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Environmental Life Cycle Assessment Framework for Sukker Production (Raw Sugar Production)

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Abstract

Life-cycle assessment (LCA) can help avoid a narrow outlook on environmental concerns by compiling an inventory of relevant energy and material inputs and environmental releases; and evaluating the potential impacts associated with identified inputs and releases. Particulate matter, combustion products, and volatile organic compounds are the primary pollutants emitted during the sugarcane processing. Combustion products include nitrogen oxides (NO_X), carbon monoxide (CO), CO_2, and sulfur oxides (SO_X). Potential emission sources include the sugar granulators, sugar conveying and packaging equipment, bulk load out operations, boilers, granular carbon and char regeneration kilns, regenerated adsorbent transport systems, kilns and handling equipment (at some facilities), carbonation tanks, multi-effect evaporator stations, and vacuum boiling pans. Modern pollution prevention technologies are capable of addressing all of these potential pollutants.

Keywords: LCA; framework; raw sugar production; emission; pollutants.

1. Introduction

The average worldwide yield of sugarcane crops in 2011 was 70.54 tons per hectare (FAO, 2010). Life-cycle assessment (LCA, also known as life-cycle analysis, ecobalance, and cradle-to-grave analysis) is a technique [1] to assess environmental impacts associated with all the stages of a product's life from-cradle-to-grave (i.e., from raw material extraction through materials processing, manufacture, distribution, use, repair and maintenance, and disposal or recycling). Interpreting the results to help make a more informed decision [2]. The goal of LCA is to compare the full range of environmental effects assignable to products and services in order to improve processes, support policy and provide a sound basis for informed decisions [3]. The term *life cycle* refers to the notion that a fair, holistic assessment requires the assessment of raw-material production, manufacture, distribution, use and disposal including all intervening transportation steps necessary or caused by the product's existence.

There are two main types of LCA. Attributional LCAs seek to establish the burdens associated with the production and use of a product, or with a specific service or process, at a point in time (typically the recent past). Consequential LCAs seek to identify the environmental consequences of a decision or a proposed change in a system under study (oriented to the future), which means that market and economic implications of a decision may have to be taken into account. Social LCA is under development [4] as a different approach to life cycle thinking intended to assess social implications or potential impacts. Social LCA should be considered as an approach that is complementary to environmental LCA. The procedures of life cycle assessment (LCA) are part of the ISO 14000 environmental management standards: in ISO 14040:2006 and 14044:2006. (ISO 14044 replaced earlier versions of ISO 14041 to ISO 14043.) GHG product life cycle assessments can also comply with standards such as PAS 2050 and the GHG Protocol Life Cycle Accounting and Reporting Standard [5-6]. According to the ISO 14040 [7] and 14044 [8] standards, a Life Cycle Assessment is carried out in four distinct phases as illustrated in the figure shown to the right. The phases are often interdependent in that the results of one phase will inform how other phases are completed. Functional unit, which defines what precisely is being studied and quantifies the service delivered by the product system, providing a reference to which the inputs and outputs can be related. Further, the functional unit is an important basis that enables alternative goods, or services, to be compared and analyzed [9].

The amount of sugarcane produced on one hectare of land (yield) in mineral soil, for the crop year 2010 has been reported at 31 tons/acre (69 tons/ha) [10-11]. Emission factors are from Andreae and Merlet (2001) [11], which are also used in the IPCC guidelines [12]. The carbon monoxide and VOCs emitted are expected to be quickly converted to CO_2, and its associated carbon will be reabsorbed in the next growth cycle of the sugarcane crop. Therefore, the net contribution to greenhouse gases for these three gases is assumed to be zero [13]. Combine harvesters require less labor, but at the same time cause damage to the cane, decreasing sugar yields [14-16]. Regardless of the method, it is important to obtain a clean, undamaged cane, minimizing the amount of trash sent to the processing plant and leaving behind viable roots in the field.

2. Goal of Study

The goal of this study is to conduct a life cycle assessment for the Sukker sugarcane production in Baghpat (UP, India) to have a better understanding of all the life-cycle stages of Sukker sugarcane production; study the environmental sustainability performance of sugarcane as Sukker production; and to find alternatives to the existing farming system in Baghpat, if needed for improved agricultural or environmental purposes. The intent of the study is to generate results that can be publicly communicated to different audiences. The functional unit used in this study is: one tonne of sugarcane Sukker production in one year (1 T y) in Baghpat (UP, India).

