Journal of Cleaner Production 93 (2015) 65–74

Contents lists available at ScienceDirect

Journal of Cleaner Production

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

Life Cycle Inventory for the agricultural stages of soybean production in the state of Rio Grande do Sul, Brazil

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A R T I C L E I N F O

Article history:
Received 11 August 2014
Received in revised form
6 January 2015
Accepted 8 January 2015
Available online 16 January 2015

Keywords:
Life Cycle Inventory
Soybean
Agriculture
Land use change
Global warming
Biodiesel

A B S T R A C T

Soybean is an important feedstock and its oil represents 70% of the raw material used for the production of Brazilian biodiesel. The main purposes of this work was to present a Life Cycle Inventory of soybean produced in Rio Grande do Sul, state in Brazil, based on primary data of agricultural soybean production in this region. Inventory data was collected in 23 municipalities that account for 32% of total soybean production. A Machinery Operation Modeling was suggested to adjust agricultural machinery inputs/outputs for harvesting under study. The soybean cultivation Life Cycle Inventory was divided into four stages and not as a black box. Based on questionnaire responses, it was possible to characterize some regional peculiarities of soybean production. For the estimation of Greenhouse Gas emissions from direct land use change and nitrous oxide emissions from soil, an assessment of soybean advancement over distinguished areas was performed. The results showed that for 15.4% of cultivated area from 1992/93 to 2012/13 transition from pasture to farming has occurred, mainly over rice and corn crops. It should be underscore that no evidence of soybean advances from forest to farming was found for the region. Moreover, this work considered nitrous oxide emissions from soil and a complete inventory was presented. Lastly, this works aims to offer soybean inventory data specifically to Rio Grande do Sul state and presents a new approach to perform environmental results related to agricultural life cycle assessment.

1. Introduction

Soybean is a major source of protein and vegetable oil in the world (FAO, 2013). Besides these main products a wide range of co-products can be obtained form soy, especially glycerin, lecithin, carboxylic acids and its derivatives, lubricants and biodiesel. In Brazil soybean represents 70% of the feedstock for biodiesel production (ANP, 2013), and the increasing Brazilian biodiesel production depends strongly on soybean oil since its production chain is the only one ready to supply enough oilseed for the current demand (Castro, 2011). In 2012/2013 crop, the state of Rio Grande do Sul state (RS) harvested 12.5 million tons of soy (CONAB, 2013a), amount higher than Paraguay soybean production, the sixth biggest world producer (FAO, 2013; IBGE, 2013b).

The exponential growth of soybean's biodiesel production has been the target of discussion in the scientific community, the focus of which has been mainly its environmental performance (Castanheira and Freire, 2013; Pousa et al., 2007; Raucci et al., 2014). When life cycle assessment (LCA) studies were applied to evaluate the environmental impact of soy based biodiesel the soybean production appeared as the primary contributing stage for the environmental impacts of this product system due to several

Abbreviations: Consumption, machinery-specific consumption (L h^{-1}); d, is fuel density (kg L^{-1}); DC, distance covered (km ha^{-1}); Eg_i, (kg gas soybean kg^{-1}) is issued of a substance from a particular machinery or intervention eq (equivalent).; FC, fuel consumption specific to each intervention (L ha^{-1}); Fg_i, factors emissions from the combustion of Diesel (kg gas kg^{-1} Diesel); GHG, Greenhouse Gas; hia, number of harvests under the influence of the application; LCI, Life Cycle Inventory; LUC, land use change; MOM, Machinery Operation Modeling; p, soybean yield; RS, Rio Grande do Sul; TCi, total consumption of fuel to a specific equipment (kg ha^{-1}); WF, Work Factor; WS, Working Speed (km h^{-1}); wsa, number of works done in the same application.

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http://dx.doi.org/10.1016/j.jclepro.2015.01.016
0959-6526/

inputs and agricultural practices, specially for Greenhouse Gas (GHG) emissions (Cavalett and Ortega, 2010; Panichelli et al., 2008). Other important sources of GHG are the land use change (LUC) and emissions of nitrous oxide from soil (Borjesson and Tufvesson, 2010). Studies point out that impacts due to GHG emissions differ greatly if the changes in the land used were accounted for (Gnansounou et al., 2009; Cherubini, 2010; Humpenöder et al., 2013). According to the Lapola et al. (2014) 80% of CO_2 eq emissions in Brazil in 2005 arised from LUC and agriculture. Nitrous oxide, a GHG 298 times more important than CO_2, is naturally produced in the soil, and is related to the use of nitrogen fertilizers, crop residue and LUC.

Based on this information, it is necessary to evaluate which environmental impacts result exclusively from the agricultural stage in soybean production of RS and other Brazilian states. Following ISO standards 14040:2006 and 14044:2006, Life Cycle Inventory (LCI) is one of the LCA phases in which the production system is defined and its modeling might be the hardest and most difficult effort due to the lack of high quality data, and historically estimation has sometimes been necessary (Ruviaro et al., 2012).

