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# Environmental study of the sugarcane Value Chain in the province of Tucumán (Argentina) considering different technology levels

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## Abstract

*Purpose*. The purpose of this work is to quantify the environmental impact of the sugarcane industry in Tucumán (Argentina) through the Life-Cycle Analysis (LCA). The distinctive feature is the consideration of different technology levels (TL) in the agricultural stage: high, medium and low. *Methods*. The scope of the study covers the agricultural and industrial stages through a "from cradle to gate" approach (from sugar cane cultivation until production of finished products: sugar and alcohol).Data used for the inventory are mainly provided by local experts, sugarcane growers and processing companies. For the impact assessment, the CML-2001 model is used. *Results and discussion*. There is a positive environmental impact related to global warming coming from the $CO_2$ consumption during photosynthesis. In most categories, the TL "high" has less impact values than the others do. However, in few categories the level "low" has some advantages. This behaviour is analysed in the article. *Conclusions*. This study explores the implications of using different TL in agricultural tasks. The increase in the degree of mechanization of farming results in a reduced environmental impact in most categories.

*Keywords: biofuel; sugar; sustainability.*

## Introduction

According to the Food and Agriculture Organization of United Nations (FAO, www.fao.org), about 115 countries produce sugar from either sugar cane (67%) or sugar beet, being Brazil the main world producer of sugar cane (more than 22% of the global production).

In Argentina (18th in the world ranking of sugar producers), the sugar industry is composed of 23 sugar mills, 16 distilleries and 9 plants for ethanol dehydration. This industry is one of the cornerstones of the economy of the province of Tucumán (15 sugar mills). There prevails a productive structure formed by independent growers, with different technology levels (TL) and with different degrees of access to the productive factors.

# Methods

The methodology used in this study follows the guidelines of the ISO 14040 and 14044 standards on LCA (2006), along its four phases. The objective is to outline the environmental profile of sugar cane value chain in Tucumán, taken into account three TL for the agricultural labors: high (HTL), medium (MTL) and low (LTL) (Giancola *et al*. 2012). The main features of each TL are shown in Table 1.

| | High | Medium | Low |
|---|---|---|---|
| Crop yield [t/ha] | 75 | 62 | 55 |
| Harvest system | mechanized | semi-mechanized | semi-mechan. + manual |
| Trash burning | scarce | total | total |
| Agrochemicals use | intensive | moderate | scarce |

Table 1 - Main features of the three technology levels considered for the agricultural labors.

While working on the same basis, the LCA is a very suitable tool to carry out this comparison. The approach is “from cradle to gate”, which covers the activities from raw materials extraction (agricultural stage) to products manufacturing (sugar mills and distilleries). The system description and inventory data are the existing ones for this industry in Argentina in 2013. System boundaries are expanded to include the impact associated with the production of all inputs (e.g., fertilizers, energy, etc.). The functional unit is referred to 1 kg of ethanol.

To build the inventory (LCI), information related to agricultural tasks comes from local producers, the Argentinean Institute of Agricultural Technology (INTA) and other governmental institutions. For the industrial stage, experts from National University of Tucumán (Amores *et al*. 2013, Mele *et al*. 2011, Nishihara Hun 2014) provide data concerning sugar mills and distilleries. The gaps are filled using specific literature and databases (e.g. Ecoinvent v3.1, www.ecoinvent.ch).

Ten impact categories corresponding to the CML2000 Baseline model (CML, 2001) are assessed: depletion of abiotic resources (AD), acidification (AC), eutrophication (EU), global warming (GW), ozone layer depletion (OD), human toxicity (HT), freshwater aq. ecotoxicity (FE), marine aq. ecotoxicity (ME), terrestrial ecotoxicity (TE) and photochemical oxidants formation (PO). Calculations are performed with the support of Simapro® 8.0.3 (PRé Consultants 2014).

# Case study

The system under study is split into: *Agriculture*, *Mill* and *Distillery* (see Figure 1). For the sake of space, inventory tables are not reported but they are available to the interested reader.

