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An LCA Study on Feedstocks and Processes for Biofuels Production

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Biofuels represent a valid alternative to traditional fossil fuels, going to suffer in the next future of the complete depletion of fossil sources. In this context, we present a critical survey upon the production of the three commonest biofuels (biodiesel, bioethanol and biogas), analysing the feedstocks and the transformation process by means of the LCA assessment. Actually, a complete evaluation of the environmental footprint for biofuels production should guide the actual and forthcoming lines of massive fuel production worldwide.

1. Introduction

Liquid biofuels, extracted by biological feedstocks, represent a valid replacement of fossil fuels and play a crucial role for transportation (Huber et al 2006; Granda et al. 2007; Demirbas 2009; Reijnders 2006; Singh and Olsen 2011), even if their sustainability however, is still an open issue (Granda et al. 2007; Reijnders 2006). First generation biofuels, produced from purposed crops, compete with food production, whereas second generation biofuels, produced from biological wastes, constitute a sustainable route, solving as well the “food vs. fuel” question (Cassman and Liska 2007) with a large environmental and economic gain (Schenk et al. 2008; Havllik et al. 2011).

The sustainable development assessment of a productive process accounts for the environmental impact of the whole supply chain, evaluated through specific tools (Böhringer and Jochem 2007). Life Cycle Assessment (LCA) methodologies provide several eco-indicators of the environmental impact of productive processes, but it is however challenging asserting which process is more eco-friendly than another, because, for instance, the process A might consume less water than the process B, but produce higher greenhouse gases emissions. Many literature reports deal with the application of Life Cycle Assessment (LCA) methods to compute the biofuels environmental impact (Piemonte et al. 2011; Tan et al. 2008); however, biofuels obtained from different feedstocks have not been comprehensively compared yet.

In this work, we propose an LCA-based analysis for production processes of biofuels by using both a mid-point and end-point methodology in order to evaluate the overall environmental impact of each biofuel, for determining an unambiguous metrics for the environmental impact of each process. In a scenario of complex systems analysis – as environment is - we do require methodologies able to provide a straight answer to the straight question: “Which process results into the most reduced environmental impact?

2. System Boundaries Description

In the following we report a brief description of the biofuels production processes considered in this study along as the systems boundaries.

2.1 Biodiesel from rape seeds

The transesterification process converts vegetable and animal oils into methyl ester, commonly known as biodiesel. Although most processes follow a similar basic approach, biodiesel from vegetable oil can be produced by different esterification technologies. The biodiesel production process can be splitted up into

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two main subprocesses: the oil extraction from feedstocks and the esterification of the purified oil into methyl ester.

Rape oil extraction process considers the seeds cold pressing, after a pretreatment to remove impurities: seeds are pre-crushed and pressed for the oil extraction; the crude oil is then filtered and stored. The crude rape oil may be employed in the food industry, or as fuel for transport and/or heating purposes, after the esterification process. The residual solid part of the seeds yields a side-product used as animals feed (rape meal).

Transesterification process requires methanol (fossil) and potassium hydroxide (catalysts) to crude rape oil into methyl ester, including two-side reactions, the neutralization and the saponification.The production of pure methyl ester requires different removal stages: glycerine by decantation, water and methanol by evaporation, soap and residual glycerine by sawdust through an adsorption process and filtering (Figure 1).

2.2 Bioethanol from corn

The scheme of Figure 1 describes the dry-milling corn-to-ethanol technology: three units describe the process stages:

- the liquefaction/saccharification unit converts starch into ethanol through an enzymatic hydrolysis;
- the fermentation and distillation units provide the dehydrated ethanol up to 95 % (vol.); moreover distillation may be coupled to a pre-concentration unit to concentrate the stillage by evaporation;
- the separation unit aims at partitioning off insoluble dry matter (DDGS, Dried Distillers Grains with Solubles)from the soluble one contained in the stillage and increasing the quantities of stillage recycled in the fermentation phase.