3. Phases of LCA

Four phases (ISO, 2006) of LCA study according to the International Organization for Standardization (ISO) 14040/44 standards are (i) goal and scope definition (framework and objective of the study); (ii) life cycle inventory or LCI (input/output analysis of mass and energy flows from operations along the product's value chain); (iii) life cycle impact assessment or LCIA (evaluation of environmental relevance, e.g. global warming potential); and (iv) interpretation (e.g. optimization potential). Life-cycle phases of the sugarcane crop systems studied include (a) land preparation: considering equipment use, fuel consumption, and ancillary materials needed for the preparation of one hectare of land; (b) planting: one hectare of land, including seed cane production, cane dropping and covering, and all the equipment, materials and energy needed; (c) cultural practices: include all the agricultural work such as irrigation, fertilization, pest control and fuel, materials and energy utilized; (d) harvesting sugarcane: final product of the feedstock production process, ending with the deposit of sugarcane billets on wagons “in the field”.

4. Streamline LCA

Streamline LCA process includes three steps. First, a proper method should be selected to combine adequate accuracy with acceptable cost burden in order to guide decision making. Actually, in LCA process, besides streamline LCA, Eco-screening and complete LCA are usually considered as well. However, the former one only could provide limited details and the latter one with more detailed information is more expensive. Second, single measure of stress should be selected. Typical LCA output includes resource consumption, energy consumption, water consumption, emission of CO_2, toxic residues and so on. One of these output is used as the main factor to measure in streamline LCA. Energy consumption and CO_2 emission are often regarded as “practical indicators”. Last, stress selected in step 2 is used as standard to assess phase of life separately and identify the most damaging phase. For instance, for a family car, energy consumption could be used as the single stress factor to assess each phase of life.

5. GHG Estimation

Estimation of greenhouse gas (GHG) emissions from Fire" contained in the 2006 IPCC Guidelines for National Greenhouse Gas Inventories Volume 4: Agriculture, Forestry and Other Land Use (IPCC, 2006) and the modifications to the equation made by Murphy *et al.* (2010) was used. According to IPCC equation, L (fire)=A ×Mb×Cf×Gef× 10^{-3}, where: L(fire) = amount of GHG emissions from fire (tones of each: CO_2, CO, CH_4, N_2O, and NOx); A= area burned (ha); Mb = biomass, as fuel, available for combustion (tons/ha); Cf = combustion factor (dimensionless); Gef = emission factor (g/kg of biomass burned). Moreover, Eburn,k =fraction MBF×Cf×Efdm,k (Murphy et al. equation), Where: Eburn, k = mass of emissions for GHGs (k) emitted per mass of cane harvested; FractionBMF = mass fraction of fuel biomass (replaces A x MB in IPCC Eq 2.27); Cf = combustion factor (dimensionless); EFdm, k = emission factor (g/kg of biomass burned) for species k as given for agricultural residues per unit mass of dry matter. It is equivalent to factor G ef in IPCC Eq.

6. Conclusion

Life cycle assessment is a powerful tool for analyzing commensurable aspects of quantifiable systems. Life Cycle Interpretation is a systematic technique to identify, quantify, check, and evaluate information from the results of the life cycle inventory and/or the life cycle impact assessment. The results from the inventory analysis and impact assessment are summarized during the interpretation phase. The outcome of the interpretation phase is a set of conclusions and recommendations for the study. According to ISO 14040:2006, the interpretation should include: (i) identification of significant issues based on the results of the LCI and LCIA phases of an LCA; (ii) evaluation of the study considering completeness, sensitivity and consistency checks; and (iii) conclusions, limitations and recommendations.

Table 1: Sukker produced from sugarcane characterized by three life cycle stages.

	1	2	3
Phases	Raw material acquisition	Feedstock Preparation	Product production
Modules	Sugarcane agriculture	Cane milling	Sukker production (Raw sugar/ brown sugar)
Life Cycle stages	Land preparation Planting Cultural activities Harvesting	Juice extraction Clarification Bagasse recovery	Boiling Steam production Energy recovery

Table 2: Summary of system boundaries.

