The International Journal of Life Cycle Assessment
https://doi.org/10.1007/s11367-019-01629-3

Life cycle assessment of products from agro-based companies in Uganda

David Mfitumukiza[1] · Hawah Nambasa[1] · Paul Walakira[2]

Received: 2 February 2017 / Accepted: 24 April 2019

Abstract

Purpose Despite the fact that life cycle assessment (LCA) is a very vital tool, it has not been used in Uganda most likely because very little is known about it. In an attempt to initiate and promote LCA in Uganda, a partnership among Makerere University, selected agro-based companies, and Uganda National Bureau of Standards (UNBS) was initiated with the broad aim of promoting life cycle thinking for improved agricultural products competitiveness on regional and international market. Specifically, the study focused on assessing and quantifying the environmental impacts throughout the life cycle of selected products.

Methods Life cycle assessment tool was used to quantify environmental impacts including global warming, ecological toxicity, human toxicity, photochemical oxidation, and abiotic depletion. A detailed, process-based gate-to-gate (core process) LCA approach in accordance with ISO 14040, 14044 (ISO 2006a, b), PCR 2012:07 CPC 013 Fruits and nuts together with PCR 2011:08, CPC 2143 Fruit juices was conducted. The functional units have been redefined to; 1 litre of packaged juice ready for consumption and 1 kg of packaged dried fruits including the non-edible parts. Calculations at the farm stage involved calculations of net emission from land cover changes using; $\Delta C =$ (activity data * emission factor). Calculations of N_2O from manure management were obtained.

Results and discussion Carbon dioxide emissions mainly result from the change of tree cover to crop fields and use of fossil fuel. The other impact categories (ecological toxicity, human toxicity, photochemical oxidation, and abiotic depletion) were brought about by the packaging material used. Results also showed that energy consumption was highest at the agricultural stage of dried pineapples processing and production/factory life cycle stage of sweet bananas. The main challenge during assessment was lack of records.

Conclusions There is need for avoiding or minimizing the conversion of forest-covered land into agricultural land use due to the high-carbon emissions associated with the change, and for switching to renewable energy sources. There is need for a national database to support LCA efforts.

Keywords Agro-based · Dried · Juice · Mango · Pineapples · Sweet bananas · Uganda

1 Introduction

Uganda's economy predominantly depends on agriculture with about 80% of the population deriving livelihoods from it (FOWODE 2012). The availability of raw agricultural products is increasingly attracting the development of agro-based industries (MTTI 2008). According to the statistics of UIA (2013), Uganda is ranked number one in the production of fruits like pineapples, sweet bananas and mangoes in Africa making this sector one of the most targeted by investors in the country. New processing industries are being established to meet the increasing demand for fruit products (juice and dried fruits) on both the local and export markets. The number of agro-based industries is potentially going to increase in Uganda in the near future.

The growth in agro-based industries in Uganda is expected to lead to an increase in environmental impacts and greenhouse gas (GHG) emissions during transportation (of raw material/products), product processing, packaging, and wastes generated (Mogensen et al. 2009). Despite this eminent environmental problem, there has been no or very limited effort in Uganda to help in identifying and quantifying environmental

Responsible editor: Sonia Valdivia

✉ Hawah Nambasa
hawahnambasa@yahoo.com

[1] Makerere University College of Agricultural & Environmental Sciences, P.O Box 7062, Kampala, Uganda

[2] Uganda National Bureau of Standards, P.O. Box 6329, Kampala, Uganda

Published online: 15 May 2019

impacts across the entire life of any product or process. This in turn has limited the decision-making efforts aimed at devising environmental management approaches to these impacts (Kaval 2011). A number of tools to support decision-making processes pertaining to quantifying and managing environmental impacts have been developed and utilized (Guinée 2001). Among these tools is life cycle assessment (LCA) which is a process of compilation and evaluation of the inputs, outputs and the potential environmental impacts of a product system throughout its life cycle (ISO 14040 (2006a)). In turn, through recommendations, LCA helps decision-making in reducing costs through the use of efficient materials, production processes, and waste management practices (EEA 1997).

LCA has been used worldwide most especially in European countries (Chanaron 2007) as a tool for environmental management. Use of LCA in these countries has been the major source of information for improved management of environmental impacts from various product systems (ECA 2014). LCA has been used to quantify the effects of food productions systems on the environment through impacts like eutrophication of waterways, acidification, and emissions of GHGs resulting into global warming (Sonesson et al. 2010). LCA has also been used to establish environmental impacts associated with the production and consumption of a food product at various levels (DEFRA 2006).

A study done in Thailand by Phanchandee and Sachakamol (2013) noted that among the very many environmental problems associated with agricultural production, global warming is the most overlooked by scientists. A LCA tool was thus used to assess a number of environment impacts associated with all stages of mango and mangosteen's life from cradle-to-gate. In another LCA study, it was found out that pineapples have a higher energy demand and carbon footprint than common tree fruits like apples and oranges because of it being more input intensive (Ingwersen 2012). Also, research findings in Australia suggested that interventions in food chains to reduce on water use consumptions will likely have greater impact on freshwater resource availability as other water use efficiency measures in agriculture and food production (Ridoutt et al. 2012).

