Life Cycle Assessment of Sugarcane Growing Process in Fiji

Abstract

Sugarcane is an economically important crop in Fiji as it has considerable impact on the gross domestic product (GDP) and around 22% (200,000) of the population is directly or indirectly dependent on the sugarcane industry. Considering the importance of this crop a Life Cycle Assessment (LCA) was performed in order to understand environmental impacts. In this paper, Fijian sugarcane production was assessed to produce a set of LCA results for defined impacts. The results can be used in subsequent assessments of sugarcane related products and provide significant insighst into the current impacts. Life cycle impact assessment results were generated using CML, ReCiPe and Impact 2002+ models running in Open LCA software using the Ecoinvent database. This connected the system flows and process flow to the product systems in order to calculate the life cycle impact assessment (LCIA) results to be based on local data for comparable and accurate evaluation. Previous analysis revealed that sugarcane production has a considerable impact on global warming potential because of the significant use of fossil fuels in farm machineries and transportation, and the production and use of agrochemicals.. Results from this study show that sugarcane production has least impact on ozone layer depletion. Fertilizer production and usage was found to be one of the key issues affecting various impact categories. These results will assist further assessments on the sugarcane products and systems. However, in order to further develop the LCA tool for Fijian agricultural systems, development and testing of life cycle impact assessment models is necessary for Fijian conditions. This will ensure further accuracy of model outputs and supply more realistic and real-time results on emissions.

Keywords: LCA, climate change, global warming, environmental impacts, CML

Introduction

Sugarcane is a globally important crop which is commercially grown in many tropical and subtropical countries to support economic development and social needs. It is a dynamic plant that has the potential to convert up to 6.7 % of solar energy during photosynthesis into primary biomass (Pippo et al. 2011). Traditionally, sugarcane was grown for sugar as a sweetener, but is now grown for many other products and purposes such as ethanol and electricity. In recent years sugarcane has become highly valued globally as a bioenergy crop with a potential to produce over 100 metric tonnes of biomass per hectare per year which supports the production of feed, food, fuel, fibre and other specific products (Souza et al. 2015). While the economic value of sugarcane is recognised and current efforts to use this crop to its full potential as a clean energy source are well documented, the interest in studying the environmental impacts of the sugarcane growing process, milling and production and end-use of products using Life Cycle Assessment (LCA) are growing (Ramjeawon 2004; Ometto et al. 2009; Renouf et al. 2010; Amores et al. 2013; Guerra et al. 2014). Life cycle assessment (LCA) is the evaluation and calculation of the environmentally pertinent inputs, outputs and the impending environmental impacts of the life cycle of a material, product or service (Department of Environmental Affairs and Tourism 2004) . The ISO standard 14040:2006 describes the principles and framework for life cycle assessment (LCA) and also covers life cycle inventory studies however it does not describe the LCA technique or methodologies for individual phases of LCA (ISO 2016).

The IPCC-2014 report indicates that 24% of total global greenhouse gas emission of 49 Gt CO_{2eq} is contributed by Agriculture, Forestry, and Other Land Use. The emissions from this sector are mainly from agriculture (cultivation of crops and livestock) and deforestation (IPCC 2014). The emission from cultivating sugarcane was reported to be around 2.41-3.24 ton CO_{2eq} per hectare. This included area managed by burning practices and emissions related to fertilizers, herbicides and pesticides manufacturing (de Figueiredo et al. 2010; Carmo et al. 2013).

This assessment does not include carbon dioxide (CO_2) that the sugarcane monocrop ecosystem removes from the atmosphere by sequestering carbon in soils and dead organic matter. Past LCA studies show that the growing phase of sugarcane is one of the major contributors of environmental impacts in the life cycle of sugarcane-derived products (Ramjeawon 2008; Renouf et al. 2010; Prasara-A and Gheewala 2014). It is therefore important to fully understand the agricultural phase of sugarcane production in order to assess the implications on value-added products such as sugar and ethanol. This study is different from past studies in a sense that previous studies were either not specifically investigating the sugarcane growing process or were carried out for other regions with a climate and resources significantly different from Fiji. The sugarcane industry is important to Fiji's economy as it contributes about 1.7 percent of GDP, generates about 8.0 percent of total exports in the form of sugar and molasses (Khan 2014).

