Sustainable Agro Landuse Evaluation through Life Cycle Assessment for Sugarcane Cultivation in Cauvery Deltaic Regions of India

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Abstract
Cultivation of Sugarcane plays a pivotal role in economic, cultural and ecological fabric of a tropical agrarian country like India. Deltaic track of Cauvery River, with its blended traditional and modern agro practices has been one of the major sugarcane growing regions of this leading sugarcane-producing nation. The present study explores the cradle to gate life cycle assessment of sugarcane production in the above mentioned sugarcane growing region and presents the comprehensive picture of the four major impact categories(Global climatic threats, Ecosystem quality, Human health, Resources) using SimaPro (9.0.0.49) with information obtained from the sugarcane growers supplemented by ecoinvent database.

The study reveals the major global warming contributions, ecotoxicity (mainly aquatic) and resource depletion (mainly land occupation, non-renewable energy consumption and mineral extraction) associated primarily with plantation, soil fertility management and harvesting and transportation phases.

Keywords: Life cycle assessment (LCA), sugarcane cultivation, global warming, resource depletions.

Introduction

Sugarcane is one of the most important raw materials as human food and livestock feed because of its ease of growth and to generate bioenergy for biomass and chemical industries[12]. The sugarcane industry has been one of the key suppliers for electricity generation and ethanol[2]. In fact, of late, sugarcane has been known to be the second commodity produced worldwide and plays an essential role in the human diet[4].

Although, the sugarcane industry does play a prominent role for the global economy, the sugarcane supply chain has been largely responsible towards significant resource depletion, soil-quality deteriorations (due to excessive usage of various agro-chemicals for enhancing soil fertility as well as control of weeds, pests and diseases) and release of various toxic emissions (as a result of extensive mechanizations)[3,5,6,8,9].

Several researchers have investigated the environmental impacts associated with sugarcane cultivation, sugar production and by products management as well as waste disposal[1,7,10,11].

However, since the specific sugarcane cultivation, practices vary at different locations around the world, especially amongst non-mechanized cultivation regions and hence a comprehensive assessment of environmental sustainability associated with sugarcane cultivation is rather scarce. India happens to be the top sugarcane-producing nation i.e. 33 million metric tons of sugar (19% of the world's total sugar production); Tamilnadu being one of the top four sugarcane-producing states, with more than two lakh hectare of areas under production, yielding about 20 million tonnes per annum, as per the estimation by Indian Council for Agricultural Research (ICAR) for 2019-2020.

The present research is directed towards exploration of the life cycle assessment of sugarcane cultivation (cradle to gate) in India, with special reference to Cauvery deltaic regions. The data utilized for the present studies have been obtained from farming community as well as the ICAR recommendations (to account for inter-farm pedologic variations) to assess resource depletion, toxicity to human health, ecosystem sustainability and climate change.

Material and Methods

Data: The primary source of data used in the present study were obtained from interview with the cane growers, and field study of the farmlands. The specific components of sugarcane cultivation involve six distinct yet interdependent and non-chronological phases, namely, (a) land preparation, (b) plantation (c) soil fertility management, (d) herbicides, pesticides and disease control, (e) crop harvesting and (f) transportation to sugarcane industry.

The total water consumption during the entire cultivation cycle is accounted for during the plantation phase, which refers to the additional water requirements over and above the average decadal rainfall associated with both north-east and south-west monsoons (5000 cu.m precipitation/acre). Similarly, the ploughing and soil fertility management as well as application of herbicides, pesticides and disease control measures are distributed between the land preparation phase as well as plantation phase. The fertilizers include both locally produced vermicomposting and farmyard manure as well as chemical counterparts, based on the standard practices by the farmers. The standardized dosages of herbicides, pesticides and disease control chemicals were used in the computation based on recommendation of ICAR to account for inter-farm land variabilities.

All the electricity consumptions were calculated based on supply from conventional southern grid and computed during plantation phase, because it covers more than 90% of the total duration of sugarcane cultivation. Diesel for land preparation (ploughing and tilling) was calculated for traversing the field (with 10m inter-row spacing) using tractors. The stump preparations for plantation, application of herbicides, pesticides and disease control agrochemicals as well as harvesting have been accounted for manual labour in contrast to mechanized processing (unlike several other locations).

The transportation of harvested sugarcane is computed for utilization of lorries (3.5-7.5 metric ton; euro5) for an average distance of 40 kms (to and fro) between the farmland and the nearby sugarcane industry, which is most conventional in the study areas considered.

