PROCEEDINGS

International conference on Life Cycle Assessment as reference methodology for assessing supply chains and supporting global sustainability challenges

LCA FOR "FEEDING THE PLANET AND ENERGY FOR LIFE"

Stresa, 6-7th October 2015
Milano, Expo 2015, 8th October 2015

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MILANO 2015

European Commission

ENEA
Italian National Agency for New Technologies, Energy and Sustainable Economic Development

Rete Italiana LCA

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2015 ENEA
Italian National Agency for New Technologies, Energy and Sustainable Economic Development

Lungotevere Thaon di Revel, 76
00196 Roma

ISBN 978-88-8286-321-0

LCA and Water Footprint of biofuels used in transport sector: a review

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1. Abstract

Concerns over energy security and environmental impacts related to greenhouse gases emissions stimulate developments towards renewable energy. Over the last few years, there has been an intense debate about the major factors that determine the impacts of biofuels both in production and end use phase. The objective of this study is to review existing life cycle assessment (LCA) and water footprint (WF) studies on liquid biofuels used in transport sector to point out if: (i) LCA studies are adequate to evaluate the environmental impacts of biofuels; (ii) biofuels are environmentally sustainable when the WF is considered; (iii) it is possible to use both LCA and WF studies results to better assess the environmental sustainability of biofuels. Furthermore, different aspects of crops production are considered to assess the efficiency of the biofuels in the greenhouse gas emission reduction. The analysed LCA papers present quite different and at times contradictory results on biofuel environmental impacts. Variability in results is affected by crops used and geographical areas of cultivation and, consequently, the impact assessment of biofuels is consistent only at the local level. In conclusion, it can be stated that territory characteristics, weather conditions and farming methods should be considered to evaluate biofuels production.

2. Introduction

Many countries have established regulatory policies to promote the production or consumption of biofuels for transport. For example, in the European Union transport sector is expected to switch from fossil fuel use to a fuel mixture with 10% fraction of biofuels by 2020. As a result, global biofuel production grew from 16 billion litres in 2000 to more than 117 billion litres (volumetric) in 2013 [1]. At the same time, biofuels have to be produced in a sustainable way to reduce greenhouse gas (GHG) emissions without adversely affecting the environment or social sustainability. Over the last few years, there has been an intense debate about the major factors that determine the impacts of biofuels both in production and end use phase. Growing crops for biofuels may have serious environmental impacts such as direct or indirect land-use changes, soil degradation, nutrient depletion, loss of biodiversity, water depletion and pollution [2]. To determine and evaluate the environmental impacts of biofuels many studies have been carried out applying the life cycle analysis (LCA) methodology [3, 4, 5, 6] but only few take into account water use/consumption [7, 8]. In recent years a number of studies investigated the issue of water consumption for crops used for the biofuels production pointing out that they have relatively high water requirements at commercial yield levels. Considering that fresh water for agriculture is becoming increasingly scarce in many countries as a result of the competition with domestic or industrial uses, the paper focuses on the impact of a larger consumption of biofuels on this vital resource.

2. Materials and methods

In this paper a literature survey on LCA and WF studies of liquid biofuels used in the transport sector, namely bio-ethanol and biodiesel, has been carried out covering a time period of ten years. Because of the large number of publications only review papers on LCA have been considered whereas both reviews and original research papers on WF have been examined.

3. Results

Nine review papers have been analysed to obtain a comprehensive knowledge of the LCA studies on the environmental impacts of biofuels in transport sector. The reviews agree in pointing out two major issues: (i) most of the analysed papers calculate or estimate the GHG emissions and the energy balance whereas only few consider other impact categories [9][10]; (ii) the wide range and uncertainty in LCA results [4][5][11] and also some contradictory results [12]. Parameters that influence the variability in results are related to the study's specificity (type of crop, agricultural practices, country of cultivation and fuel processed plants) as well as to the different assumptions and methodological choices used to model the life-cycle assessment. According to Larson [4] there are four main parameters responsible of the greatest variations and uncertainties into GHG-related LCA results: "the climate-active species included in calculation of equivalent GHG emissions, assumptions around N_2O emissions, the allocation method used for co-product credits, and soil carbon dynamics". Other authors draw the same conclusion, e.g. Malça and Freire [13] state that in more recent LCA biodiesel studies, soil emissions (namely N_2O and carbon emissions) "as well as different options for dealing with co-products (scenario uncertainty), have strong influence in the results" of GHG emissions.

The results of the examined reviews can be summarized as follows. As regards biodiesel, to achieve moderate GHG savings and a favourable energy balance with respect to fossil diesel, there are at least three parameters to be met. These are: high biomass yields, low fertilizers and pesticides inputs in agricultural practices, no land use change. Overall considered palm oil is recognized as the most efficient crop to produce biodiesel [14][15] if deforestation environmental impacts are not taken into account whereas biodiesel from rapeseed cultivated in East Europe accounts for the higher GHG emissions, even higher than fossil fuel diesel emissions [10].

As regards bio-ethanol, better results for GHG savings and energy balance net gain are estimated in relation to fossil fuel and biodiesel as well [16]. Bio-ethanol produced from sugarcane in tropical countries appears by far the most efficient biofuel both for climate protection and fossil fuel conservation perspective if the residues are used to run the processing plants.

Last but not least all the reviews point out the highly site-dependent results in GHG and energy balance and the great variation in methodological choices and parameter settings that lead to a wide range of results and recommend to identify guidelines or a standard methodology to carry out LCAs on biofuels.

To exceed the LCA study limits and better evaluate the environmental impacts of biofuels a further parameter has been evaluated: the water footprint (WF) that allows to calculate water requirements for crops cultivation and accounts for both direct and indirect water consumption [17]. The WF papers analysed come to very similar results, Gerbens-Leenes and co-authors [7][8] calculated the WF of different biofuels and show that “is 70 to 400 times larger than the WF of a mix of energy from non renewable sources” and in a transition to biofuels scenario it is expected that the global annual biofuel WF will increase more than tenfold, from about 90 km^3/year in 2005 to 970 km^3/year in 2030 [17]. Furthermore, in a recent study on bio-ethanol WF Gerbens-Leenes and Hoekstra [18] state that producing bio-ethanol from maize is more favourable than using sugarcane, contrary to the results of LCA studies above mentioned. In a study comparing the WF of three biofuel crops (cassava, sugarcane, and oil palm) with other food crops in Thailand, Piyanon and Gheewala [19] show that a hectare of biofuel crop lands requires more water than a hectare of other food crops. Moreover is very important to assess the water consumption in relation to the hydrogeological conditions of the different regions [20].

4. Conclusion

Combining results from LCA and WF studies on first generation biofuels, namely biodiesel and bio-ethanol, no conclusive results can be achieved on environmental advantages in their utilization. Major uncertainties in LCA studies derive from biomass feedstocks, energy inputs, location of crop cultivation and related yields, soil emissions and allocation procedure for co-products while in WFs papers two variables, crop water requirements and crop yields, explain the large variability of the results. Overall, this brief review shows that future studies on biofuels LCA have to take into account the WF because water scarcity may become the limiting factor for biofuel feedstock production in many regions [2].

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