Sugarcane cultivation in Fiji is concentrated in the Western part of the largest island of Viti Levu and the Northern part of the second largest island, Vanua Levu. Viti Levu has three sugar mills located in Lautoka, Ba and Rakiraki (although Rakiraki mill is not currently operational) and Vanua Levu has one sugar mill located in Labasa as shown in Figure 1.

Fig. 1 Sugarcane cultivation areas in Fiji

Methods of sugarcane production are known to vary at different locations around the globe. Since sugarcane is now used globally as a source of cleaner energy products, it becomes imperative to understand the impacts of growing sugarcane. Thus the main objective of this study is to identify and understand the wider range of environmental impacts of sugarcane production specific to Fiji and compare these impacts with those of other countries using different farming techniques and higher sugarcane yield. Additionally, this study shows how Fiji is contributing to GHG emissions by producing sugarcane. A complete assessment was only possible by combining literature and published datasets with field research in Fiji as reliable location-specific industry datasets were not readily available.

Materials and Methods

The data used is the country's annual average. After the land is well tilled, sugarcane cuttings are placed in the soil in the form of a line. This first growth is called plant cane and after harvest the regrowth is called ratoon crop. These ratoon crops are harvested at 12 monthly interval subsequently for the next 6-8 years, and sometimes more for a few farmers. Data and results are averages for 1 acre over a crop cycle of 8 years.

The production of sugarcane in Fiji is not fully mechanised and 15-20% of farmers are still heavily dependent on traditional farming practices such as using bullocks for ploughing, tilling and other land preparation activities which is mechanised in developed countries. However, it is believed that the majority of these farmers use tractors to plough their fields for the very first time before planting. Harvesting is mostly still performed using manual labour but some farmers are adapting to mechanical harvesters, however these are not considered in this study because of their current insignificant use. Trucks, tractors and trains are used to transport the cane to mills, however transportation by road is substantial as rail is not able to provide consistent service due to aging infrastructure and inconsistent maintenance. Farmers use commercially available chemical fertilisers for crop growth while only very few use press-mud on a small scale. Press-mud is an industrial waste after the filtration of sugarcane juice from the sugar mills. Commercially available agrochemicals are also used to control weeds and pests. Irrigation is not used in Fiji for sugarcane cultivation and farmers only rely on rainfall. Around 29% of sugarcane is harvested 'burnt', while the rest are "green" harvested with trash either burnt later or left in-situ for mulching (Khan 2014). While burning sugarcane before harvesting is not practiced and not allowed in Fiji, farms are usually burnt as a result of other acts. The sugarcane which is harvested is transported to the 4 sugar mills in Fiji via rail and road.

Data and sources

Data for sugarcane growing inputs in this assessment were collected mainly from field research, interviewing cane-growers and the Sugar Research Institute of Fiji (SRIF). The data are presented in Table 1. The data for background processes such as use of agrochemicals, fuels, etc. were obtained by interviewing growers and personal communication with Mr. Prem Naidu, Senior Research Officer (SRIF). Other figures were obtained from published work (Renouf et al. 2010; Khan 2014). Diesel for land preparation was calculated by assuming that land is ploughed 3 times with equal application (3 times) of harrowing using tractors. Diesel for other use is calculated for transportation of agrochemicals and other short distance runs to carry out daily farming activities. Cuttings are manually cut into desired lengths and manually planted. Agrochemicals are applied manually also. Life cycle inventories (i.e. input and output of materials and energy flows of a system) were sourced from Ecoinvent database, version 3.3 (Life Cycle Inventory Database 2016) and are shown in Table 1. Ecoinvent database was also used in previous studies (Pereira et al. 2014; Silalertruksa et al. 2016; Chang et al. 2017) to study LCA of sugarcane products.