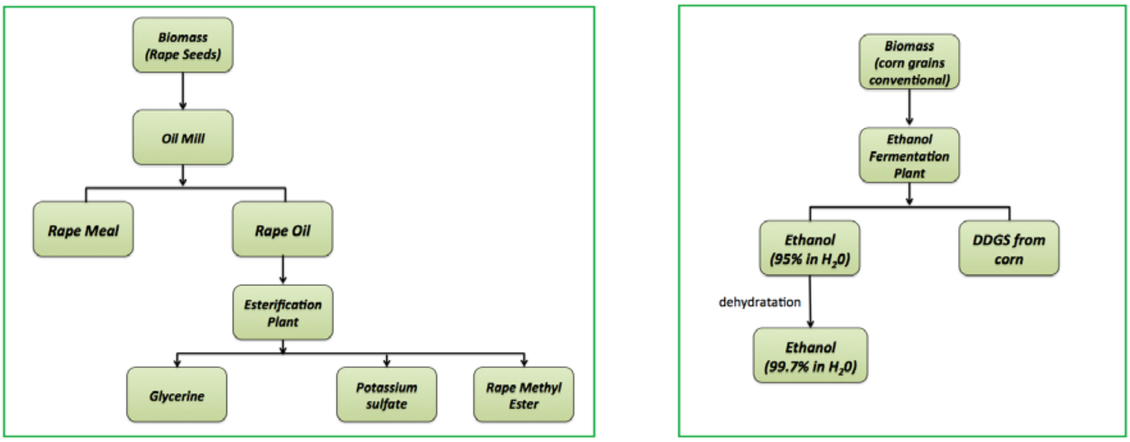

Figure 1: Biodiesel production plant scheme (left); Bioethanol from corn production plant scheme (right).

2.3 Bioethanol from wood

The schemes of Figure 2 describe the joint production of hydrated ethanol and electricity from wood (wood chips). Wood chips are converted into ethanol by the enzymatic hydrolysis of cellulose and the co-fermentation of complex carbohydrates (glucose and xylose).

The process comprehends the following steps:

- In the pre-treatment phase, a catalytic hydrolysis removes the hemicellulose, exposing the cellulose for the next enzymatic saccharification phase;
- Saccarification and co-fermentation phases occur simultaneously, so the cellusose converted into glucose by an enzymatic hydrolysis (saccarification) is converted into ethanol by fermentation;
- The distillation phase concentrates the fermented mixture up to a 95% of ethanol (in volume);the combustion of solid residual and biogas – produced from the wastewater anaerobic digestion– cogenerates heat and electricity for the process energy duties.

2.4 Co-fermentation Biogas Plant

The biogas production via a fermentation process may exploit different: liquid manure and biowastes represent an optimal choice, solving at once both the problem of energy production and wastes disposal. However, biogas properties vary according to the plant design process and the waste composition. The main steps are (Figure 2 – right):

- The substrate pre-treatment stage(shredding and mixing);

- In the digestion stage, the biogas and fertilizer are produced as result of the digestion of manure. The fermentation requires both electricity for the mixing and heat for keeping a uniform temperature to optimize bacterial activity; temperature ranges between 30° and 40°;
- The co-generation section provides both heat and electricity from the biogas combustion.

Biogas obtained from a fermentation process can be used as transportation fuel,, for heating, in co-generation systems, or fed in to the gas distribution network.