System Boundaries: The system boundary involves various inputs from field preparation through crop harvesting and transportation to sugarcane industry. The functional unit utilized for the entire study is 1 tonne of sugarcane transported to the sugarcane industry. The production systems (for seedling, seeds and supporting materials, as well as manure, pesticide and herbicide), machine manufacturing systems, co-product and by-product management, waste life cycle (including *in situ* combustion of post-harvested cane residues) and processing and distribution of supply chain are not included in system boundaries (Fig. 1).

Impact Assessment: The LCA studies were carried out using SimaPro 9.0.0.49 software, with Ecoinvent database, version 3.5. Impact 2002+ (2.15) was used to model the life cycle impact assessment (LCIA)

Results and Discussion

Contribution Analysis of the Stages: The results obtained from the study according to the functional unit of one tonne sugarcane productions per acre of cropland, for the 15 midpoint impact categories and the four endpoints categories following IMPACT 2002+ methodology.

Global climatic threats: The major global climatic threats, namely the global warming potential are shown in figure 2. Plantation (65%), harvesting and transportation (56%) are the most severe impact found in these phases possibly because of heavy dependencies on tilling and ploughing machineries. Besides the extensive usage of grid electricity for round the clock over pumping, because of free electricity subsidy by the government, may be a factor, which can be ascribed for high global warming potential. The second most important contribution to the overall global climatic threats was soil fertility management phase; contributing for global warming potential (25%) mainly caused by the extensive use of fertilizers.

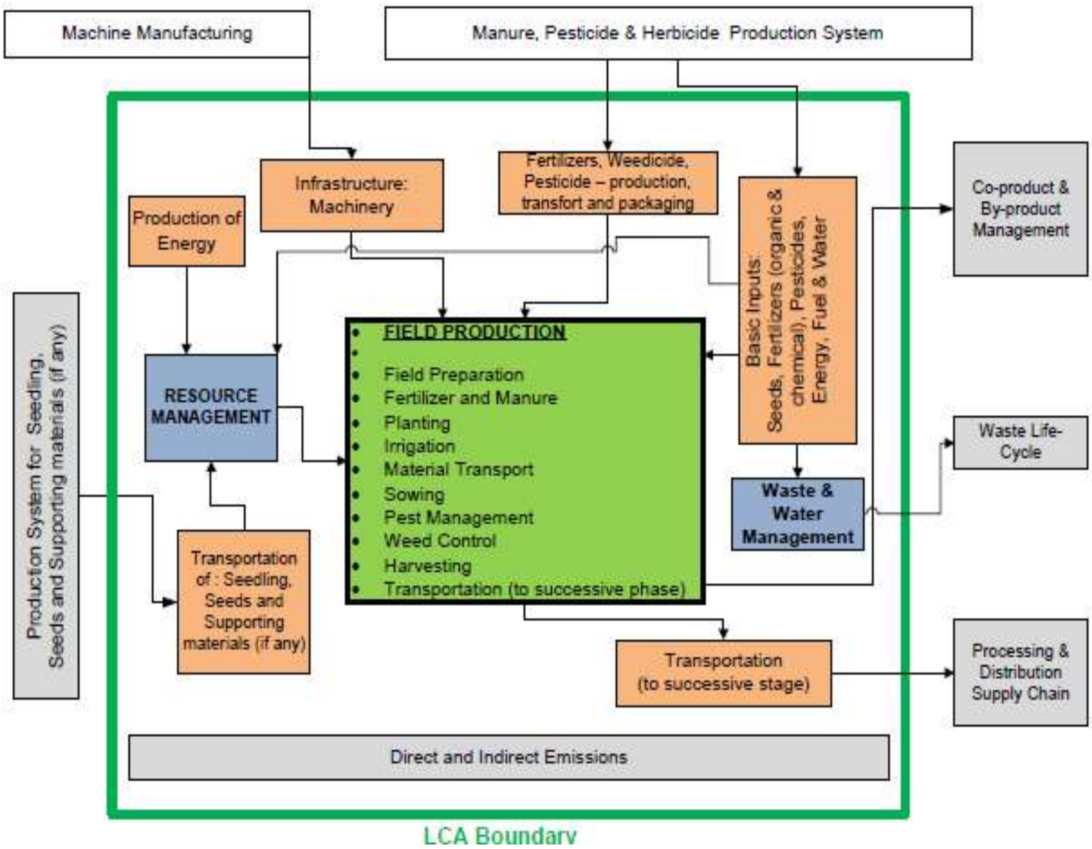

Figure 1: LCA boundary in the production of sugarcane

In fact, the major components of the fertilizers used in sugarcane production in the study area are organic fertilizers, either prepared in and around the cultivation area (such as farmyard manure) or transported from vicinity (such as vermicomposting), which because of associated high NoX and CO_2, are likely to be the major contributors of greenhouse gases leading to global warming. The ozone layer depletion potential was observed to be very low (at microgram CFC equivalent level) because of predominantly non-mechanized cultivation practices.