Impact assessment

The tool used to study the life cycle assessment is OpenLCA (Stavropoulos et al. 2016). The Ecoinvent database was used to connect the system flows and process flow to the product systems in order to calculate the life cycle impact assessment (LCIA) results to be based on the local data, lending for comparable and accurate evaluation. CML, ReCiPe and 2002+ models were used as a LCIA method from Ecoinvent version 3.3 because they consists variety of impact categories that can help policy decision makers (Silalertruksa et al. 2016) and can be compared with other studies using same models and impacts in other countries.

Table 1 Sugarcane production parameter for one tonne cane delivered to mill

Inputs	**Unit**	**Average**
Energy Input		
Diesel-Tractors (Land Preparation) [a]	L	2.10
Diesel-Tractors (Other use) [a]	L	1.49
Seed Cane [b]	Kg	66.67
Fertilizers and agrochemicals		0.00
Nitrogen - total [a,b]	kg	4.35
Phosphorus [a,b]	kg	1.29
Potassium [a,b]	kg	2.83
Diuron [a,b]	kg	0.05
Velpar [a,b]	kg	0.05
Amine [a,b]	L	0.03
Glyphosate [a,b]	L	0.05
Transport for farming inputs		0.00
Shipping [c]	t.km	60.00
Articulated Truck [c]	t.km	3.00
Rigid Truck [c]	t.km	0.10
Burnt cane harvested	%	29.00
Green cane harvested	%	71.00
Transportation of Cane to mill		0.00
Road [a]	t.km	56.23
Rail [a]	t.km	13.10
Sugarcane yield	t/ha	74

[a]Survey data (field study). [b]Personal communication with senior research officer of SRIF. [c]Literature data (Renouf et al. 2010; Khan 2014).

System Boundaries

The system boundaries for this study include all farming processes from land preparation up to harvesting and transportation including other connected inputs. Figure 2 shows the system boundaries (dashed line). The functional unit of this study is one tonne of sugarcane delivered to the mills. Production of farm-used capital goods such as tractors, harvesters and rail systems are not included for simplicity because the life span of such goods is too long to have a substantial impact on a single production as outlined in previous studies (Ramjeawon 2008; Prasara-A and Gheewala 2014; Stavropoulos et al. 2016). The clearing of bushland is not included in the system boundary because many existing farms are now vacant and underutilised. Future use of bushland (land use change) is out of the scope in this study.

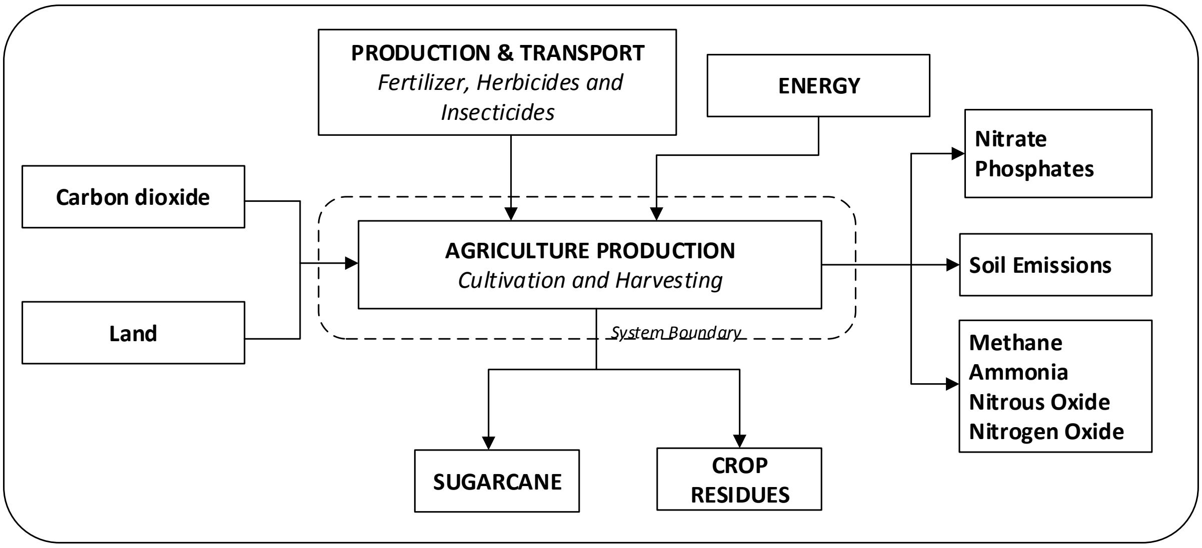

Fig. 2 System boundary (refer to dashed line)