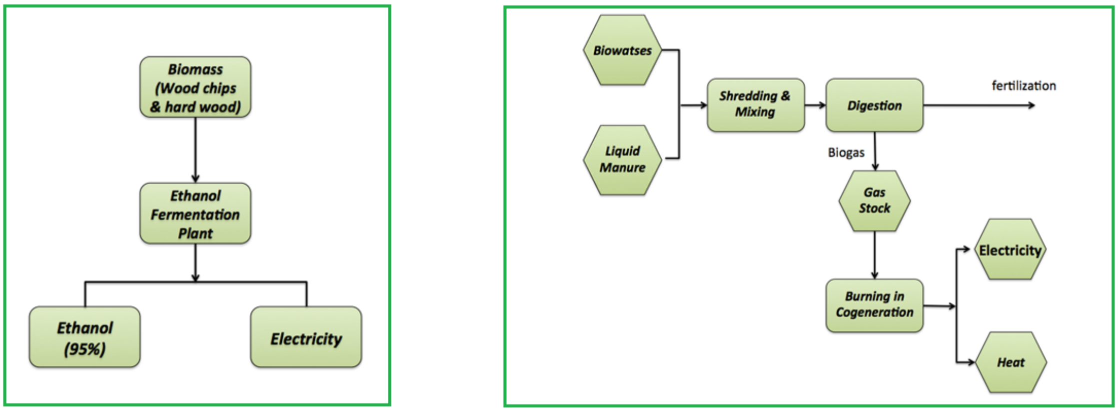

Figure 2: Bioethanol from wood production plant scheme (left); Biogas production plant scheme (right).

3. LCA Methodologies

We carried out the LCA anlaysis by the‘‘SimaPro7.2’’ LCA software that implements different LCA methodologies: we selected the CML 2001 methodology for the analysis of mid-point level and the Ecoindicator 99 as end-point methodology.

3.1 Mid-Point Methodology

The CML 2001 mid-point methodology computes 10 impact categories: Abiotic depletion, Acidification, Eutrophication, Global warming (GWP 100), Ozone layer depletion, Human toxicity, Fresh water aquatic ecotoxicity, Marine aquatic ecotoxicity, Terrestrial ecotoxicity and Photochemical oxidation (Goedkoop et al., 2008).

3.2 End-point Methodology

TheEco-indicator 99 end-point methodology introduces11 impact categories (mid point level): Carcinogens, Respiratory Organics, Respiratory Inorganics, Climate Change, Radiation, Ozone Layer, Ecotoxicity, Acidification/Eutrophication, Land Use, Minerals and Fossil Fuels. These categories are aggregated in to macro-categories:

– “Human Health” includes the first six indicators, normalized and grouped(end-point level),considering the overall impact on human health;
– “Ecosystem Quality” macro-category gathers Ecotoxicity, Acidification/Eutrophication and Land Use flow, evaluating the overall damage on the Environment;
– ‘‘Minerals and Fossil Fuels’’ indicators are grouped in the macro-category ‘‘Resources’’ that accounts for the depletion of non-renewable resources (Goedkoop et al., 2008).

3.3 Functional Unit and Allocation Criteria

We set up a functional unit of 1 kWh - produced by a generation plant fed with the target biofuel- as reference for the LCA analysis.
As for the allocation procedure, we accounted for the economic value of by-products associated to biofuels production.

4. LCA Results and Discussion

Figure 3 reports LCA results obtained by CML 2001 methodology (mid-point): the figure clearly highlights the carbon credits associated to the production of biofuels as for the Global warming impact category, except for bioethanol from corn, for whom we accounted for the CO_{2eq} due to Land use change (LUC) emissions (Piemonte and Gironi, 2011 and 2012). As for single biofuels environmental impact, the biogas shows a lower environmental footprint on 8 out of 10 total impact categories. Both bioethanol from corn (green and yellow) and biodiesel from rape seed (grey) come with high environmental burdens: the Figure