Ecosystem quality: The contribution to the toxicological contribution to regional unto aquatic and terrestrial ecosystem categories shows the following results. Among the various categories of ecotoxicity associated with sugarcane cultivation, the primary process is observed to be aquatic ecotoxicity yielding about 972 kg TEG water followed by terrestrial ecotoxicity (at a level of 270 kg TEG soil). Plantation phase was found to be a major cause of both these toxicity categories followed by harvesting and transportation. The primary reason of these toxicity might be high leaching of fertilizers and fertilizer residues as well as release of unburnt hydrocarbon associated with heavy duty transportation and cultivation machineries primarily run by diesels.

Interestingly, aquatic acidification and eutrophication are found to be very low (less than 0.5 kg SO_2 eq and 0.005 kg PO_4 P-lim respectively), which is much lower than that emitted during sugarcane cultivation in many other countries which may be because of low leaching of K, NO_3, NOx and ammonia, caused by high temperature volatilizations associated with the tropical agricultural practices as in case of India (esp. Southern India).

As evident from the figure 3, during soil fertility management, emission of toxic leachates shows moderately high release primarily onto water (about 86%).

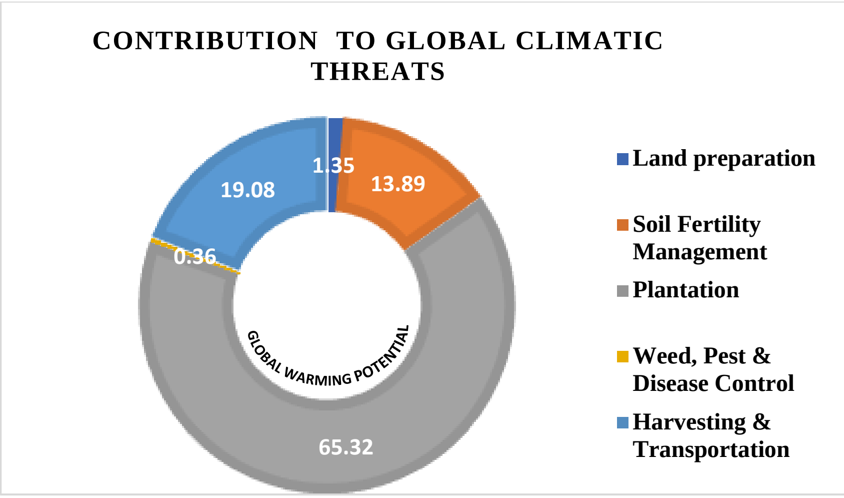

Figure 2: Contribution to Global Climatic Threats

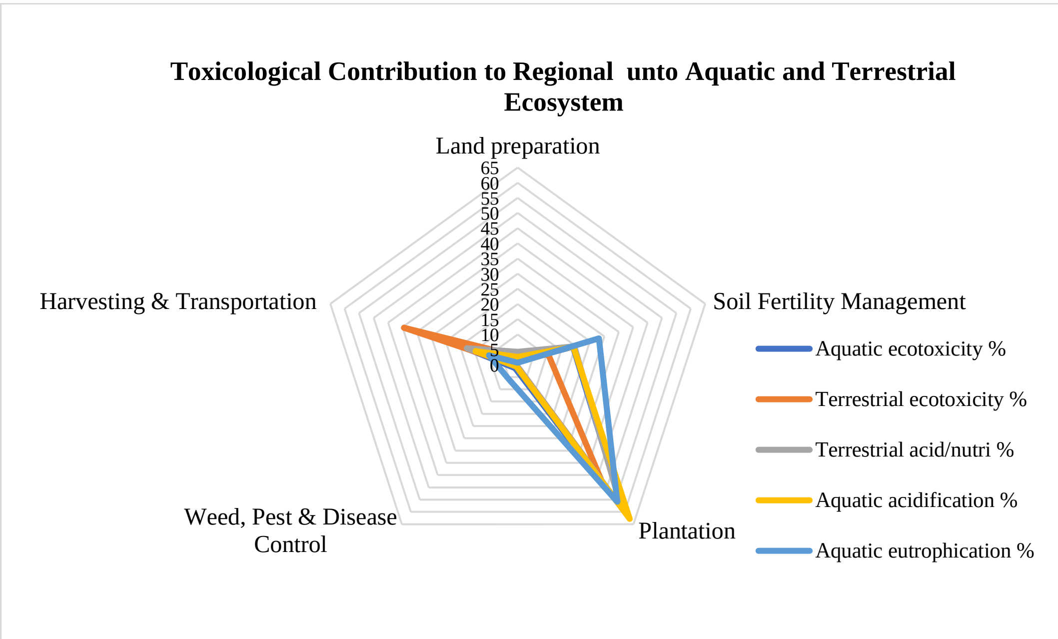

Figure 3: Toxicological Contribution to Regional unto Aquatic and Terrestrial Ecosystem