Pesticide, nitrogen (N) and phosphorous (P) emissions from sugarcane fields are included. Methane release or uptake from the farms are excluded because recent experimental studies suggest that methane does not have a net flux from sugarcane fields (Denmead et al. 2010; Renouf et al. 2010; Sornpoon et al. 2013). Pre-harvest burning and trash burning is not considered for net CO_2 release and has been excluded because it is assumed that carbon in the sugarcane is recycled (Ramjeawon 2004).

Normalisation

Normalisation of impacts was also important in order to see the significance of the impacts related with the sugarcane cultivation (Renouf et al. 2010; Prasara-A and Gheewala 2014). The 2002+ model (endpoint impact level) was used since it provides normalised data with “points” as a unit. “Points” represent the average impact in a specific category caused by a person during one year in Europe (Humbert et al. 2012). The weakness of this study is applying European based LCIA models to Fijian inventory data. The Fijian toxicity characteristics can be substantially different to those of European conditions due to climate and demographic.

Nevertheless in the absence of detailed Fijian or Pacific LCIA methods, CML (baseline and 2001) and impact 2000+ methods are adopted as best practice (Foley and Lant 2009).

Results and discussion

The categorised LCIA result for the average scenario are shown in Figure 3 and the significance of characterised impacts are presented in Table 2 and Figure 4.

Table 2 LCIA results (per one tonne of sugarcane delivered to the mill (units are in points))

Impact Category	2002+
Global warming potential	0.006354972
Fossil Fuel Depletion	0.005873592
Human Toxicity	0.002531347
Ozone Layer Depletion	1.26079E-06
Terrestrial Ecotoxicity	0.001528454
Terrestrial Acidification	0.000146774
Marine Aquatic Ecotoxicity	5.04892E-05
Water Depletion	0.206246206
Land Use	134.86

Global warming potential

The global warming potential is also referred as climate change in all LCIA models. Global warming potentials are given for emissions of greenhouse gases to the atmosphere only and are expressed as kg CO_{2eq}. The majority of the global warming potential of sugarcane production is a result of the direct and indirect use of fossil fuels such as during the production of nitric acid and ammonia for fertilizers. N_2O is considered to be the key element having a greater effect in creating inconsistency in global warming potential. The global warming potential for the CML model was 79.85 kg CO_{2eq} and ReCiPe was 79.67 kg CO_{2eq}. These two results are similar to those of an Australian study (Renouf et al. 2010) with an emission of 77.9 kg CO_{2eq} for the production on one tonne of sugarcane. The difference is due to different transport distance and different land preparation techniques hence a difference in fuel use. Global warming potential consists of 57.69 % carbon dioxide from fossil fuels, 39.79 % dinitrogen monoxide (N_2O), and 2.52 % methane from fossil fuels. From Figure 4 it can be seen that the global warming potential is highest impact in the sugarcane production.

Fossil fuel depletion (abiotic resources)

Fossil fuel depletion is also represented as depletion of abiotic resources associated with the extraction of fossil fuels and minerals. It is expressed as MJ of total primary non-renewable energy. One of theet al reason for this depletion is during the production of fertilizers, the use of fuel in farm machinery and transportation. The depletion of fossil fuel (non-renewable energy) was 799 MJ for CML and 825 MJ for ReCiPe. A similar study carried out in Australia (Renouf et al. 2010) found 536.8 MJ for this category, and this difference is this is likely due to more efficient mechanised agricultural machinery and transport, as well as higher yields and efficiencies of scale in Australia when compared with Fiji.. The production of urea contributes to the majority of energy used for agrochemical production because its usage is extensive in the growing stage of sugarcane in Fiji. The depletion of abiotic resources consist of the extraction of 66.41 % crude oil, 21.81 % natural gas, 9.80 % hard coal and 1.98 % lignite. It was also noted that the depletion of abiotic resources (fossil fuels) is substantial in the production of sugarcane as represented in Figure 4. The major reason for a higher depletion rate for Fiji is due to lower sugarcane yield (74 tonnes per hectare) whereas the neighbouring country, Australia, has 85 tonnes per hectare (Renouf et al. 2010).

