Life Cycle Assessment: a preliminary study for second-generation biodiesel[1]

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Abstract

Second-generation biomass production might be an opportunity for organic farmers to reduce greenhouse gas (GHG) emissions, to advance economic development and a way to diversify risk. Life Cycle Assessment (LCA) framework for estimating second-generation biodiesel impact assessment has been defined. Theory and principles of method, process flow diagram structuring and questionnaire for data collection have been analyzed. LCA study reliability depends strongly on data of good quality. It is essential that data collected are specific and of primary origin (collected directly on the field) in order to have a reconstruction of the system as objective as possible. The questionnaire contains all inputs and outputs processes and sub-processes. The flow diagram defines the spatial, temporal and production chain limits of the process.

Keywords: *Life Cycle Assessment (LCA); Process flow diagram; Questionnaire for data collection; Second-generation biodiesel.*

Introduction

The strong fluctuations in fossil fuels prices and climate change are encouraging many governments to accelerate the research in biofuels. Can biofuels be an opportunity for the sustainable agriculture? Can agriculture slow global warming and in particular can bioenergy production make the organic farming more sustainable? (Pugesgaard, 2008). Agriculture is both cause and effect of climate change. Therefore it has to adjust itself to those changes and also trying to mitigate them (reducing greenhouse gas emissions and store carbon) (ITC UNCTAD/WTO and FiBL, 2007). Also, bioenergy production could represent a new market, a way to diversify risk in the farming business and a way to foster economic development in rural areas (Schlegel and Kaphengst, 2007). According to the principle of ecology *"organic agriculture should be based on living ecological systems and cycles, work with them, emulate them and help sustain them"* (Luttiklot, 2006); organic bioenergy production might be an opportunity for organic farmers to become self-sufficient in energy and an opportunity to diversify products, to develop a multifunctional farm which no longer producing only raw materials but provides services to the territory. According to the United Nations Framework Convention on Climate Change (UNFCCC, 1992), which requires all members countries to work out mitigation programs, European Union (EU), in January 2007 (COM 2007a), took on the unilateral commitment to reduce regional greenhouse gas (GHG) emissions at least 20% by 2020. Today, the European Union is the largest producer of biodiesel, representing over 80% of the world's biofuel production (COM 2007b). The European Commission has set up relevant targets for the development of biofuel production: the goal is that by 2020 the renewable energy produced must be equal to 20% of gross domestic consumption (GDC), while produced biofuels should reach a minimum target of 10% (COM 2007a, COM 2006). To overcome the risks of competition with food crops, most researchers focus on the so-called second-generation technologies. Second-generation bioethanol are biofuels that are made from non-edible sources such as lignocellulosic biomass, which comprises mainly cellulose, hemicelluloses and lignin (Tan et al., 2008). For example, some studies, such as Openshaw (2000) on *Jatropha curcas*, deal with non-edible plants with many attributes, multiple uses and considerable potential (such as prevent and/or control erosion, to reclaim land, grown as a live fence, commercial crop). Even in the Mediterranean area, the research goes towards the identification of crops with same characteristics: good productivity/yield and non-competitiveness with food and feed crops. This paper is conducted within the BIOFORME project whose goal is to evaluate, from a technical, environmental and economic point of view, the opportunity to use lignocellulosic and algae materials for, in same order, the ethanol and oil production. The crops analyzed are giant reed (*Arundo donax)* and sulla (*Hedysarum coronarium)* for the ethanol production and Microalgaes for oil production. Ethanol and oil can be used as *tel quel* fuels or combined into biodiesel. The choice of studying giant reed and sulla has been suggested since both species show a high yield potential and a low input demands in the Mediterranean area. Moreover both contribute to improve the environmental conditions and soil fertility, and also can represent an opportunity for organic farmers to become self-sufficient in energy and an opportunity to diversify their outcomes. Instead, the microalgaes represent an efficient alternative to land crops for biofuels; their high turnover rate provide a wide production amount of biomass in narrow space and in a relative short time. In

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§ This paper was conducted within the BIOFORME project.

particular, this paper deals with the first steps of environmental impact valuation and energetic efficiency of biofuels, through the use of Life Cycle Assessment (LCA) approach. LCA is an internationally computational method for estimating and assessing environmental life cycle impacts of a product or process (Rebitzer et al., 2004). LCA helps identify processes and sub-processes where technological innovation or strategic changes are needed to make such energy alternative efficient and sustainable (Nguyen and Gheewala, 2008). ISO 14040-series provides the standard for LCA and the framework includes: definition of goal and scope, inventory analysis, impact assessment and interpretation of results. This study describes the LCA preliminary setting and its data collection questionnaire, therefore we won't show final LCA results but just the methodology and its preliminary phases application for a kind of crops that were really few studied in an organic Mediterranean farming context.