Human health: The contribution to the human health related impacts are shown in the figure 4. Among the various categories of human health related impacts, ionizing radiations were observed to be the major type (45.6 Bq C-14 eq), with very low contribution with regard to carcinogens, non-carcinogens as well as respiratory organics and inorganics. Plantation, harvesting and transportation and soil fertility management account for about 99% release of agents responsible for the cumulative threats to human health. The values associated with human health toxicity are of similar level as reported in similar studies elsewhere[8], yet the primary causes for these are yet to be explored with certainty.

Resources: Finally, the contribution towards resource depletion (fig. 5) is observed to be primarily contributed by soil fertility management, plantation and harvesting and transportation. As evident from the figure, the major contributor of resource depletion during soil fertility management phase is land occupation followed by mineral extractions, which may be accounted to the very usage of the land and fertilizer manufacturing related emissions. During plantation phase and harvesting and transportation, the primary resource depletions are non-renewable energy and mineral extractions, primarily because of the diesel driven vehicles and other machineries.

Analysis of Environmental Emissions at Endpoint Categories: The contribution to the endpoint categories shows the following results (fig. 6). Weed, pest and disease control account to about 50% of all the four types of impacts under consideration (human health, ecosystem quality, climate change and resources). The second major contributor is found to be the planation in all the categories except ecosystem quality. Harvesting and transportation and fertilizers seem to be the least contributors for all the impact categories except ecosystem quality where fertilizers seems to be almost 50% contributor.