does not clearly indicate the best biofuel in terms of the lowest environmental impact. To overcome this intrinsic weakness point of the LCA methodology, an end-point approach has been carried out.
Figure 4 reports LCA results of the Ecoindicator 99 methodology: the environmental score of the four biofuels comply qualitatively with that of the CML 2001 methodology, even considering different impact categories of mid-point level. For this methodology, the impact categories are grouped in three end-point level categories named "Damage categories" (see Figure 5).
Biodiesel production from rape seed (grey) shows the higher environmental impact on the ecosystem quality mainly due to the high impact on the Land use mid-point category; conversely, as for the human health impact, biodiesel reports the best performance, followed from biogas (cyano) and bioethanol from wood (blue) and corn (yellow), respectively. In terms of fossil resources depletion, the lower environmental impact score is associated to biogas (cyano), followed by bioethanol from wood (blue), biodiesel (grey) and bioethanol from corn (yellow) respectively; the lower impact of biogas is due to the scarce use of fossil fuels in the biogas production process.

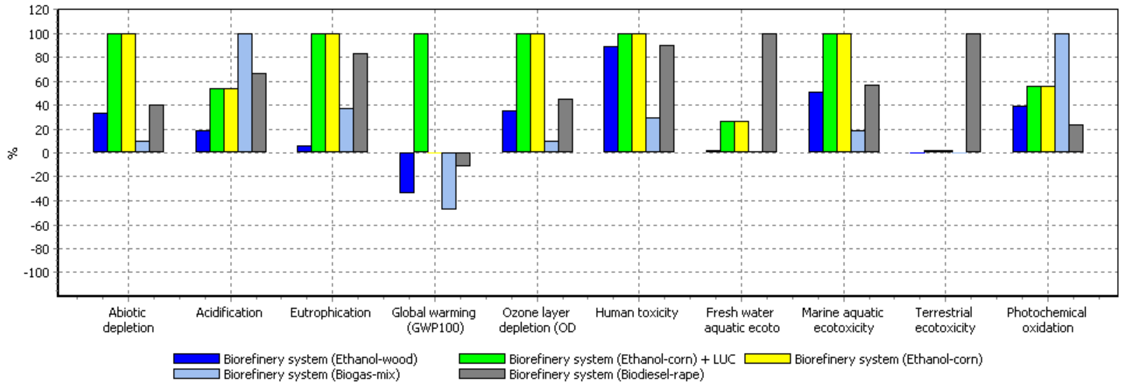

Figure 3: LCA results by CML 2001 Methodology (Mid-Point Level).