Material and Methods

Theory

The ISO 14000-series defines the standards for LCA studies. In particular, the ISO 14040-1997 defines the principles and the framework of a LCA study, which can be logically divided in four steps:

– *goal definition and scoping* (ISO 14041-1998): the system under study is defined (definition of the production system, functional unit, approach to co-product allocation, environmental impact categories, detail level of the study, ...)
– *life cycle inventory* (ISO 14041-1998): input and output data are collected and analyzed
– *life cycle impact assessment* (ISO 14042-2000): the emissions in air, soil, water, as well as raw materials and energy consumptions, are standardized and translated into environmental effects
– *life cycle interpretation and improvement* (ISO 14043-2000): identify weaknesses and possible improvements of the processes.

Sources of information for LCA practitioners can be of various types, such as reports, books, calculations, personal information, LCA-databases, etc. (Von Bahr and Steen, 2004). It is essential that data collected are specific and of primary origin (collected directly on the field) in order to have a reconstruction of the system as objective as possible. The system boundary coordinates (Fig. 1) are given by spatial, temporal and production chain limits (start and end points) of the process that is being analyzed (Davis et al., 2009).

Questionnaire for data collection

In a LCA study, data collection is among the most challenging steps in terms of time and effort. As shown in Table 1, the questionnaire contains all input (output) processes and sub-processes: materials, amount of inputs, labour hours, packing, emissions, wastes and waste treatments, transports, energy, water. For each item, information about costs is required, because the BIOFORME project has also the aim to evaluate the economic efficiency of biomass crops, e.g. trough partial and total budget analysis. Some processes have common features in every geographical context while others have typical continental, national, or even regional properties (Rebitzer et al., 2004).

It is important to collect specific processes data and to create a specific database for each LCA study. To implement the LCA of the BIOFORME project, we have built an appropriate questionnaire for collecting the data needed to build the specific project database. For brevity, here we just list the main questionnaire items. The last column in Table 1 shows an example of the data needed to describe processes and sub-processes, which are also graphically displayed in Figure 1 to form the system boundary of the biodiesel life cycle. The questionnaire has been sent to each research unit participating in the BIOFORME project. A specific questionnaire and flowchart for the microalgae chain has been constructed but we cannot show it for reasons of space. Once data will be collected, the ISO 14048 (2001) identifies the technical specifications to describe the LCI (Life cycle inventory) data documentation format. The latter is structured in three areas: *process (description and inputs/outputs)*, *modeling and validation*, *administrative information* (Rebitzer et al., 2004). We will use the software SIMAPRO 7.3.2 for data processing and analysis.

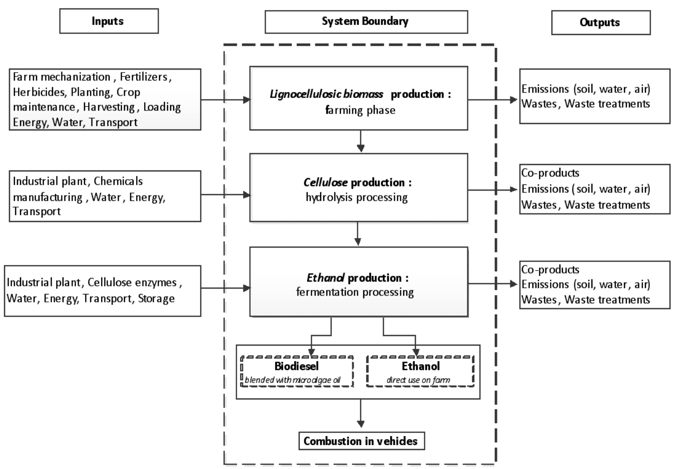
Table 1 - *Data required for the realization of lignocellulosic crops* (*Arundo donax* and *Hedysarum coronarium*) *questionnaire.*

