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Environmental and life cycle analysis of a biodiesel production line from sunflower in the Province of Siena (Italy)

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HIGHLIGHTS

- Environmental profile of the biodiesel production from sunflower was evaluated.
- Agricultural phase is the critical step in the whole production line.
- Biodiesel from sunflower cannot be considered a totally renewable energy source.
- Biodiesel shows advantages in respect to mineral diesel but a higher land demand.
- Biodiesel mix may be a good solution on local scale.

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ABSTRACT

The Directive 2009/28/EC established the overall target that 20% of energy consumption should be represented by renewable energy sources by 2020 in each European member state. Furthermore, the Directive sets a mandatory 10% minimum target for biofuels in the transport sector.

Biofuels are potentially an important alternative to mineral diesel. We propose a pilot production line of biodiesel from sunflower on local scale in the Province of Siena (Tuscany) to research a possible reduction of fossil fuel consumption in the transport sector.

This study might represent an opportunity to reduce petroleum dependence in the transport sector.

Environmental Impact Indicators were provided by Material Flow Accounting, Embodied Energy Analysis and Emergy Accounting. Results showed that agricultural phase is the critical step in the production line.

A comparative Life Cycle Assessment analysis for the biodiesel production line with mineral diesel production showed environmental advantages of the biofuel production, however requiring a higher land demand. Therefore, biodiesel may not the optimal solution on large scale but might be a good alternative to fossil fuel. This would depend upon the entire production cycle taking place in a limited area. This is necessary in order to fulfill the needs of local farms and small enterprises.

1. Introduction

The biofuels are liquid or gaseous fuels for the transport sector that are produced from biomass. Biofuels can be of first-generation or second-generation (Naik et al., 2010). First-generation biofuels are made from sugar, starch, vegetable oil, animal fats and seeds. Second-generation biofuels are made from biomass consisting of the residual non-food parts of crops.

Recently, biofuels have been considered to offer sustainability and regional development (social structure and agriculture advantages) (Pousa et al., 2007; Van Dyne et al., 1996). As a consequence, researchers have recently focused on their development as renewable resources for the transportation sector. For this reason, in developing countries there is an increasing effort to employ modern technologies and biotechnology applications (Shweta and Munishwar, 2007; Rodrigues et al., 2010). This involves using a variety of biofuels which are becoming competitive with fossil fuels on a cost scale (Demirbas, 2000).

Biofuels are generally more expensive than traditional fossil fuels, but the expected gain in greenhouse gas emission reduction are believed to reduce the importance of the cost gap, and to provide an important alternative (Duer and Christensen, 2010). First, biofuels can easily replace mineral diesel fuel in boilers and internal combustion engines without major adjustments (Qi et al., 2009). Second, when mineral diesel is replaced by biofuel only a small decrease in performance has been reported. It was also

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observed that sulfate and CO_2 emissions (when the whole cycle was considered) were minimal. Furthermore, when a biofuel was used, emissions of pollutants were comparable to those of mineral diesel (Puppan, 2002).

Currently, the market for biofuels is concentrated in a limited set of European Member States (Germany, France, Spain, Sweden, and Austria) (European Commission, 2006).

The European framework for the biofuel sector dates back to 2003, when Directive 2003/30/EC set an indicative target of 5.75% biofuel for the transport sector by 2010 (Garofalo, 2007). In 2009, the new European Directive established the overall target that 20% of energy consumption should be represented by renewable energy sources by 2020 in each European member state (European Commission, 2009; Fischer et al., 2010). In addition, the Directive sets a mandatory 10% minimum target for biofuels in the transport industry. In Italy, 17% of energy consumption must be due to renewable resources by 2020 (European Commission, 2009).

Greenhouse gas savings of at least 35% will be required for biofuels in comparison with the fossil fuels, and feedstock will need to come from areas without a high biodiversity value, or without high carbon stock (in order to avoid deforestation practices) (European Commission, 2009).

With regard to first generation biofuels, the use of resources from agricultural sector induces a lower climate change potential, but can create other environmental issues (e.g. eutrophication, resource depletion, ecotoxicity, biodiversity, …) and generates competition with food crops for the use of arable land (Zah et al., 2007). Therefore, the production of second generation biofuels from the whole plant matter of dedicated energy crops or agricultural residues, forest residues or wood processing waste, rather than from food crops should be implemented as soon as possible (Moore, 2008). However, on local scale, when there is a need for improving a farmers' agricultural budget by means of even a small income or savings from bioenergy production, first generation biofuel could still be considered.