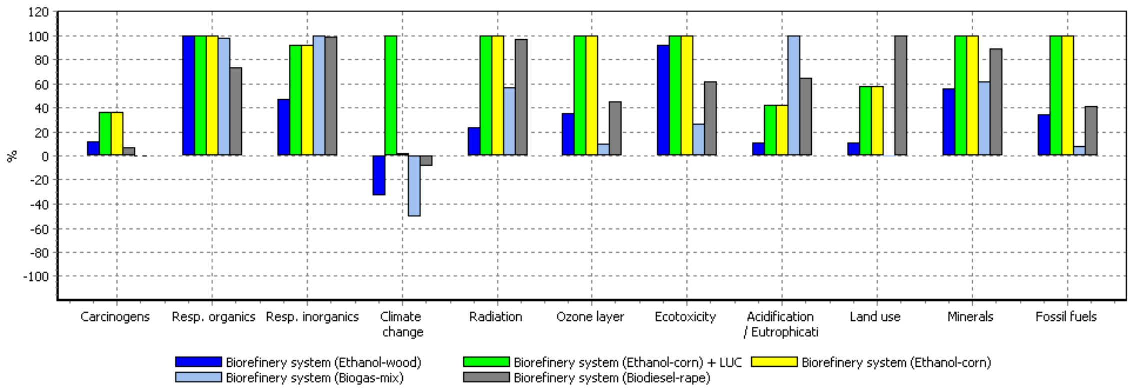

Figure 4: LCA results by Eco-indicator 99 Methodology (Mid-point categories),

To perform a final and exhaustive comparison between the different biofuel production processes and then give an answer to the key question "Which process results into the most reduced environmental impact?", the environmental impact for each biofuel on each damage category has been reported in a triangle diagram (mixing triangle, Gironi and Piemonte, 2011): assigning a priority weight (percentage scale) to each damage category, it is possible to define an overall environmental impact for each biofuel production process. Figure 6 shows the mixing triangles for three different comparisons: on the left, the biogas production process occupies the greater area with respect to bioethanol production from wood. In other words, only assessing the impact on human health and ecosystem quality, the bioethanol from wood "gains" on the biogas.
In the middle, the mixing triangle reports the comparison between the bioethanol from wood and the biodiesel production from rape seed oil: the predominant blue area clearly points out the superiority, from an environmental point of view, of the bioethanol on the biodiesel. We decided not to include bioethanol from corn for comparison in mixing triangles because of its high environmental impact in all the damage

categories with respect to other biofuels, as already reported in Figure 5.On the right, the mixing triangle compares biodiesel from rape seed with biogas production: only including with high weightsthe human health and ecosystem quality macro-categories, the biodiesel appears more sustainable with respect to biogas.

5. Conclusions

This work has strived to give an overall point of view on the environmental impact of the most important biofuels produced on the international panorama.

The application of the LCA methodology, universally recognized as the best tool to assess the environmental footprint of a product and to drive it towards a large scale sustainable production, does not allow to univocally define the environmental score of each product. The combined use of an end point methodology and of a mixing triangle, applying proper damage category priority weights, allows to overcome this limitation, so as to apply the LCA results for a real quantitative comparison. Following this

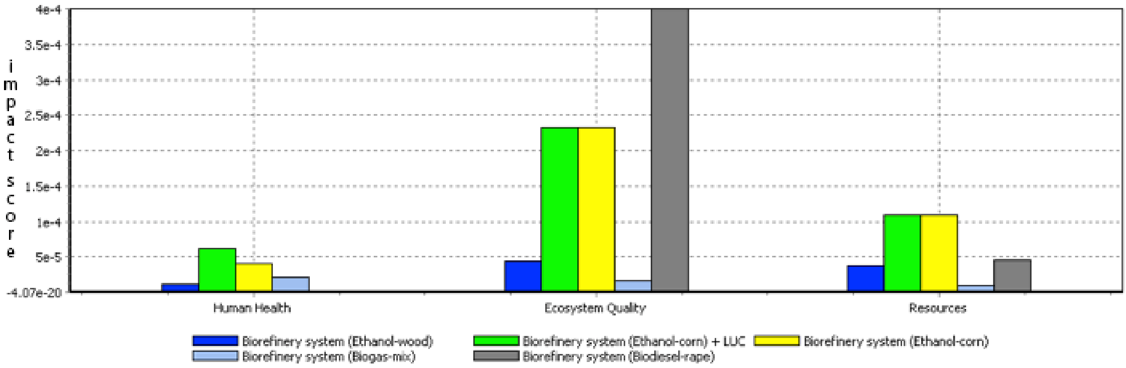

Figure 5: LCA results by Eco-indicator 99 Methodology (End-point Categories).

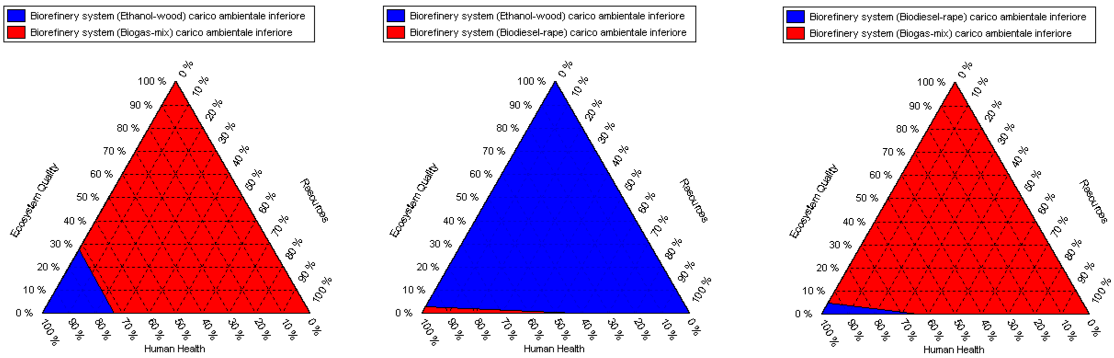

Figure 6: LCA results by Ecoindicator 99 Methodology – Mixing Triangle view.