Included	Excluded
Seed-cane and ancillary inputs (i.e. pesticides and fertilizers)	Machine manufacture
Energy; e.g. fuel used for land preparation, planting, cultural activities and harvesting; purchased electricity for irrigation	Maintenance and operation of agricultural equipment
Water used	Infrastructure production

Table 3: Impact Categories selected for the study.

Category Indicator	Impact Category	Description	Unit	Reference
Energy Use	Primary Energy Demand	A measure of the total amount of primary energy extracted from the earth. PE is expressed in energy demand from non-renewable resources (e.g. petroleum, natural gas, uranium, etc.) and energy demand from renewable resources (e.g. hydropower, wind energy, solar energy, etc.).	MJ	An operational guide to the ISO standards (Guinee, 2002).
Climate Change	Global Warming Potential (GWP)	A measure of greenhouse gas emissions, such as CO2 and methane. These emissions are causing an increase in the absorption of radiation emitted by the earth, magnifying the natural greenhouse effect.	kg CO2 equivalent	Intergovernmental Panel on Climate Change (IPCC). 2006 IPCC Guidelines for National Greenhouse Gas Inventories.
Eutrophication	Eutrophication Potential (TRACI)	A measure of emissions that cause eutrophying effects to the environment. The eutrophication potential is a stoichiometric procedure, which identifies the equivalence between N and P for both terrestrial and aquatic systems.	kg Nitrogen equivalent	Bare *et al.*, 2002. TRACI: the Tool for the Reduction and Assessment of Chemical and Other Environmental Impacts. JIE, MIT Press.
Acidification	Acidification Potential (TRACI)	A measure of emissions that cause acidifying effects to the environment. The acidification potential is assigned by relating the existing S-, N-, and halogen atoms to the molecular weight.	kg H^+ equivalent	Bare *et al.*, 2002. TRACI: the Tool for the Reduction and Assessment of Chemical and Other Environmental Impacts. JIE, MIT Press.
Water Use	Water Intake	Measure of the water used. Sources include surface and ground water.	Water Liter	

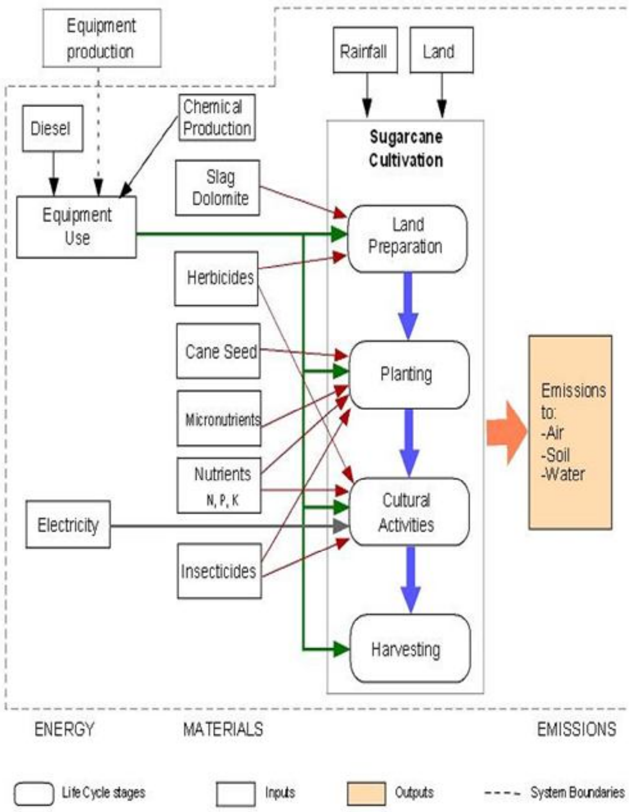

Figure 1: System scope and system boundaries for sugarcane sucker life cycle.

Table 1 indicates Sukker produced from sugarcane characterized by three life cycle stages; and Table 2 shows summary of system boundaries. Table 3 explains Impact Categories Selected for the proposed Study. Figure 1 shows system scope and system boundaries for sugarcane Sukker life cycle. A key purpose of performing life cycle interpretation is to determine the level of confidence in the final results and communicate them in a fair, complete, and accurate manner.

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