Data categories	Processes and sub-processes	Data required
General data	**Plot –level data** (*size and location of the cultivated area)* **Farm-level data** (*total area, area designed for industrial plan, agricultural warehouse, …)* **Soil analysis**	All information needed to define the farm framework
Farming data	**Crop production** (*cultivar, seeds/ha, yield/ha, crop rotation, …*) **Land preparation** (*drainage system, fertilization, preliminary tilling, …)* **Sowing** (*sowing time, density, modality, machineries, …*) **Irrigation** (*plant, water, amount of water used, irrigation numbers, …*) **Crop production system management** (*fertilization, weed control, crop protection, harvesting, …*)	Every item require: machinery technical notes, inputs amount, labour hours, packing, emissions, waste and their treatment, transports, energy, water. For each process costs is required.
Biomass pre-treatment	*Technique, active principle, plant, storage*	*Idem*
Hydrolysis processing	*Technique, reagents, plant, storage*	*Idem*
Fermentation processing	*Technique, microorganism, catalyzers, plant, storage*	*Idem*

Results

Figure 1 shows the second-generation bioethanol processing steps. The system boundaries go from farming to the biodiesel use. The main processes taken into account are: lignocellulosic biomass production, cellulose production through hydrolysis processing, ethanol production for

Figure 1 - *System boundary of the biodiesel life cycle.*



fermentation, ethanol utilization. The ethanol obtained can be used for the transesterification of the microalgae oil (as planned in the BIOFORME project) or used directly as fuel for farm machinery. The flowchart show the *inputs* (energy, water, transport, industrial plant, etc…) and *outputs* (soil, water, air emissions, waste, co-products, etc…) involved in the processes. The flow diagram can only be an approximation of the system and its quality will depend on the presence within it of all components that contribute to the system. On the base of this flowchart the various questionnaires for data collection have been prepared. The database was designed to be as comprehensive as possible in order to obtain a general picture of all inputs and outputs involved in the LCA.

Discussion

Several studies have analyzed impact assessment of second-generation biodiesel through LCA method. Variations on data collected and different system boundaries definition produce diverse LCA analysis. Considerable variation exists in the decision rules for inclusion or exclusion of various operations (Vigon and Jensen, 1995). This work points out the importance of the preliminary study phases of LCA just because an adequate and transparent setting of work and an appropriate questionnaire are basic conditions for a reliable LCA. Process-flow diagram displays how processes of a product system are interconnected through commodity flow (Sush and Huppes, 2005) and it is useful to ensure that the system boundaries are properly described. To accurately estimate the costs and benefits of a system an holistic view of the system itself is needed, and of alternative fuel systems as well. Furthermore, feedbacks between policy, economics and land-use changes are required for a truly complete LCA (Davis et al., 2009). Then is very important to include all components that contribute to the system studied. For each process and sub-process, an adequate dataset is needed, and data collection requires a complete knowledge of each unit process. Qualitative and quantitative description of each item is also required. Once processes have been defined, the next steps is the questionnaire drafting which is designed to collect all necessary data. Data collected directly on field are preferable but there are some public databases which have been created and that include many processes and sub-processes. For example, E-coinvent database system (Frischknecht and Rebitzer, 2005) offers several thousand processes that can modified by including your own data. Our study will involve researchers of several fields, stakeholders and farmers of the Regions participating to BIOFORME project (Marche, Sicilia, Campania) to collect data.

Conclusion

One of the most important renewable energy resources is the second-generation bioethanol. Nevertheless, there are several position in the scientific literature about their environmental and economic sustainability. The BIOFORME project aims to contribute to scientific discussion on the second-generation biofuels. In particular, the project studies, from a technical, environmental and economic point of view, three different types of biomasses such as Giant Reed, Sulla and Microalgae that are really few investigated in Mediterranean area. The target is to characterize alternative biomasses for organic bioenergy production aiming at self-sufficiency and diversification of organic farms. Numerous studies have used a life cycle approach to estimate environmental efficiency and impact of bioenergy systems (Cherubini and Strømman, 2011). The evaluation of biomass crops economic efficiency will be studied through partial and total budget analysis. In this paper we described only the preliminary steps of a LCA study on organic biodiesel chain because the study is still in progress. A good LCA study and a reliable assessment of the benefits of the biofuels production chain may be obtained via a partnership between agronomists, biologists, chemists, economists and engineers.

Acknowledgment

The authors would like to acknowledge MIPAAF (Ministero delle Politiche Agricole Alimentari e Forestali) for the financial support given and partners of BIOFORME project for the scientific support.

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