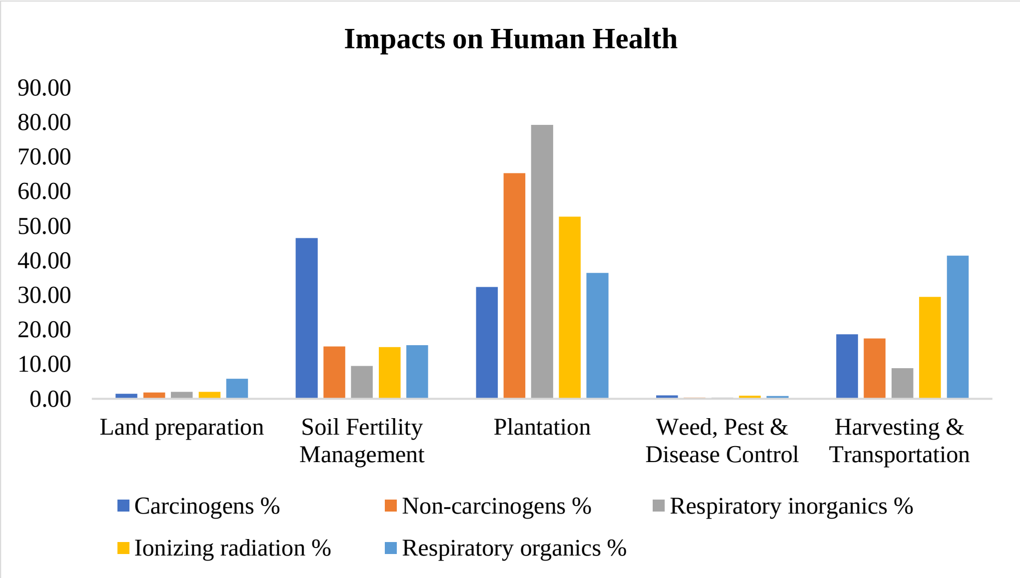

Figure 4: Human Health Impacts

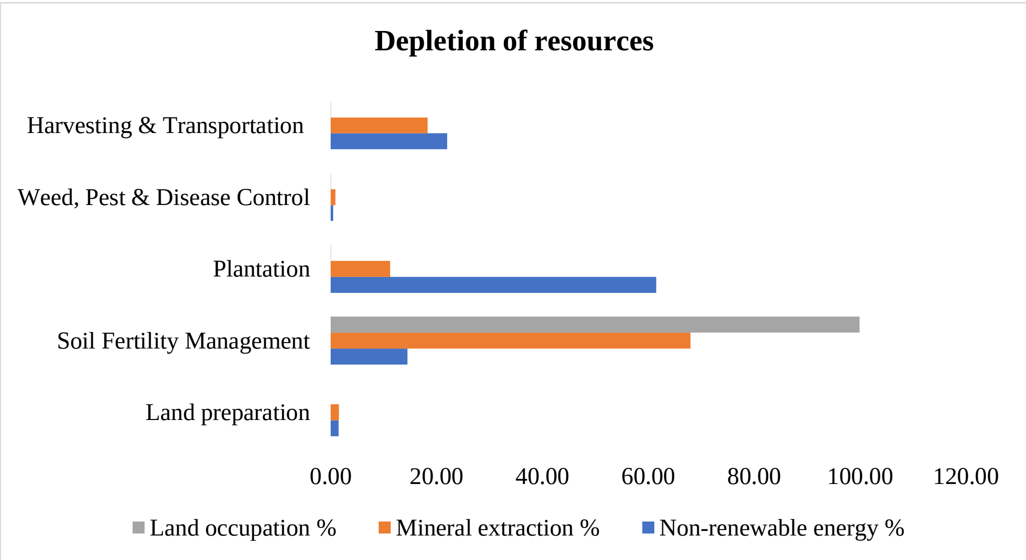

Figure 5: Resource Depletions

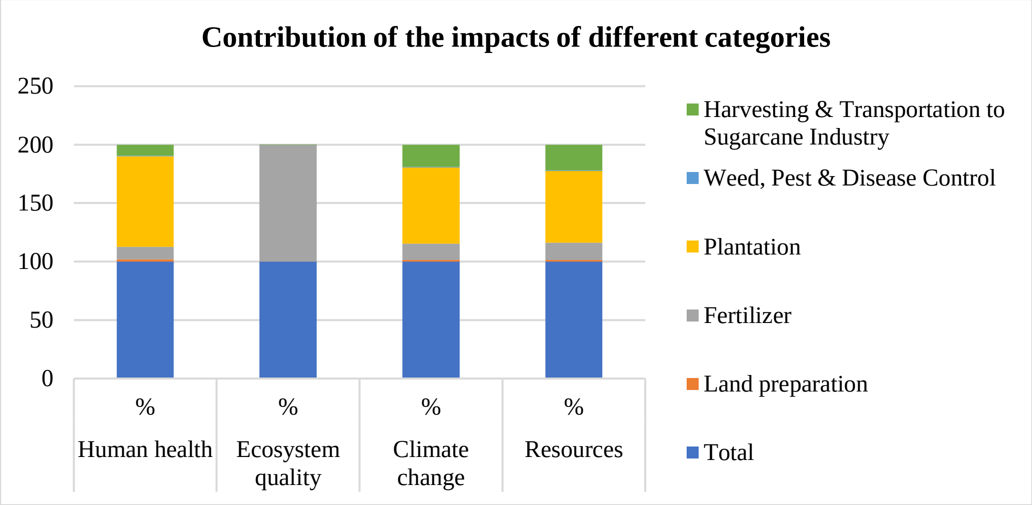

Figure 6: Contribution of the impacts of different categories

Conclusion

The studies indicate extensive usage of diesel powered tilling and ploughing machineries and excessive pumping of water for irrigation (often more than necessity, probably because of heavy governmental subsidy to the farmers) and resultant excess usage of grid power seem to be primary reasons for higher global warming potential. Secondarily, moderately high GHG emissions (mostly in the form of NOx and CO_2) released by the organic fertilizers are found to be contributed by during soil fertility management phase of sugarcane cultivation. Among the various impacts onto the ecosystem, aquatic ecotoxicity plays an important role, especially during plantation phase and harvesting and transportation phase because of associated leaching of fertilizers and emission of unburnt hydrocarbons during transport respectively.

The major resource depletions associated with sugarcane cultivation are land occupations and mineral extractions (during soil fertility management) and non-renewable energy (during plantation). Since, sugarcane is a major cash crop produced in India, which is the global leader among the sugarcane producing nations, a better understanding of its environmental impacts (and suitable planning based on such understanding) can play a crucial role in ensuring a sustainable agro technological landscape in the country (and other location sharing the similar agro climatic and cultural attributes).

Acknowledgement

The authors acknowledge Dept. of Science and Technology (DST): SUTRAM for easy water (DST/TM/ WTI/ WIC/ 2K17/82(G)) and Indian Space Research Organization (ISRO): (ISRO/ RES/ 4/684/19-20) for financial support for carrying out this research.

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(Received 03rd December 2020, accepted 07th January 2021)