Applied Energy 89 (2012) 254–261

Contents lists available at ScienceDirect

Applied Energy

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

System expansion for handling co-products in LCA of sugar cane bio-energy systems: GHG consequences of using molasses for ethanol production

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ARTICLE INFO

Article history:
Received 28 April 2011
Received in revised form 24 June 2011
Accepted 12 July 2011
Available online 23 August 2011

Keywords:
System expansion
Molasses ethanol
Indirect land use change
Greenhouse gases

ABSTRACT

This study aims to establish a procedure for handling co-products in life cycle assessment (LCA) of a typical sugar cane system. The procedure is essential for environmental assessment of ethanol from molasses, a co-product of sugar which has long been used mainly for feed. We compare system expansion and two allocation procedures for estimating greenhouse gas (GHG) emissions of molasses ethanol. As seen from our results, system expansion yields the highest estimate among the three. However, no matter which procedure is used, a significant reduction of emissions from the fuel stage in the abatement scenario, which assumes implementation of substituting bioenergy for fossil-based energy to reduce GHG emissions, combined with a negligible level of emissions from the use stage, keeps the estimate of ethanol life cycle GHG emissions below that of gasoline. Pointing out that indirect land use change (ILUC) is a consequence of diverting molasses from feed to fuel, system expansion is the most adequate method when the purpose of the LCA is to support decision makers in weighing the options and consequences. As shown in the sensitivity analysis, an addition of carbon emissions from ILUC worsens the GHG balance of ethanol, with deforestation being a worst-case scenario where the fuel is no longer a net carbon saver but carbon emitter.

1. Introduction

One of the main policy rationales for promoting bioenergy as a viable alternative source of energy is its potential to reduce greenhouse gas (GHG) emissions. Bioenergy can be produced from different biomass producing sources, e.g. plants, animal, organic waste etc., and can take the form of gaseous/liquid/solid fuels, heat, or electricity. The liquid fuels in the 'fuel' group, commonly referred to as biofuels, include ethanol and biodiesel whose production is growing driven by worldwide efforts to reduce oil dependence in transport. Due to their carbon–neutral nature, these two biofuels are in general thought to be more climate friendly than gasoline and diesel, though this has been questioned recently when GHG implications of land use change are taken into account [1,2]. As the demand for biofuels increases, so does the percentage of cropland to be devoted to the production of fuel rather than food. This would result in land use change and the related carbon emissions will offset the carbon 'savings' from substituting biofuels for conventional fuels. Only in the past few years has land use for feedstock production been increasingly considered a key factor in determining biofuel sustainability.

The biofuel receiving the most attention today is ethanol, which can be produced from a wide variety of feedstocks. Until recently, several published studies showed that ethanol from food crops (e.g. corn, wheat, sugar cane) can offer GHG savings compared to gasoline [3–7]. However, due mainly to methodological problems in environmental impact assessment of land use and probably to assumptions behind the analysis, virtually all of these studies failed to include such important variable in their final results.

Worldwide, life cycle assessment (LCA) is recognized as a standardized and structured method for evaluating the environmental impacts arising throughout the entire life cycle of a product, process or activity. A challenging issue in LCA nevertheless is the selection of methods to allocate the environmental burden of a specific production system between products and co-products. It can be regarded as crucial since using different methods would produce different results and consequently different interpretations. In relation to allocation, the first priority as recommended by ISO 14044 [8] is to avoid allocation whenever possible by dividing the unit process to be allocated into sub-processes, or expanding the product system to include the additional functions of the co-products. Otherwise, allocation for the system can be done in such a way that it reflects the physical properties or the relative economic values of co-products. There is a relationship between the choice of method, allocation or system expansion, and the choice of LCA approach, attributional or consequential [9]. The

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doi:10.1016/j.apenergy.2011.07.023

attributional approach deals with co-product allocation by partitioning the environmental impact related to the product using allocation factors based on mass, energy or economic value. The consequential approach, seeking to capture change in environmental impact as a consequence of actions, avoids co-product allocation by system expansion.

In the context of a growing interest in ethanol from a wide range of feedstocks, recent analyses have been undertaken to assess the environmental costs and benefits of ethanol production from molasses, a co-product of sugar production. In most of the few published works dealing with co-product issues in sugar cane systems, the environmental costs of molasses were accounted for using either economic allocation alone [10–13] or both economic allocation and system expansion [14], yet only in one study [15], was neither allocation nor system expansion applied. Since the ISO standard [8] recommends to avoid allocation by expanding system boundaries, it can be inferred that system expansion is preferred to allocation but the task is to identify close substitutes for the co-product considered and their product systems. This study aims to explore the applicability of system expansion to avoid allocation between sugar and molasses as two important products in a typical sugar cane system. The procedure is essential for environmental assessment of ethanol from molasses where the consequential approach appears to be best suited, especially when the debate over whether crops should be used for food/feed or fuel has been central to policy thinking on the adoption of biofuels as a sustainable energy source. An interesting case study would be Thailand which is one of the world's main cane molasses producers [16] and where an ethanol demand for domestic consumption of E10 and E20, i.e. the 10:90 and 20:80 (v/v) ethanol–gasoline blends, respectively, has taken up 21% of the total national molasses produced in 2008 [17].

