Applied Energy 114 (2014) 837–844

Contents lists available at SciVerse ScienceDirect

Applied Energy

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

Environmental life-cycle assessment of rapeseed-based biodiesel: Alternative cultivation systems and locations

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HIGHLIGHTS

- We present a comparative LCA for alternative RME production systems.
- Different cultivation systems and geographical locations for rapeseed are addressed.
- Environmental impacts of cultivation far outweigh impacts of other life-cycle stages.
- Cultivation practices strongly influence the global warming impact of RME.
- The geographic region for cultivation is a key aspect in the impact assessment of RME.

ARTICLE INFO

Article history:
Received 28 February 2013
Received in revised form 22 June 2013
Accepted 25 June 2013
Available online 18 July 2013

Keywords:
CML 2001
Environmental impacts
Land use
LCA
Rapeseed methyl ester (RME)
Transportation

ABSTRACT

This article presents an assessment of the environmental performance of rapeseed-based biodiesel, addressing alternative geographical locations and cultivation systems for rapeseed (in Spain, France, Germany and Canada). Four environmental impact categories have been assessed using the CML 2001 life-cycle impact assessment method: abiotic depletion; global warming; acidification; and eutrophication. Results show that rapeseed cultivation has the highest contribution to all the environmental impact categories evaluated, with a share between 40% (abiotic depletion, Germany) and 98% (eutrophication, Spain). The use of fertilizers and associated soil emissions are the main contributions to the environmental impacts of cultivation. Soil carbon changes due to different agricultural practices are particularly important in terms of the global warming impact of rapeseed-based biodiesel. The use of fossil methanol in biodiesel production has significant impacts in terms of abiotic depletion and the consumption of heavy fuel oil in transoceanic transportation is an important contributor to acidification.

1. Introduction

Biofuels have emerged as the main alternative for fossil fuels in the transportation market, due to growing concerns about climate change, dependence on the oil sector and increasing fuel prices. However, the production of biofuels requires fossil inputs and may have significant environmental impacts, particularly associated with biomass cultivation. To assess the environmental impacts of biofuels delivered to consumers, a life-cycle approach must be employed, considering all stages from land use change, biomass cultivation, production, distribution and use of the biofuel. The main goal of this article is to assess the environmental life-cycle performance of rapeseed-based biodiesel produced in Portugal, addressing alternative geographical locations and cultivation systems for rapeseed (in Spain, France, Germany and Canada).

The European Union holds the leading position at worldwide level in terms of biodiesel production and consumption [1,2]. The most used raw material is rapeseed, accounting for nearly 80% of the total European biodiesel feedstock [3,4]. Rapeseed-based biodiesel has good cold flow properties and oxidation stability, and fits better within European biodiesel standard specifications. In terms of consumption, biodiesel reached 10.6 million tonnes of oil equivalent in 2011, which represents 78% of the energy content of all biofuels used in European road transport, compared to 21% for bioethanol, 0.5% for vegetable oil and 0.5% for biogas [5]. In terms of total fuel consumption in the European transportation sector, biodiesel reached a market share of approximately 3.9% in 2012, or 5.8% if compared with fossil diesel consumption only [6]. Concerning Portugal, biodiesel is mainly produced through raw material imports and is dependent on fossil diesel sales under a blending quota system. In 2011, biodiesel production in Portugal amounted to 343 ktonnes, which represents approximately 7% of the fossil diesel marketed for road transport and 55% of the maximum biodiesel production capacity estimated by the industry: 626 ktonnes/year in seven biodiesel plants [7].

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http://dx.doi.org/10.1016/j.apenergy.2013.06.048

This investigation draws on previous life-cycle studies addressing straight rapeseed oil and rapeseed-based biodiesel [8–10]. These previous studies were however limited to energy and greenhouse gas (GHG) emissions and did not address cultivation and geographical variability. The majority of studies in the literature have also restricted the assessment to energy and GHG emissions, neglecting other environmental impact categories [10–14]. Some LCA studies calculated other environmental impacts in the life-cycle of rapeseed-based biodiesel, but did not assess important aspects, namely soil carbon emissions from alternative cultivation systems [15,16] or land use change [15–18]. Despite its importance, the assessment of agricultural practices is a frequently neglected aspect in LCA studies [18]. Improving agricultural practices (e.g. use of no-till practices instead of mechanical tillage; maximize the return of harvest residues to arable soils) should be an important focus towards higher soil carbon stocks and lower life-cycle GHG emissions of biofuel systems [19]. Direct soil carbon emissions from land use change are also an important issue affecting the GHG intensity of biofuels [19,20]. Land use change is understood as referring to changes in terms of land cover between six land categories used by the IPCC, namely forest land, grassland, cropland, wetlands, settlements and other land [21].

