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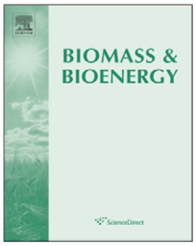

An environmental life cycle assessment comparing Australian sugarcane with US corn and UK sugar beet as producers of sugars for fermentation

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ABSTRACT

Sugarcane is a highly suitable substrate for the production of bio-products. As well as producing high yields of sugar, much of the plant's fibre is also recovered and used as a source of renewable energy. A life cycle assessment (LCA) of sugarcane production and processing in Australia was performed to develop an environmental profile of sugarcane as a source of bio-products. The application examined was fermentation products from sugar. The sugarcane results were compared with results for other sugar producing crops—US corn and UK sugar beet—to gauge its relative environmental performance. The results show sugarcane to have an advantage in respect of energy input, greenhouse gas emissions and possibly acidification potential due to its high saccharide yield and the displacement of fossil fuels with surplus renewable energy from cane fibre (bagasse). However Australian sugarcane can exhibit high nitrous oxide emissions, which would reduce greenhouse gas advantages in some regions. For eutrophication, sugar beet provides advantages due to the avoided production of other agricultural crops displaced by the use of beet pulp as an animal feed. The three factors found to have the most influence on the environmental impacts of these agro-industrial systems were the commodities displaced by by-products, agricultural yields, and nitrogen use efficiency.

1. Introduction

Sugarcane is a valuable substrate for bio-products because it produces high yields of fermentable sugars and because the plant's fibre is also recovered (as bagasse) and used as an energy source in downstream processing. The resulting energy and greenhouse benefits of sugarcane-derived products have been shown previously [1–3]. However, the wider environmental implications of sugarcane-derived products (beyond energy and greenhouse gas emissions) have not been fully evaluated to date.

The aim of this work was to develop environmental data for sugarcane grown in Australia, and to compare it with other sugar-producing crops to gauge its relative environmental performance as a source of bio-products. The specific application is the use of sugars to produce fermentation products. Life cycle assessment (LCA) was used as the evaluation method, with the aim of assessing a wider range

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of impacts than has been assessed for sugarcane systems to date.

2. Methodology

2.1. *LCA of fermentable sugar solution from sugarcane*

The LCA of the sugarcane system was based on practices in the State of Queensland, which accounts for 94% of Australian production. The system includes all processes from planting through to the milling of the cane to produce clarified cane juice, as depicted in Fig. 1. Also included are the background processes for the production and delivery of agricultural and milling inputs, energy sources and transport. Capital goods associated with the agricultural phase were included since their impacts are usually significant in LCAs of agricultural systems [4]. Capital goods associated with milling infrastructure were considered insignificant and not included, due to the large throughput and long effective life of sugar mills.

The output of interest is sugar in the clarified juice extracted from the sugarcane stalks, as this is the substrate used for fermentation of bio-products. Therefore, it is a “cradle to gate” analysis with the functional unit being a kilogram of monosaccharide (glucose or fructose).

Consideration was given to differences in cane growing practices, since variation in cropping practices has been found to have considerable influence on LCA results for agro-industrial systems [5,6]. As well as an average farming system, two region-specific cane-growing scenarios were modelled, which approximate low- and high-input cane growing practices.

It was assumed that sugarcane is processed in conventional sugar mills. Apart from small quantities of fuel used for boiler start-up, all energy for processing is met by bagasse. Material inputs to the milling process are lime, phosphoric acid, and flocculants for juice clarification. Inputs to ancillary operations (lubricants, biocides, antifoaming agents, and anti-scaling agents) were not included due to the low quantities involved.

Foreground data for sugarcane production and processing were obtained from industry statistics and surveys [7–14], published literature [15–25], and personal communications with industry experts. Data for background processes were mostly sourced from the Australian Life Cycle Inventory Database [26] and Ecoinvent Database [27]. Refer to Table 1 for data sources.

2.2. *Comparing sugarcane with corn and sugar beet*

The comparison of sugarcane with corn and sugar beet was made on the basis that each crop produces a functionally equivalent product—a sugar solution containing monosaccharide of similar purity. The processes for extracting sugar solution from each crop are different, but the fermentation stream is the last common point in processing, and was used as the reference stream. For sugarcane this is the cane juice produced after milling and clarification (93% purity). For sugar beet this is the beet juice produced after diffusion and purification (92% purity). For corn it is the hydrolysate solution produced after saccharification (hydrolysis) and filtration (95% purity). Clarification/filtration is included in the boundary of each system as waxes, oils and proteins are likely to foul processes in downstream bio-product applications.

The corn analysis was based on data from the United States. Data for corn growing came from Kim and Dale [28], who provide data for the seven corn belt states responsible for much of the total US corn production. Data for corn wet milling came from a detailed production inventory of a modern corn wet mill in the US, as used by Kim and Dale [29].

The sugar beet analysis was based on data from the United Kingdom. Data for sugar beet growing was adapted from Tzilivakis et al. [30], who presented data for 13 beet growing scenarios, representing over 90% of UK sugar beet production. A small number of scenario based on sugar beet production in peat were excluded. Data for sugar beet processing came from Mortimer et al. [31], who provided a detailed inventory for a modern UK sugar beet plant.

These data sources were chosen for the comparison because they represent established agro-industries from which sugar solutions are currently derived, analogous with the Australian sugarcane case. They were also comprehensive enough for an LCA, and allowed for the assessment of low- and high-input crop growing scenarios to gauge variation.

The comparison focused on the agronomic and processing characteristics of the three crops and not on factors related to where they are grown. Therefore, geographic and site-specific factors were standardized wherever possible. Each crop was assumed to use the same suite of N, P and K fertilizers (urea, diammonium phosphate, and potassium chloride), and to use the same transport infrastructure and sources of inputs. Background processes used for sugarcane were applied for corn and sugar beet. Each crop was assumed to be grown at a similar location relative to suppliers of inputs and markets for products. Therefore, distances for transporting inputs and co-products were assumed to be the same for each crop. Distances for transporting the harvested crop between farms and processing plants were not standardized. Distances cited in the original sources were used since they were assumed to reflect the most economically efficient transportation network for each crop.

The comparison assumed each crop is grown as a monoculture using conventional agricultural practices. More progressive cropping systems such as those incorporating break crops, minimal tillage, integrated pest management, precision application of fertilizers, etc., were not considered in the analysis.

Table 2 details the inputs and outputs for the production of sugarcane, corn, and sugar beet per hectare. The most significant difference is sugar (monosaccharide) yield per hectare. Corn kernels have higher recoverable sugars (60% (wt)) compared with sugarcane and sugar beet (both around 15% (wt)). However, the high crop yields of sugarcane (85.0 $\mathrm{t\,ha^{-1}}$ compared with 49.6 $\mathrm{t\,ha^{-1}}$ for sugar beet and 9.1 $\mathrm{t\,ha^{-1}}$ for corn) means sugarcane can provide the highest yields of monosaccharide per hectare.