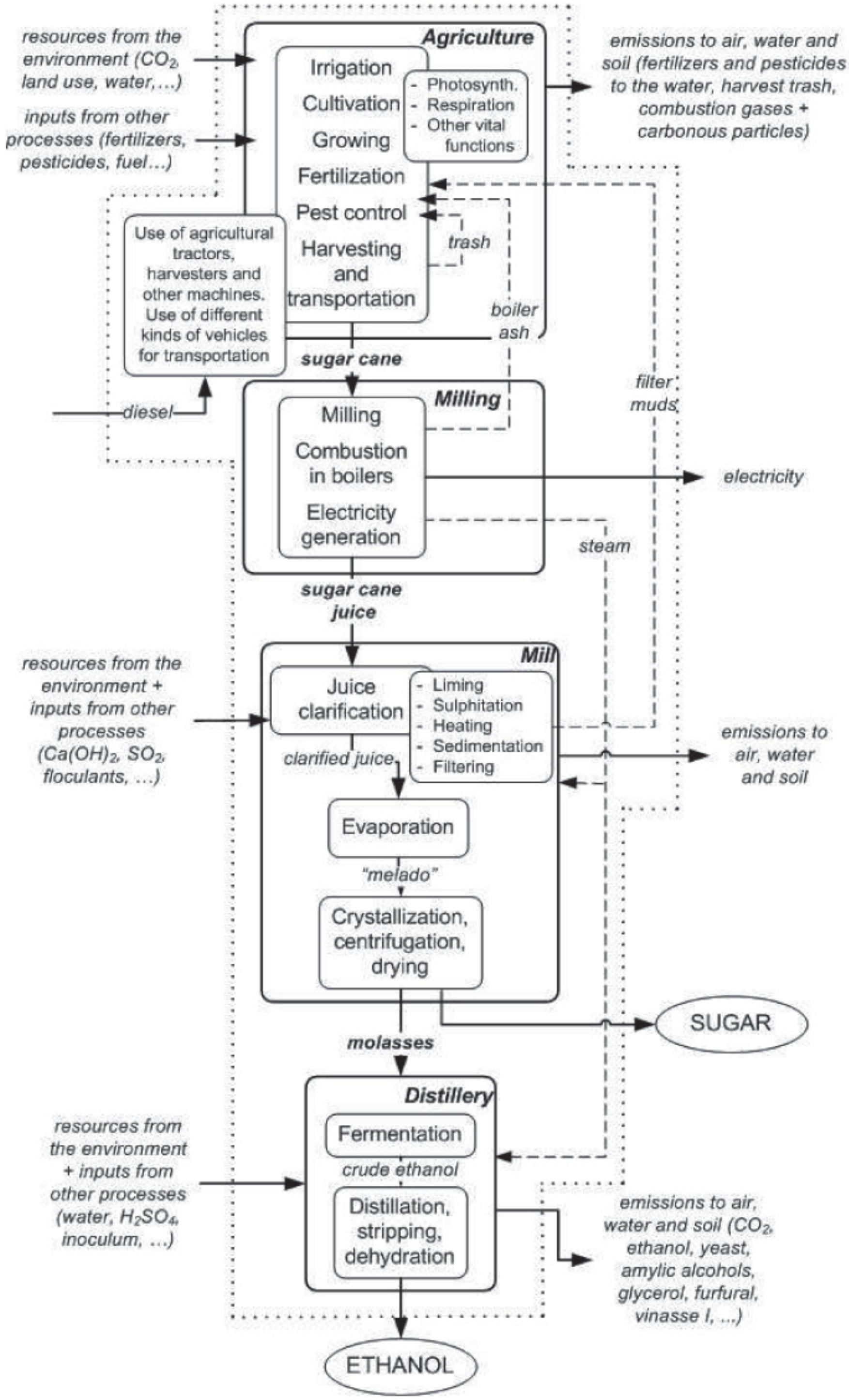


Figure 3 - Schematic of the overall system under study with three subsystems: *Agriculture*, *Mill* and *Distillery*.

