Science of the Total Environment 408 (2010) 5010–5018

Contents lists available at ScienceDirect

Science of the Total Environment

journal homepage: www.elsevier.com/locate/scitotenv

Greenhouse gases emissions and energy use of wheat grain-based bioethanol fuel blends

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ARTICLE INFO

Article history:
Received 10 March 2010
Received in revised form 9 July 2010
Accepted 17 July 2010
Available online 7 August 2010

Keywords:
Bioethanol
Greenhouse gas emissions (GHGs)
Life cycle assessment (LCA)
Lombardia
Wheat
Biofuel

ABSTRACT

This study focuses on the potential energetic and environmental impacts associated with the production of wheat grain-based bioethanol in Lombardia (Italy), with a "seed-to-wheel" approach (i.e. taking into account the production and use phase). Greenhouse gas emissions (GHGs) were estimated through the CML 2 baseline 2000 methodology counting the CO_2 equivalent emissions, while the energy flow indicator was estimated using the Ecoindicator 95 methodology. The impact of the different phases involved in the production and use of bioethanol have been analysed: the agricultural production of wheat grain, its transformation into bioethanol, the production of gasoline and the use of 5 different blends (from pure gasoline to pure ethanol).

The results show that ethanol fuel, used in the form of blends in gasoline, can help reduce energy use and GHGs. In particular, the use of pure ethanol was found to be the best alternative presenting the lowest GHGs (saving about 32% of CO_2eq emissions in comparison to gasoline) and the minor energy use (63% saving). Differences between low-ethanol blends and gasoline are minimal and dependent on the specific fuel consumption of the vehicle. The sensitivity analysis performed to test the robustness of results through the change of some basic assumptions (specific fuel consumption, N_2O emissions from agricultural phase, allocation method) shows the sensitivity of GHGs saving to the adopted allocation method.

1. Introduction

Nowadays society faces important decisions regarding climate change mitigation with concerns to potential accumulation in atmosphere of greenhouse gas emissions (GHGs). In the European Union (EU), transport is responsible for an estimated 21% of all GHGs that are contributing to global warming, and the percentage is rising (EC, 2006). The use of biofuel is one of many strategies proposed by the European Commission to reduce GHGs in this sector. In order to improve the usage and production of biofuels, the Renewable Transportation Directive was adopted in 2003 with the aim of increasing biofuel share in transportation fuels to 2% in 2005 and 5.75% in 2010 (EPC, 2003).

Major studies show that most biofuels produce lower levels of GHGs than fossil fuels on a life cycle basis (Johansson et al., 1993; Edmonds et al., 1996; Nakicenovic et al., 2000; Edwards et al., 2007). Nevertheless, according to Zah et al. (2007), the environmental impacts of biofuels are variable and depend very much on location and production methods and consequently a case-by-case assessment may be required.

This work aims thus to evaluate the GHGs and energy use of bioethanol produced from wheat in Lombardia (northern Italy) using the life cycle assessment (LCA) methodology. Although many studies have been performed concerning this topic (as reviewed by Von Blottnitz and Curran, 2007), the originality of this is the specific geographical localization analysed (Lombardia), together with the "seed-to-wheel" approach which considers the entire life cycle of the five ethanol blends analysed. The Lombardia region is characterised by high production of wheat (Fig. 1; Istat, 2007) and 200 km proximity of recently designed refinery plants of grain-based ethanol. These considerations, along with the remarked objective of EU in the biofuel issue (EPC, 2009) and the great increase of CO_2 emissions from transport (+41% between 1990 and 2005 in Lombardia, Caserini, 2008), were the basis of this study in relation to wheat grain-based bioethanol production and use.

2. Goals and scope definition

2.1. Objectives

The main objective of this study has been the evaluation of the impact of both production and use of bioethanol, comparing different

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doi:10.1016/j.scitotenv.2010.07.046

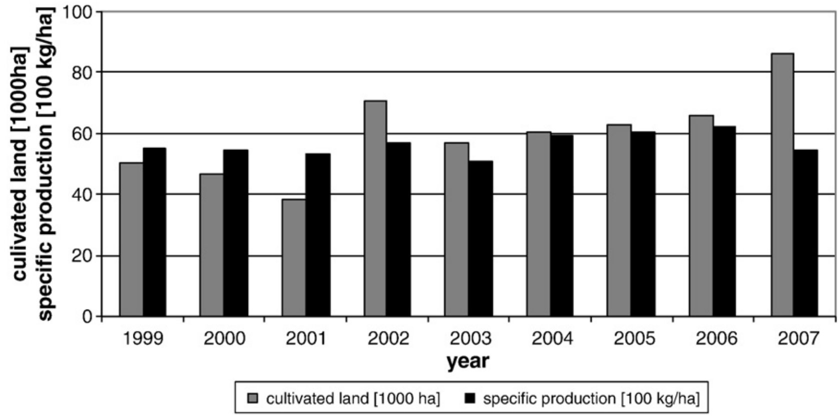

Fig. 1. Land dedicated at wheat cultivation and specific production in Lombardia (Northern Italy). Data source: Istat, 2007.

ethanol blends with consideration to total energy use (all energy input including fossil and non-fossil based energy) and environmental impact in terms of CO_2 equivalent emissions.