2. Methodology

2.1. Goal and scope definition

The objective of this study is to verify the procedures of system expansion and allocation against the estimate of GHG emissions associated with ethanol production from molasses in a baseline and an alternative abatement scenario. The study also includes a sensitivity analysis to investigate the issue of 'indirect land use change' arising from an increased demand for land to grow crops to fill the gap in feed supplies when molasses is diverted to fuel production. The three GHGs considered are CO_2, CH_4 and N_2O having 100-year global warming potential of 1, 25 and 298, respectively [18]. The calculated emissions are based on primary inventory data and emission factors obtained from available reference sources.

2.2. Life cycle GHG inventory

The flowchart in Fig. 1 is a graphical representation of a typical sugar cane system where sugar and its co-products, e.g. molasses and bagasse are produced. The figure also shows the way in which each co-product of sugar is used. The use of molasses, in particular, is considered in both conventional and alternative way as a feed additive and a feedstock for ethanol production, respectively. The consequence of the alternative use of molasses would be that some feed crop needs to be produced elsewhere. An overview of the three main segments of the system: sugar cane farming, sugar milling and ethanol conversion can be found in Nguyen et al. [19] whereas a detailed description is available elsewhere [20].

2.2.1. Inventory for sugar cane farming and sugar milling

Basic processes involved in sugar cane farming are land preparation, planting, crop maintenance, harvesting, and transportation. Once the sugar cane crop is about one year old, it is ready for harvesting and processing into sugar. Only cane stalks are cut and collected from the fields whereas the trash (leaves and tops) left is either open burned or ploughed back into the soil. The process of cane milling to extract sugar typically yields two important co-products, molasses and bagasse. Molasses has long been an ingredient in livestock feeds [21] but currently is being promoted for ethanol production as a solution to fossil-fuel dependence. As a fuel, bagasse is used to generate steam and electricity for on-site use and electricity for export to the grid. All the processes involved, cane trash burning, cane trash incorporated into soil and bagasse combustion, are considered creators of non-CO_2 greenhouse gases, e.g. CH_4 and N_2O. The sale of electricity to the grid, in contrast, saves GHG emissions (mainly CO_2) by avoiding use of fossil-based grid electricity. The savings of emissions are thus credited to the sugar cane system.

Key assumptions in relation to emissions generated, emissions avoided due to displaced grid electricity, and outputs associated with sugar cane farming and milling in Thailand are summarized in Table 1.

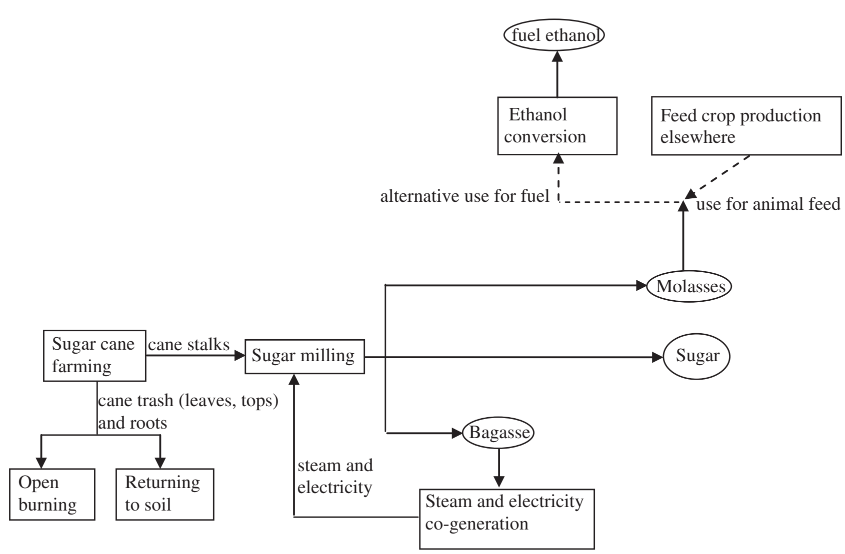

Fig. 1. Life cycle diagram for a typical sugar cane system with alternative use of molasses.