The subsystem *Agriculture* includes all activities involved in sugar cane production. Three versions of this subsystem are assessed, according to the TL (Table 1). The processes that contribute to this subsystem are mainly three: sugar cane plants cultivation, sugar cane ratoons cultivation and harvesting. The main product of this subsystem is millable cane stalks at the entrance of the sugar cane mill. The emissions are mostly those derived from the pre and post-harvest burning of agricultural crop residues, as well as due to agrochemicals volatilization and leaching. Diesel and electricity production/distribution are adapted as much as possible to the regional conditions.

After harvesting, sugar cane is transported to subsystem *Mill* as a raw material for sugar production. Cane is milled to yield two products: juice and bagasse. Bagasse is a fibrous material, which is burnt in boilers to fulfil the heat and power requirements of the process, through a cogeneration unit. Juice is sent to clarification to remove impurities, and then it is concentrated and crystallized. From this process, white sugar, raw sugar and molasses are obtained. As *Mill* is a multi-output system, environmental burdens have been allocated by mass. A comprehensive list of other inputs and outputs to this subsystem are also taken into consideration.

The subsystem *Distillery* uses molasses as a raw material. Molasses are fermented by yeast to convert sugars to ethanol. It is a batch process that yields a product of 7-10 ºGL (ºGL = % ethanol by volume). This product is then distilled nearly to 96 ºGL generating vinasses, the most important residue of *Distillery*. Finally, ethanol 96 ºGL is dehydrated by azeotropic distillation to produce anhydrous ethanol. Molasses entering *Distillery* brings an 'inherited' environmental burden from *Mill* and *Agriculture*. Again, all the inputs and outputs of this system are accounted.

# Results and Discussion

Figure 2 shows the environmental profile of sugar cane at the entrance of the mill.

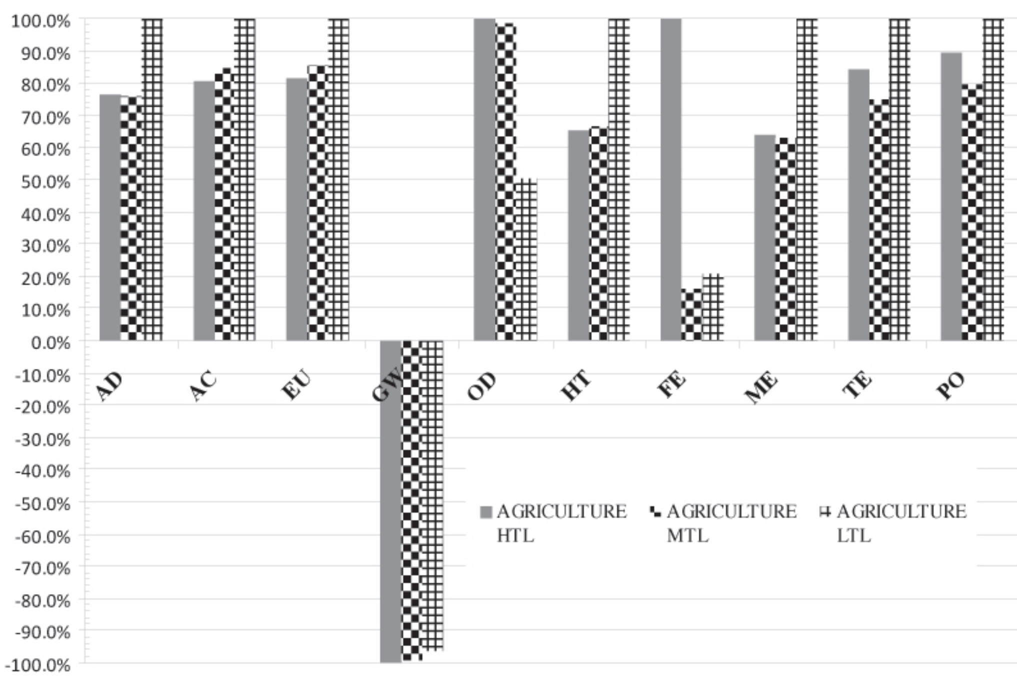


Figure 4 - Environmental profile of sugar cane harvested, by TL: high (HTL), medium (MTL) and low (LTL). Acronyms key in text.