Five different blends were considered:

- E0: pure gasoline;
- E5: 5% ethanol and 95% gasoline;
- E10: 10% ethanol and 90% gasoline;
- E85: 85% ethanol and 15% gasoline;
- E100: pure ethanol.

LCA methodology was used to estimate the impacts of these products, following the ISO standards (ISO 14040 and 14044, 2006). In particular the impact due to GHGs associated with the different blends were estimated through the CML 2 baseline 2000 methodology (Heijungs et al., 1992; Guinée et al., 2001) whereas energy flow indicator was performed with the Ecoindicator 95 methodology (Goedkoop, 1995).

CML 2 baseline is an update of the CML method, issued in 1992 by the "Centre of Environmental Science" of Leiden University. It contains ten impact categories defined for the midpoint approach (PRé Consultants, 2008). The characterisation model used for the definition of the characterisation factors of "global warming (GWP100)" category was developed by the Intergovernmental Panel on Climate Change (IPCC, 2001): these factors are defined as Global Warming Potential for a time horizon of 100 years (GWP 100) and are expressed in $kgCO_2/kg_{emission}$.

The Ecoindicator 95 method was developed under the Dutch NOH (National Reuse of Waste Research) program by PRé-consultants. This method is implemented in the software used for this study (i.e. SimaPro) with eleven impact categories characterised by a damage oriented approach (PRé Consultants, 2008). "Energy resources" category refers to the extraction and production of fuels and to energy generation, accounting for energy efficiency.

2.2. Functional unit

The functional unit (FU) is the quantified performance of a product system used in reference in a LCA study (ISO 14040, 2006). In this assessment, the FU assumed is the amount of fuel required for 1 km distance: it was assumed that, whether used neat or in blends, the fuel consumption on energy basis would remain the same as for the base fuel (Edwards et al., 2007). Thus, gasoline consumption was set equal to 6.95 l per 100 km whereas that of pure ethanol was set equal to 10.5 l per 100 km.

2.3. Description of the system under study

Fig. 2 shows the flowchart representing the system analysed, which can be broken up in the following subsystems:

- Agricultural Subsystem (S1), which deals with wheat-growing. Wheat is cultivated in a farming system using the most common farming practices in Lombardia (intensive and non-irrigated culture from October/November to June/July). Rainwater was considered to be an adequate supply of water for wheat cultivation. This subsystem includes all agricultural field operations for wheat cultivation (ploughing, harrowing, fertilizers and pesticide spreading, sowing and harvesting), based on a survey of collected data including questionnaires filled by farmers and manuals of farming techniques related to northern Italy territory. The analysis included wheat seeds, tractors, machineries, fertilizers and pesticide production as well as their transportation to the farm gate. The amount of agricultural machinery required for a specific work process was obtained by multiplying the weight of the utilised machinery by the time required for the field work over the lifetime of the machinery (Nemecek et al., 2004). Energy carrier (mainly diesel) production and transportation were included, too.
- Refinery Subsystem (S2), which deals with the production of bioethanol. Harvested grain is transferred to the refinery plant whereby it is transformed into bioethanol through fermentation. Distillation processes which consume electricity and steam are included. Production and use of chemicals is accounted for, too. The transport of grain from farm to refinery plant is delivered by a 40 t lorry covering a distance of 200 km (one-way trip, from Lombardy to Venice), while transport of chemical compounds is carried by a 32 t lorry covering a distance of 110 km (Bernesson et al., 2006). During the fermentation process 1.01 $kgCO_2/kg_{ethanol}$ are generated and released to air (Lechón et al., 2005).
- Gasoline Production Subsystem (S3), which describes the production and distribution of fossil gasoline. It includes oil field exploration, crude oil production, long distance transportation, oil refining and regional distribution. Emission of air and waterborne pollutants, waste production, and requirements of energy and working material have all been considered and included in the subsystem boundaries (Dones et al., 2004).
- Fuel-use Subsystem (S4), which describes the production and use of the five blends. Emissions due to the combustion of these different blends in a flexi fuel vehicle was calculated according to the quantity of bioethanol added to gasoline, emission factors found in literature (Table 1) and specific fuel consumption. Emissions were referred to the same reference vehicle (a passenger car, 1.6 cm^3), whose manufacture, servicing and disposal were excluded being the