIA methods Impact assessment methods in Life Cycle Assessment and their impact categories. pages 1-23.

Brander, M., R. Tipper, C. Hutchison and G. Davis, G. (2008). Consequential and attributional approaches to LCA: a Guide to policy makers with specific reference to greenhouse gas LCA of biofuels. **Econometrica Press.** pages 1-14. http://onlinelibrary.wiley.com/doi/10.1002/cbdv.200490137/abstract, http://www.globalbioenergy.org/uploads/media/0804_Ecometrica_-_Consequential_and_attributional_approaches_to_LCA.pdf, http://d3u3pjcknor73l.cloudfront.net/assets/media/pdf/approachesto_LC

Braungart, M., W. McDonough and A. Bollinger. 2007. Cradle-to-cradle design: creating healthy emissions-a strategy for eco-effective product and system design. **Journal of Cleaner Production.** 15(13-14):1337-1348. http://doi.org/10.1016/j.jclepro.2006.08.003

Canals, L. M. I., I. Muñoz, S. McLaren and B. Miguel. 2007. LCA Methodology and Modelling Considerations for Vegetable production and Consumption. **CES Working Papers 02/07.** United Kingdom, Centre for Environmental Strategy, University of Surrey. page 46.

Cardone, M., M. Mazzoncini, S. Menini, V. Rocco, A. Senatore, M. Seggiani and S. Vitolo. 2003. Brassica carinata as an alternative oil crop for the production of biodiesel in Italy: Agronomic evaluation, fuel production by transesterification and characterization. **Biomass and Bioenergy.** 25(6):623-636. http://doi.org/10.1016/S0961-9534(03)00058-8

D'Avino, L., R. Dainelli, L. Lazzeri and P. Spugnoli. 2015. The role of co-products in biorefinery sustainability: energy allocation versus substitution method in rapeseed and carinata biodiesel chains. **Journal of Cleaner Production.** 94:108-115. http://doi.org/10.1016/j.jclepro.2015.01.088

Dreyer, L. C., M. Z. Hauschild and J. Schierbeck. 2006. Societal Assessment (Subject Editor: David Hunkeler) A Framework for Social Life Cycle Impact Assessment. **International Journal.** 11(2):88-97. http://doi.org/10.1065/lca2005.08.223

Dreyer, L. C., M. Z. Hauschild and J. Schierbeck. 2010. Characterisation of social impacts in LCA: Part 1: Development of indicators for labour rights. **International Journal of Life Cycle Assessment.** 15(3):247-259. http://doi.org/10.1007/s11367-009-0148-7

Enrique, C. Y., O. Rodríguez, C. V. S. R. Ii, C. L. Raúl and P. Serrano. 2014. Balance energético de tres tecnologías de labranza en un Vertisol para el cultivo del tabaco (*Nicotiana tabacum* L.). Energy balance of three farming technology in a Vertisol for the cultivation of tobacco (*Nicotiana tabacum* L.). 4(2):35-41.

European Commission–Joint Research Centre–Institute for Environment and Sustainability. 2010. International Reference Life Cycle Data System (ILCD) Handbook–General guide for Life Cycle Assessment–Detailed guidance. Constraints. http://doi.org/10.2788/38479

European Environment Agency. 2012. Environmental Indicator Report 2012–Ecosystem Resilience and Resource Efficiency in a Green Economy in Europe. **Eea.**

Gallejones, P., G. Pardo, A. Aizpurua and A. Del Prado. 2015. Life cycle assessment of first-generation biofuels using a nitrogen crop model. **The Science of the Total Environment.** 505:1191-201. http://doi.org/10.1016/j.scitotenv.2014.10.061

Gasol, C. M. 2009. Environmental and economic integrated assessment of local energy crops production in southern europe. **Universidad Autonoma de Barcelona, Tesis Doctoral.**

Grießhammer, R., C. Benoît, L. C. Dreyer and A. Flysjö. 2006. Feasibility Study: Integration of social aspects into LCA. **Main.** May 2005. 1-14.