It can be seen that there is a *positive* environmental impact in GW coming from the $CO_2$ uptake during cane growing. For each category, there are three bars corresponding to the impact of each TL. The comparison is made on a percentage basis, corresponding 100% to the TL with the highest impact. In five impact categories, HTL has less impact values than MTL and LTL, and in

eight categories, it is better than LTL. Broadly speaking, this is due to better cultural yields in HTL, and to the fact that, in HTL, sugar cane is not burnt before harvesting as it is in MTL and LTL. LTL has less impact in only two categories, OD and FE. This is due to a less intensive use of agrochemicals (and packaging waste) and fossil fuels during the harvest, which is manual.
Figure 3 shows the profiles of the fuel grade ethanol at the distillery gate.

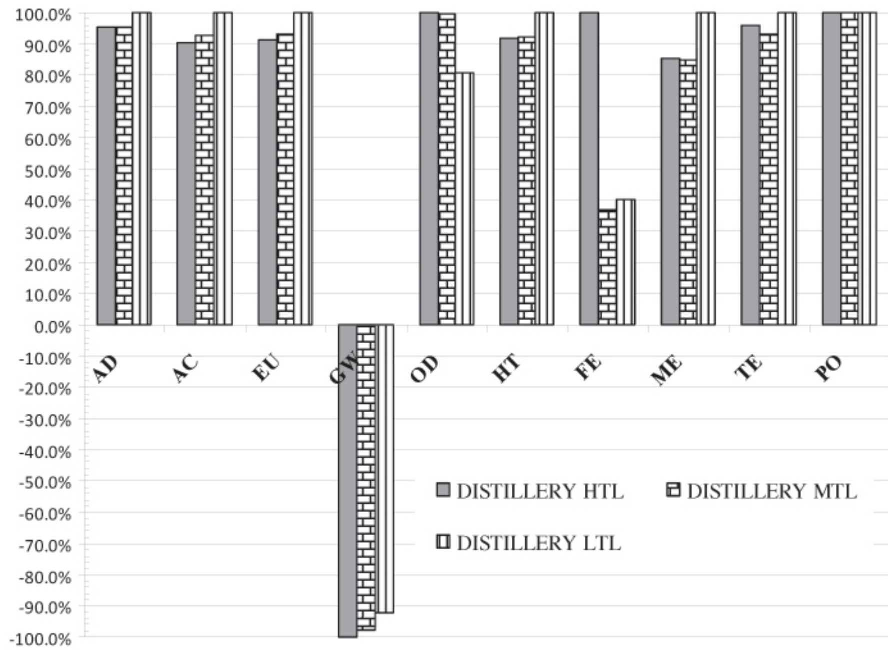


Figure 5 - Environmental profile dehydrated bioethanol, by TL: high (HTL), medium (MTL) and low (LTL). Acronyms key in text.

In comparison with Figure 2, it can be seen that Figure 3 is qualitatively similar but differences between TL result smoothed. This is due to, regardless of the TL of agricultural practices, the processing technology (in mills and distilleries) does not vary.

# Conclusions

A contribution to the study of the environmental profile of the sugar cane industry in Tucumán, using an LCA-based approach is presented. It is important to highlight the value of this article since research concerning the application of LCA in this area is rather limited in Argentina. Specifically, this study explores the implications of using different TL in agricultural tasks, which have been identified in other studies (Amores *et al*. 2013) as the main source of impact related to the production of sugar and bioethanol. As a conclusion, the increase in the degree of mechanization of farming results in a reduced environmental impact in most categories.

# Acknowledgements

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