approach, this work has highlighted the sustainability of the biogas production process, mainly in terms of fossil resources saving. Conversely, in a world where the fossil resources are doomed to the final depletion, bioethanol from wood appears the more sustainable biofuel option in perspective.

References

Böhringer C. andJochem Patrick E.P., 2007, Measuring the Immeasurable — A Survey of Sustainability Indices, Ecological Economics, 63 (1): 1–8.

Cassman, K.G. and Liska A.J.,.2007, Food and Fuel for All: Realistic or Foolish?, Biofuels Bioprod Biorefin 1: 18–23.

Demirbas A., 2009a, Progress and Recent Trends in Biodiesel Fuels, Energ Convers Manage 50: 14–34.

Demirbas A., 2009, Biofuels Securing the Planet’s Future Energy Needs, Energ Convers Manage 50: 2239–2249.

Granda C.B., Zhu L. and Holtzapple M.T., 2007, Sustainable Liquid Biofuels and Their Environmental Impact, Environ Prog 26 (3): 233–250.

Gironi F. and Piemonte V., 2011, Life Cycle Assessment of PET and PLA Bottles for Drinking Water. Environmental Progress & Sustainable Energy, 30(3), 459-468.

Goedkoop M., Oele M., Schryver M., and Vieira M., 2008, SimaProdatabase manual: methods library, PRe` Consultants, pp 22–25.

Havllik P., Schneider U., Schmid E., Bottcher H., Fritz S., Skalskyy R., Aoki k., et al., 2011, Global Land-Use Implications of First and Second Generation Biofuel Targets, Energy Policy 39 (10): 5690–5702.

Huber G.W., Iborra S. and Corma A., 2006, Synthesis of Transportation Fuels from Biomass: Chemistry, Catalysts, and Engineering, Chem Rev 106: 4044–4098.

Piemonte V.,De Falco M. and Giaconia A., 2011, Life Cycle Assessment of a High Temperature Molten Salt Concentrated Solar Power Plant, Solar Energy 85 (1101-1109).

Piemonte V. and Gironi F., 2012, Bioplastics and GHGs Saving: The Land Use Change (LUC) Emissions Issue, Energy Sources Part A: Energy, recovery and Environmental Effect 34 (21), 1995-2003.

Piemonte V. and Gironi F., 2001, Land Use Change Emissions: How Green Are the Bioplastics?, Environmental Progress & Sustainable Energy, 30 (4), 685-691.

Reijnders L., 2006, Conditions for the Sustainability of Biomass Based Fuel Use, Energy Policy 34 (7): 863–876.

Schenk P.M., Thomas-Hall S.R., Stephens E,, Marx U.C., Mussgnug J.H., Posten C., Kruse O. and Hankamer B., 2008, Second Generation Biofuels: High-Efficiency Microalgae for Biodiesel Production., Bioenerg Res 1: 20–43.

Singh Anoop and Stig Irving Olsen, 2011, A Critical Review of Biochemical Conversion, Sustainability and Life Cycle Assessment of Algal Biofuels, Applied Energy 88 (10): 3548–3555.

Tan Kok Tat, KeatTeong Lee and Abdul Rahman Mohamed, 2008, Role of Energy Policy in Renewable Energy Accomplishment: The Case of Second-Generation Bioethanol, Energy Policy 36 (9): 3360–3365.