The most representative cultivation system for rapeseed-based biodiesel marketed in Europe is rapeseed cultivated in existing cropland. This system is not considered land use change according to the guidelines on the calculation of soil carbon stock variations associated with direct land use change [21], although it may be associated with different agricultural practices. To show the importance of different cultivation practices in the GHG assessment of rapeseed-based biodiesel, this article assesses two extreme scenarios concerning soil carbon changes using data from the IPCC [22] and the European Commission [23]. This article is organized in 4 sections, including this introduction. Section 2 ("Methods") presents the LCA methodology implemented and the life-cycle modeling of biodiesel from rapeseed, including soil carbon stock variations due to changes in agricultural practices. Section 3 ("Results and Discussion") discusses the main results for selected environmental impact categories: abiotic depletion; global warming; acidification; and eutrophication. Finally, section 4 ("Conclusions") draws the conclusions together.

2. Methods

2.1. Goal and scope

This article aims at assessing and comparing the environmental performance of rapeseed-based biodiesel in terms of alternative cultivation systems and geographical locations. The environmental life cycle assessment (LCA) methodology has been employed. LCA is based on system analysis and handles the process as a chain of subsystems that exchange inputs and outputs. According to ISO standards [24,25], an LCA has four interrelated phases: the goal and scope definition (including the definition of a functional unit and system boundaries), the Life-Cycle Inventory (LCI), the Life-Cycle Impact Assessment (LCIA) and interpretation. This LCA follows a "well-to-tank" approach, which includes all steps from resource cultivation to final distribution of the fuel (Fig. 1). The functional unit selected is 1 MJ of biodiesel energy content, measured in terms of the lower heating value.

Four alternatives have been selected regarding rapeseed cultivation, namely in terms of the type of fertilizer and geographical location considered for growing the crop: two representative regions in the two most important rapeseed-producing countries in Europe (France and Germany) together with rapeseed cultivation systems in Canada and Spain. According to [26], 21% of global rapeseed production has been exported to the world market in 2012, mainly from Canada and mostly to the EU. Canada is the world's largest single rapeseed producer – 23.7% of total production, or 14.6 Mtonnes in 2012 – and exports more than 60% of its production [26]. On the other hand, the European Union is the largest importer of rapeseed, representing 29% of the world's total imports [26]. Nevertheless, the European Union produced approximately 19 Mtonnes in 2012: France and Germany are the main producers, with a share of nearly 40% of total EU production [26,27]. The fourth rapeseed cultivation system considered in this article is located in Spain, which is a potential rapeseed-exporting country to Portugal due to its geographical vicinity.

2.2. Life-cycle inventory

Data collection has been carried out to build LCI tables of the biodiesel production system for each alternative. The four alternatives, including transportation systems and distances considered, are described in Table 1. In the LCIA phase, inventory data has been aggregated into specific environmental impact categories according to the CML 2001 method (*Institute of Environmental Sciences, Leiden University*). Four relevant environmental impact categories have been assessed: abiotic depletion; global warming; acidification; and eutrophication.

Rapeseed cultivation includes several steps, namely soil preparation, fertilization, sowing, weed control, and harvesting. Seeds are separated from the rest of the plant during harvesting. The straw (consisting of stalks, pods and leaves) is usually plowed back into the field, which is a farm management activity with several benefits, namely the return and cycling of nutrients, the building of soil organic matter and the prevention of soil erosion [28,29].

Following harvesting, oilseeds are cleaned and dried. The typical moisture content of oilseeds is reduced, as required by oil extraction facilities and to ensure stability in storage. Oilseeds are transported to Portugal, where the final steps of the life-cycle

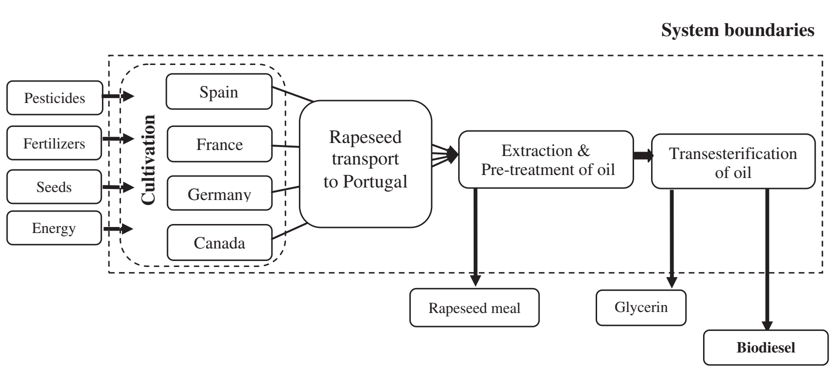

Fig. 1. Flow chart illustrating the life-cycle chain (well-to-tank) of rapeseed-based biodiesel.