Hauschild, M. Z., L. C. Dreyer and A. Jørgensen. 2008. Assessing social impacts in a life cycle perspective-Lessons learned. **CIRP Annals–Manufacturing Technology.** 57(1):21-24. http://doi.org/10.1016/j.cirp.2008.03.002

International Organization for Standardization. 2007. NTC-ISO 14044. **Gestión ambiental, análisis del ciclo de vida.** page 16. http://tienda.icontec.org/brief/NTC-ISO14044.pdf

Jørgensen, A. 2013. Social LCA–a way ahead? **The International Journal of Life Cycle Assessment.** 18(2):296-299. http://doi.org/10.1007/s11367-012-0517-5

Lambin, E. F., B. L. Turner, H. J. Geist, S. B. Agbola, A. Angelsen, C. Folke,... T. A. Veldkamp. 2001. The causes of land-use and land-cover change: moving beyond the myths. **Global Environmental Change.** 11:261-269. http://doi.org/0959-3780/01/

Lapola, D. M., R. Schaldach, J. Alcamo, A. Bondeau, J. Koch and C. Koelking. 2010. Indirect land-use changes can overcome carbon savings from biofuels in Brazil. **PNAS.** 107(8):1-6. http://doi.org/10.1073/pnas.0907318107

Li, X. and E. Mupondwa. 2014. Life cycle assessment of camelina oil derived biodiesel and jet fuel in the Canadian Prairies. **Science of the Total Environment.** 481(1):17-26. http://doi.org/10.1016/j.scitotenv.2014.02.003

Menichetti, E. and M. Otto. 2009. Energy Balance and Greenhouse Gas Emissions of Biofuels from a Life Cycle Perspective. **Environment.** September 2008. pages 81-109. http://cip.cornell.edu/DPubS?service=UI&version=1.0&verb=Display&page=current&handle=scope

Nemecek, T., C. Frick, D. Dubois and G. Gaillard. 2001. Comparing farming systems at crop rotation level by LCA. **Proceedings of the International Conference on LCA in Foods.** pages 65-69.

Piringer, G. and L. Steinberg. 2006. Reevaluation of Energy Use in Wheat Production in the United States. **Journal of Industrial Ecology**. 10(1-2):149-167. DOI:10.1162/108819806775545420.

Ramachandran, S., S. K. Singh, C. Larroche, C. R. Soccol and A. Pandey. 2007. Oil cakes and their biotechnological applications–A review. **Bioresource Technology.** 98:2000-2009. http://doi.org/10.1016/j.biortech.2006.08.002

Rebitzer, G., T. Ekvall, R. Frischknecht, D. Hunkeler, G. Norris, T. Rydberg,... D. W. Pennington. 2004. Life cycle assessment Part 1: Framework, goal and scope definition, inventory analysis, and applications. **Environment International.** 30:701-720. http://doi.org/10.1016/j.envint.2003.11.005

Schmidt, J. H. 2008. System delimitation in agricultural consequential LCA. **The International Journal of Life Cycle Assessment.** 13(4):350-364. http://doi.org/10.1007/s11367-008-0016-x

Spugnoli, P. and R. Dainelli. 2013. Environmental comparison of draught animal and tractor power. **Sustainability Science.** 8:61-72. http://doi.org/10.1007/s11625-012-0171-7

Spugnoli, P., R. Dainelli, L. D. Avino and M. Mazzoncini. 2012. Sustainability of sunflower cultivation for biodiesel production in Tuscany within the EU Renewable Energy Directive. **Biosystems Engineering.** pages 49-55. http://doi.org/10.1016/j.biosystemseng.2012.02.004

Thomassen, M. A., R. Dalgaard, R. Heijungs and I. de Boer. 2008. Attributional and consequential LCA of milk production. **The International Journal of Life Cycle Assessment.** 13(4):339-349. http://doi.org/10.1007/s11367-008-0007-y

Unep Setac Life Cycle Initiative. 2009. Guidelines for Social Life Cycle Assessment of Products. **Management.** volume 15. http://doi.org/DTI/1164/PA

Van Der Werf, H. M. G. 2004. Life Cycle Analysis of field production of fibre hemp, the effect of production practices on environmental impacts. **Euphytica.** 140:13-23. http://doi.org/10.1007/s10681-004-4750-2

Weidema, B. P. 2005. ISO 14044 also Applies to Social LCA. **The International Journal of Life Cycle Assessment.** 10(6):381-381. http://doi.org/10.1065/lca2005.11.002