Human Toxicity

Human toxicity relates to the effect of toxic substances on the human environment. It is influenced by respiratory disorders caused by inorganic substances (toxic metal dust) released into the air and is expressed as kg 1,4 DCB_{eq} (1,4-Dichlorobenzene). Human toxicity was 39.03 kg 1,4 DCB_{eq} and 22.36 kg 1,4 DCB_{eq} CML and ReCiPe respectively. Human toxicity consists of actions taken to supply capital goods, exhaust emissions from the use of farm machineries and production and use of agrochemicals. During these processes, the emission of heavy metals have impacts on human health. The comparable impacts in Figure 3 show that human toxicity impact from sugarcane production is relatively high. Similar results were also presented in an earlier study (Silalertruksa et al. 2016).

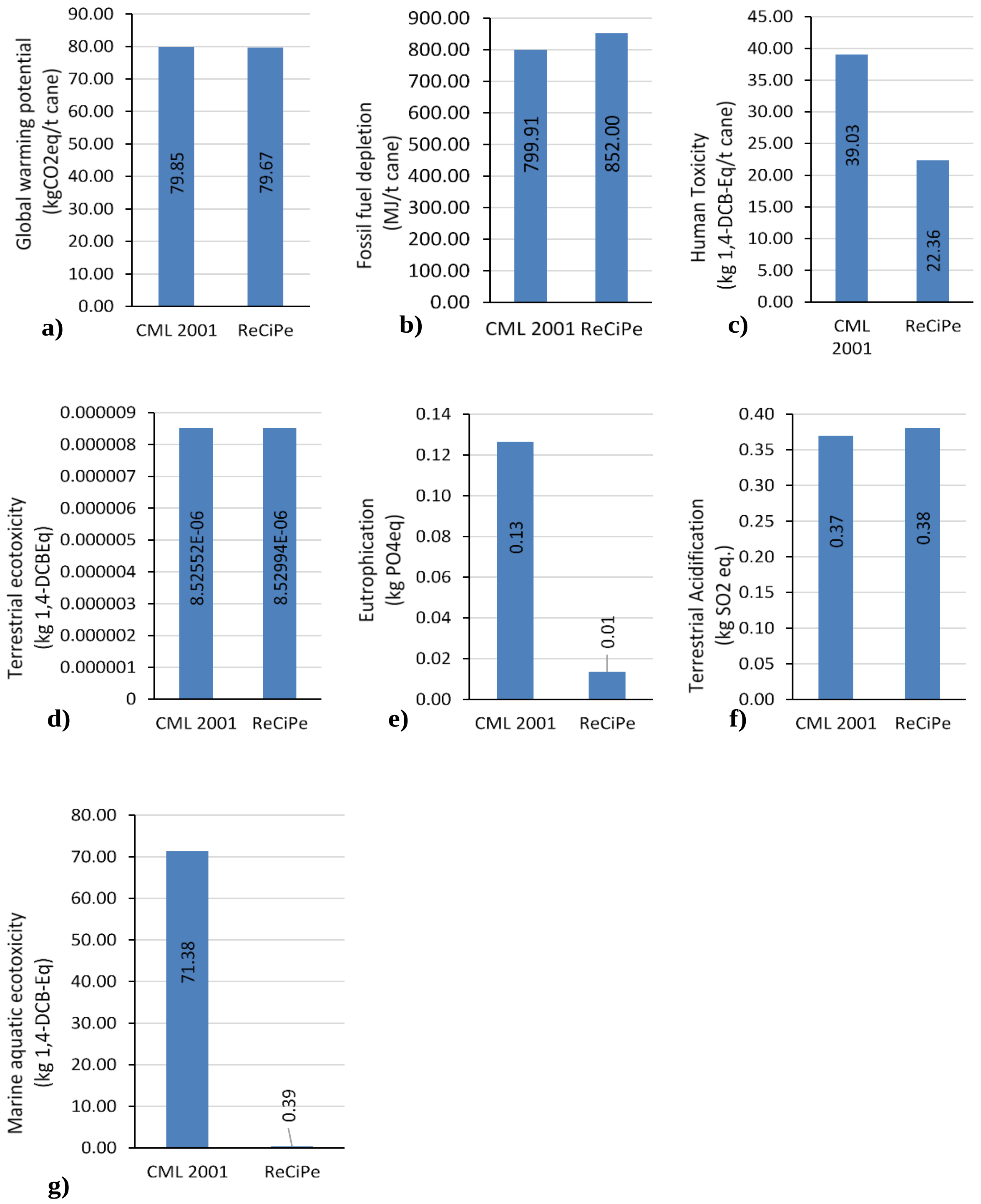

Fig. 3 Characterisation results of impacts of sugarcane cultivation per one tonne of sugarcane transported to sugar mill

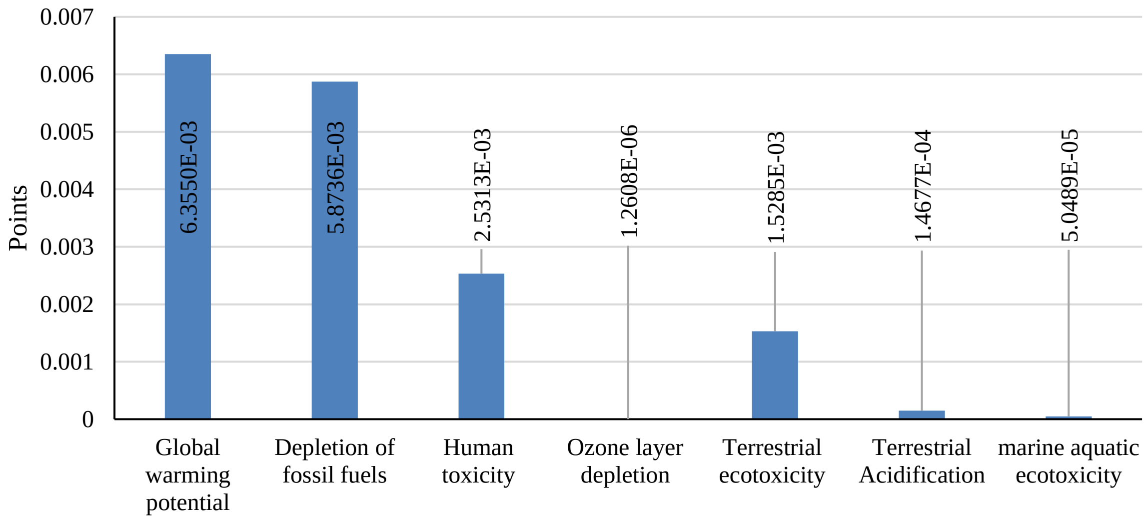

Fig. 4 Significance of characterisation results of impacts for cultivation one tonne of sugarcane and transporting to mill

Ecotoxicity

The ecotoxicity impacts are described for "Terrestrial Ecotoxicity" and "Marine Aquatic Ecotoxicity" and are expressed as kg 1,4 DCB_{eq} (1,4-Dichlorobenzene). Marine aquatic ecotoxicity is given for emissions in water, air and soil and determines the effects on fresh water. The aquatic ecotoxicity is only for heavy metal applicable to metals released in dissolved form (ions). Terrestrial ecotoxicity is also given for emissions in air, water and soil and are only for heavy metals based on the release of metals in dissolved form. However, the eco-toxic effects are only by contact with aqueous phase in soil. In our study, the terrestrial ecotoxicity was 8.525 $x10^{-6}$ kg 1,4 DCB_{eq} for CML model and 8.529 $x10^{-6}$ kg 1,4 DCB_{eq} for ReCiPe model. On the other hand, the marine aquatic ecotoxicity was 71.38 kg 1,4 DCB_{eq} and 0.39 kg 1,4 DCB_{eq} for CML and ReCiPe models. It is noted in Figure 4 that terrestrial ecotoxicity has higher impacts while marine aquatic ecotoxicity has lower impacts during the production of sugarcane, however an earlier study (Prasara-A and Gheewala 2014) showed the opposite.