Several authors has pointed out that there is a high discrepancy among the LCA results related to soybean production (Malça and Freire, 2011; Panichelli et al., 2008; Raucci et al., 2014) since regional specificities are key factors for assessing environmental impacts and discrepancies can emerge from the consideration of different energy sources, modes of transportation, agricultural practices and whether or not the LUC will be accounted for (Piekarski et al., 2012). Most of the published studies have considered Brazilian soybean production taking in account national averages, disregarding that there are several very distinct regions where this grain is cultivated. It is important to remind that traditionally several LCA studies approach the agricultural phase as a black box, disregarding an important source of information for assessing the environmental performance of product systems based on agriculture feedstock. In fact at our best knowledge there is only one important LCA approach for GHG emission related to Brazilian soybean production that has collected primary data directly from producers in Mato Grosso state (Raucci et al., 2014).

This work aims to construct an LCI for soybean production avoid using data sources that diverge from the actual practices in the region under study, making an inventory that resembles as closely as possible the existing conditions for soybean production in RS. Data were collected from the local offices for technical support for agricultural activities and the material flows modeling was structured by describing four distinct phases for soybean production, taking in account the machinery operation. For the first time a LUC related GHG emissions were also evaluated after the assessment of soybean advancement over other cultivations and grassland areas in RS in the last 20 years.

2. Methods

The LCI elaboration was conducted accordingly to the ISO 14040 and 14044 standards. The system boundaries and the reference flow with energy and material inputs/outputs are presented in Fig. 1. The functional unit (FU) is one kg of soybean produced.

Primary data were collected aiming to model the steps that compose the main links of soybean production using questionnaires and interviews. It was also adopted calculation methodologies to estimate GHG–LUC emission flows, nitrous oxides from the soil and limestone use. The GHG emissions from fossil fuels combustion by agricultural machinery were calculated based on emission factors available in the bibliography.

A Machinery Operation Modeling (MOM) is suggested to adjust inputs/outputs flows related to agricultural machinery to harvest the season under study.

2.1. Study considerations

Only direct LUC related GHG emissions. The indirect land use change (iLUC) was not addressed, because according to Broch et al. (2013) there is uncertainty and variability related to iLUC modeling, given the lack of available data on the indirect conversion of soils (Castanheira and Freire, 2013; Milazzo et al., 2013; Kendall e Chang, 2009).

The soybean cultivated in RS does not use irrigation, i.e., depends on only rain season. Infrastructure, electrical energy and maintenance of machinery were not taken in account.

This study considers that the whole mass of pesticides and fertilizers are issued to the soil, the worst-case scenario. However, for nitrogen fertilizer was necessary to consider the loss to the air, associated with the emission of N_2O from soil.

2.2. Data collection

The data collected by the questionnaire refers the 2012/2013 soybean crop cultivated in RS. The main goal of this questionnaire was to quantify inputs and outputs, productivity, agricultural practices and the kind of machinery used.

The information was collected from 2013 July to November. The questionnaire was drawn up based on five field visits made to farms, consultation of LCA experts and agronomy subjects, as well as technical literature (EMBRAPA, 2011; SBCS, 2004) in order to seek for reliability in the data collected.

The target audience was local offices of the department of rural technical supports of RS. The collected data prioritized municipalities that presented the biggest recent soybean harvests. From the data of the municipal agricultural production (IBGE, 2013b), it is observed that 405 of the 497 municipalities in RS have some record of soybean production in the period between the years of 2007–2011. Considering the average production in this period, we can see that the fifteen largest producers accounted for 25% of production and the forty-six largest producers are responsible for 50% of production.

Each local office answered a questionnaire, where answers from municipalities whose representativeness were less than 0.01% were not considered. The average value for each input and output was calculated by arithmetical average of the answers in each municipality.

2.3. Machinery Operation Modeling (MOM)

This modeling was used to determine the amount of fuel consumed for machinery in each farming phase. The main idea is to obtain an index for actual covered distances and the number of

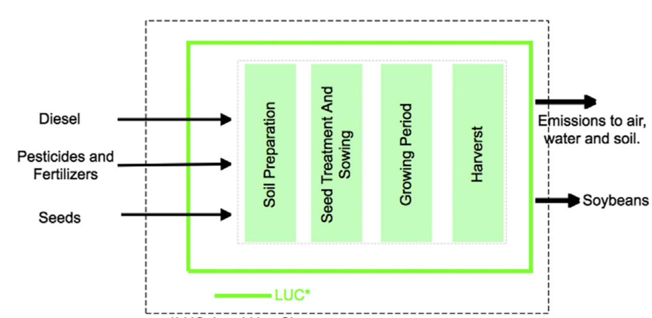

Fig. 1. System boundaries.