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Origins of the debate on the life-cycle greenhouse gas emissions and energy consumption of first-generation biofuels – A sensitivity analysis approach

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ABSTRACT

Available results about energy and GreenHouse Gases (GHG) balances of biofuels from Life-Cycle Assessment (LCA) or life-cycle based studies present large discrepancies and thus, may lead to contradictory policy-making measures. This work reviewed seven important European LCA studies in a sensitivity analysis approach in order to get a better understanding of the roots of such a debate for three major biofuels in European production: rape methyl ester and ethanol from wheat and sugar beet. Global trends and variability of energy and GHG balances were depicted and completed with a sensitivity analysis carried out for each methodological and data parameter, which allowed making recommendations on the carrying out of LCA in a policy-making or a biofuels comparison context. Methodological choices, and especially allocation rule, appeared as key elements for results variation with influences on balances up to 149%; system expansion approach was identified as the most relevant rule since it integrates the market potential and the environmental interest of by-products promotion, which was pointed out as a crucial point for biofuels sustainability.

The influence of local specificity for cultivation data was evaluated up to 167%, which puts too large geographical coverage in question. Modelling uncertainties due to N_2O emissions from soils showed influences from 17 to 46%, which represents a crucial challenge for research and for LCA results accuracy. Approximations evaluation pointed out the need to integrate agricultural machinery into the assessment. Finally, land-use issue revealed its dramatic importance for LCA results and the need to define explicit scenarios for land-use alternatives.

1. Introduction

In 2007, biofuel consumption in the European Union was 322 PJ, accounting for 2.6% of the energy content of all fuels used in road transport. This share increased sharply in a few years since it was 0.5% in 2003, and 1.0% in 2005. Domestic production of FAME (Fatty Acid Methyl Ester) is predominant and was 205 PJ in 2007, mainly from Germany (50.6%) and France (15.3%), and from rapeseed. Domestic production of ethanol was 38 PJ, mainly from France (32.4%), Germany

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(22.8%) and Spain (21.0%), and from cereals especially wheat, and from sugar beet. Imported biofuels were principally FAME from U.S. soybeans [1,2].

The promotion of biomass for energy purposes is generally based on two potential advantages: biomass may reduce the consumption of fossil materials and so mitigate climate change, and since it is a local resource it may decrease the energy and raw material dependence from other parts of the world. Liquid biofuels, as fuels derived from biomass, may offer the same benefits specifically for the sector of transportation which especially suffers from these difficulties. Furthermore, biofuels represent a market opportunity for the European agriculture in prospect of the 2012 Common Agricultural Policy reform, and a potential means to improve local economies.

However accurate evaluation of the environmental benefits from biofuels has been a controversial issue for the last years. Available results from Life-Cycle Assessments (LCA) or life-cycle based studies strongly disagree, as Fig. 1 illustrates for GreenHouse Gases (GHG) emissions reduction potentials and as previous studies already pointed out over a more exhaustive number of publications [3,4]. Since this disagreement may lead to contradictory policy-making measures, from moratorium to promotion of biofuels, this work aims at giving a better understanding of these discrepancies in results. Previous studies, mainly those from Farrell et al. and Bureau et al. [5,6], had similar objectives and used similar techniques, i.e. sensitivity analysis or meta-analysis approaches, and Monte Carlo techniques. Here focus is given on the European Union, and the review of data and methodology from 7 major LCA studies for biofuel production in Europe allow bringing three different outcomes: a global picture of results and trends for European biofuel performances, an identification of the key parameters for energy consumption and GHG emission calculations, and a proposal of recommendations for LCA carrying out for policy-making purposes and LCA simplification for comparison purposes.

2. Materials and methods

2.1. *Life-Cycle assessment (LCA)*

The fundamental principle of LCA is to study the environmental impacts of a product during its whole life-cycle, or "from cradle to grave", it is to say from the extraction of raw materials to their final disposal. LCA first appeared in the 1970s, and was standardized in the late 1990s. These standards were reviewed in 2006, leading to two international standards: ISO 14040:2006 for general public [7] and ISO 14044:2006 for practitioners [8].

Several guidelines are available to carry out an LCA [7–12]. From these valuable references, the following key notions can be described:

- the functional unit, which must be representative of the product system function, is a reference unit for life-cycle flows and indicators; it allows dematerializing the need and comparing systems;
- the system boundaries define the elements taken into account within the product life-cycle; some elements may be assumed to be negligible and excluded from the LCA if they meet the cut-off criteria;

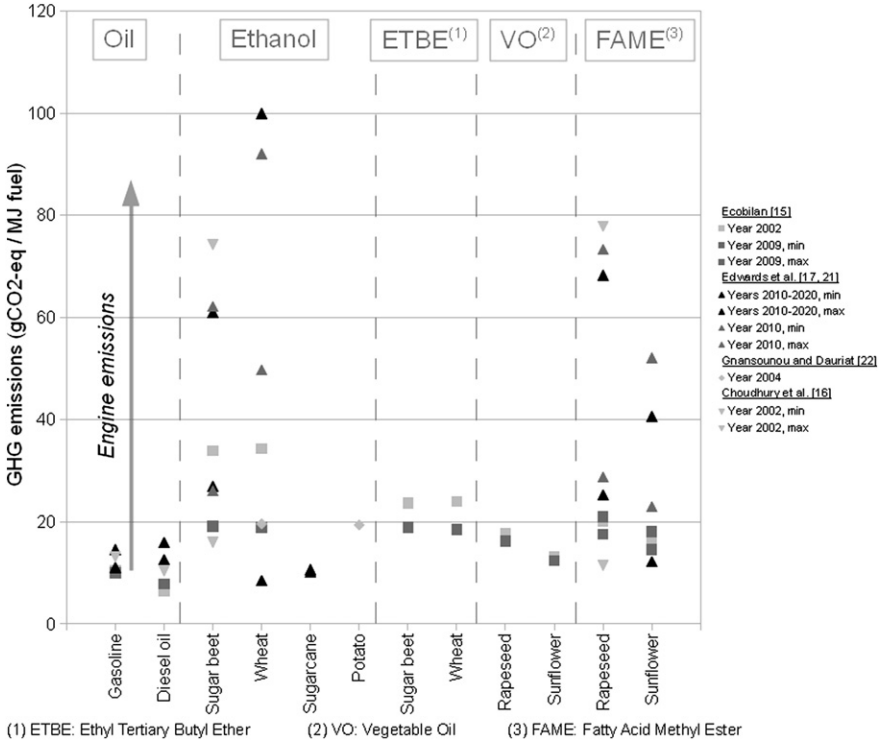

Fig. 1 – GHG emissions results from literature of different fossil fuels and biofuel chains.