The merits of using energy crops for biofuel production in Tuscany (central Italy) have been recently analyzed in terms of both bioethanol (maize) and pure vegetable oil (sunflower) (Dalla Marta et al., 2010). There are several studies in the literature that evaluate environmental profiles of biofuels production (Sanz Requena et al., 2011; Tsoutsos et al., 2010; Iriarte et al., 2010; Chiaramonti and Recchia, 2010; Ragaglini et al., 2011; Reijnders and Huijbregts, 2007). In general as discussed in a key paper by Cherubini et al. (2009), caution should be exercised in interpreting results as they can be affected by input parameter values, system boundaries, allocation procedures and fossil reference system. More recent papers focused on the greenhouse gas emission related to the reduction of soil carbon stocks due to land use change and farming practices (Vleeshouwers and Verhagen, 2002; Canals et al., 2012; Di Lucia et al., 2012). Clearly in case of growing crops on deforested land or grassland, the loss of carbon from soil in converting the area into arable land has a very high impact on the life cycle greenhouse gas emissions of biodiesel production (Reijnders and Huijbregts, 2008). European biodiesel production is less affected from the biogenic CO_2 emission if the crops are cultivated in pre-existent arable lands and no changes in the management activities on cropland occurred. Thus soil organic carbon could be considered in a quasi-steady state (Spugnoli et al., 2012) and changes in agricultural practice as conservation tillage, return of harvest residues and improving N-efficiency by precision agriculture may reduce or reverse carbon loss from soils (Reijnders and Huijbregts, 2007).

The purpose of this paper was to design an LCA study of a biodiesel production line on a local scale from sunflower oil in a provincial area and a comparative evaluation with the mineral diesel production plant. In particular, the study evaluated the reduction of CO_2 emissions by use of biofuel in a fuel mixture of 25% with mineral diesel.

2. Material and methods

2.1. Goal and scope definition

The Province of Siena represents an area in the Tuscany region of Italy with a surface of 3820 km^2 with a predominant hilly landscape (92%). Agricultural activity (wheat, grapes and fruit) represents the main economic sector of this district (Basosi et al., 2006). In this context, a pilot production chain of biodiesel from sunflower represents an opportunity to examine a possible reduction in the local fossil fuel consumption. The scope included the agricultural phase, sunflower oil extraction, transesterification and all transportation activities within the system boundary. The functional unit of this study was defined as 1 kg of biodiesel from sunflower oil.

Average data for 2008 from five farms (Table 1) and a conversion plant were used. Sunflower seeds were transported to the extraction plant by a 18 t road truck over a distance of 50 km. Sunflower oil was obtained by hot crushing and solvent extraction system using hexane. Sunflower oil was transported to the transesterification plant by a 32 t road truck over a distance of 290 km. Then biodiesel was obtained via a transesterification process with sodium methoxide in acidic environment (phosphoric acid). Alkaline metal alkoxides (as sodium methoxide) are the most active catalysts and they give very high yields ($>98\%$) (Vicente et al., 2004; Demirbas, 2008; Lang et al., 2001; Shahid and Jamal, 2011).

Three environmental assessment methods were adopted for the analysis: Material Flow Accounting (MFA), Embodied Energy

Table 1
Average data and standard deviation for sunflower cultivation from five farms of the Province of Siena (year 2008).

Flow and Unit (amount per ha per year)	Farm 1	Farm 2	Farm 3	Farm 4	Farm 5	Average value	Standard deviation
Inputs							
Loss of topsoil (g)	1.72E+07	1.72E+07	1.72E+07	1.72E+07	1.72E+07	1.72E+07	–
Nitrogen fertilizer (g)	7.50E+04	1.14E+05	1.01E+05	1.22E+05	1.03E+05	1.03E+05	1.78E+04
Phosphate fertilizer (g)	4.05E+04	2.20E+04	4.05E+04	1.58E+04	3.03E+04	2.98E+04	1.10E+04
Insecticide, pesticide, erbicide (g)	1.00E+03	1.00E+03	1.00E+03	3.50E+03	1.42E+03	1.58E+03	1.09E+03
Diesel (l)	1.60E+02	1.39E+02	1.53E+02	1.36E+02	1.51E+02	1.48E+02	9.81
Lubricants (l)	0.48	0.42	0.46	0.41	0.45	0.44	2.94E−02
Steel for agricultural machine (g)	1.90E+02	1.65E+02	1.98E+02	1.73E+02	1.90E+00	1.83E+02	1.37E+01
Seeds (g)	5.00E+03	5.00E+03	5.00E+03	5.00E+03	5.00E+03	5.00E+03	–
Output							
Sunflower seeds (g)	2.27E+06	2.47E+06	1.97E+06	1.98E+06	1.85E+05	2.11E+06	2.52E+05