Eutrophication

Eutrophication is the depletion of oxygen in the water column. The main factors leading to and manipulating the changes in eutrophication are emissions; from agriculture such as fertilizers run-offs, leaching, denitrification of nitrogen oxides and ammonium. Other minor contributions are from transportation and machinery operation. The eutrophication potential was 0.13 kg PO_{4eq} and 0.01 kg PO_{4eq} for CML and ReCiPe models respectively. The eutrophication values for 2002+ (endpoint) was not available in the model for comparative analysis on the significance of impact in the sugarcane production.

Terrestrial Acidification

The terrestrial acidification potential is expressed comparative to the acidifying effects of SO_2. The substances leading to acidification are usually ammonia and nitrogen oxide. The acidification potential was 0.37 kg SO_{2eq} and 0.38 kg SO2eq for CML and ReCiPe models respectively. The terrestrial acidification potentials are a result of fossil fuel usage and reflect the depletion of fossil fuels. Agricultural emissions from the use of fertilisers are also key factors that influence the variability in this acidification potential. A comparative analysis of the significance of these impacts shows that terrestrial acidification is not extensive in sugarcane growing. Other studies (Renouf et al. 2010; Prasara-A and Gheewala 2014) also suggested that terrestrial acidification is not significant in sugarcane production.

Land and water use

Land and water used in the production of sugarcane is related to farm cultivation and this does not have background processes. Lands used for cultivation are all traditional lands which were used for sugarcane farming for decades and no new areas (forest) are cleared for the cultivation of sugarcane. Water is not used for the irrigation of sugarcane and only comes from natural rain. Only 2% of the total land (area) is used for cultivating sugarcane in Fiji. The results in this paper do not present the impacts of land and water use in terms of their depleting potential. However it should be noted that sugarcane requires a substantial amount of water during its growing phase which is obtained from rain. Further assessment of land use and water is therefore required with an appropriate methodology suitable for the Fijian context.

Conclusions

The environmental impacts of sugarcane production were analysed for sugarcane growing areas in Fiji. Since Fiji is hoping to fully utilise its' existing sugar industry and diversify into energy generation (cogeneration, ethanol, biomass), this study has produced some important data on various environmental impacts of sugarcane production in Fiji. These results will lead to further assessment of Fijian sugarcane products and systems. In particular it was found that field emissions such as the use of fertilizers, transportation and machineries contribute significantly to a number of different impact categories such as fossil fuel depletion, global warming potential, human toxicity and terrestrial ecotoxicity. Nitrogen-related emissions are an important concern for sugarcane cultivation as it leads to nitrification, leaching and denitrification processes in soils.

The characterised impacts prove that sugarcane cultivation significantly contributes to the global warming potential, the depletion of fossil fuels and substantially contributes to human toxicity and terrestrial ecotoxicity. It also revealed that sugarcane growing does not have high impacts on ozone layer depletion, terrestrial acidification and marine aquatic ecotoxicity. Since the LCIA models used are not Fijian-based ones, it is anticipated that the results may not exactly reflect the Fijian emissions in real-time but nevertheless the results provide an important understanding of the emissions related to sugarcane production. The LCIA results of the CML and ReCiPe models show some discrepancies and this is likely because of the approach taken by these models in calculating respective impact categories which is different as they use different weighting coefficients and elementary flows (Stavropoulos et al. 2016). However, any of these LCIA models should produce similar categorised impacts when compared in normalised form as shown in Figure 4 to indicate the significance of each impact.

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