Quantification of energy consumption is another important way in which LCA provides support on product life cycle management (LCM) especially through providing information on indirect effect of climate impact through GHG emissions (Nilsson et al. 2011). LCA studies have remained vital in providing detailed information for strategic planning and decision-making during product manufacturing so as to reduce on the environmental impacts (Liamsanguan and Gheewala 2008). Through LCA, a product design can be improved by considering raw material, production technologies, and waste management strategies which emit less GHGs to the atmosphere.

Despite the importance of LCA, it has not been used in Uganda most likely because very little is known about it. Even those who may be interested in LCA face a challenge of limited skills and knowledge that are required for a meaningful LCA process (Walakira et al. 2013).

In an attempt to initiate and promote LCA of agro-processing production systems in Uganda, a partnership among Makerere University, selected agro-based companies, and Uganda National Bureau of Standards (UNBS) was initiated with support from the Swedish Standards Institute (SIS). This specific partnership effort is a follow-up on earlier identified needs pertaining to carbon footprint and life cycle management in Uganda (Walakira et al. 2013). The broad aim of the current initiative was to promote life cycle thinking and facilitate understanding and implementation of life cycle sustainability principles for improved agricultural products competitiveness on regional and international market. Among the activities of the partnership, there was a pilot LCA study based on three selected agro-based companies in order to demonstrate the importance of LCA as a tool for decision-making around adopting new and alternative methods of production that consider reduction of environmental impacts and promotes food products' sustainability in agro-processing systems in Uganda. Therefore, the aim of the study was to contribute to the understanding of Uganda specific environmental impacts from agro-based industries for improved life cycle management. The specific objectives of the study were to quantify the various inputs and outputs at the different stages of the product systems, assessing the associated environmental impacts, and quantifying waste released to the environment and documentation of the challenges and limitations for implementing LCA. The products considered for this study were dried pineapples, dried sweet bananas, pineapple juice, and mango juice.

2 Materials and methods

2.1 Study area description

The agro-based companies from which data collection was done were: Rural Community in Development (RUCID), Flona Commodities, and Be Organic. RUCID Company is located in Lubanja Village, Mityana District. The company processes dried fruits, juice, jam, and wine from various fruits it receives from farmers. RUCID uses a company truck to collect fruits from various farms in Mubende and Mityana districts. Flona Commodities is a company located in Kangulumira, Kayunga District. Flona collects fruits to be processed from various sites in Eastern Uganda using pickups to Kayunga where they are processed into dried products and juice. Be Organic Company is located in Busi Island, Wakiso District. This company only deals in processing dried fruits. Some of the farms that supply this company with fruits are located on Busi Island. Other farms are located on the other surrounding islands. Boats are used to transport the fruits between Islands. Trucks are used to transport the fruits within the island to the factory. All these companies sell their products in local, regional, and international markets. Dried pineapples and mango juice were considered at RUCID for this study. For Flona Commodities, dried pineapples and pineapple juice were considered, while dried pineapples and dried sweet bananas were considered at Be Organic.

This LCA study includes goal and scope definition, life cycle inventory analysis, impact assessment, and result interpretation basing on ISO 14044 requirements.

2.2 Goal and scope

This study focuses on and used life cycle assessment as a tool to quantify the environmental impacts of global warming, ecological toxicity, human toxicity, photochemical oxidation, and abiotic depletion during the production of fruit products. Identification of the environmental impacts was based on descriptive LCA. The products considered in the study are pineapple and mango juice and dried pineapple and sweet bananas. The targeted audience for data and information from the study are academia, agro-based companies, business individuals and institutions, policy makers, standards institutions, and organizations, among others.

2.2.1 System boundary

A detailed, process-based gate-to-gate (core process) LCA approach in accordance with ISO 14040, 14044 (ISO 2006a, b), PCR 2012:07 CPC 013 Fruits and nuts together with PCR 2011:08, CPC 2143 Fruit juices was conducted as summarized in the flow diagram (Figs. 1 and 2).

In the following lines, there is a description of the production processes of the fruit products concerned.

2.2.2 Fruit juice

Fruit juice processing involved transportation of fruits from the farms to the factory, fruit juice production (selection and sorting, washing, peeling and cutting, juice extraction, juice filling), packaging and labeling, and waste generated.

2.2.3 Dried fruit

Dry fruit processing included the agricultural phase (land clearing, cultivation, harvesting), transportation dried fruit production (selection and sorting, washing, peeling and cutting, fruit drying, packaging and labeling, and waste generated).

2.2.4 Functional units

Selected functional units were; 1 litre of packaged juice ready for consumption and 1 kg of packaged dried fruits including the non-edible parts. The following packaging size functional units per fruit product were used in this study: dried pineapples (poly-ethylene 0.00370 kg and poly-vinyl chloride 0.00159 kg), dried sweet bananas (poly-ethylene 0.00098 kg), mango juice (poly-ethylene 0.00284 kg and glass jar 0.21212 kg), and pineapple juice (poly-ethylene 0.00106 kg).

The inventory analysis was mainly based on primary data from farms and factories collected in June 2014. Secondary data for GHG emissions from land use change was obtained from the default IPCC values.

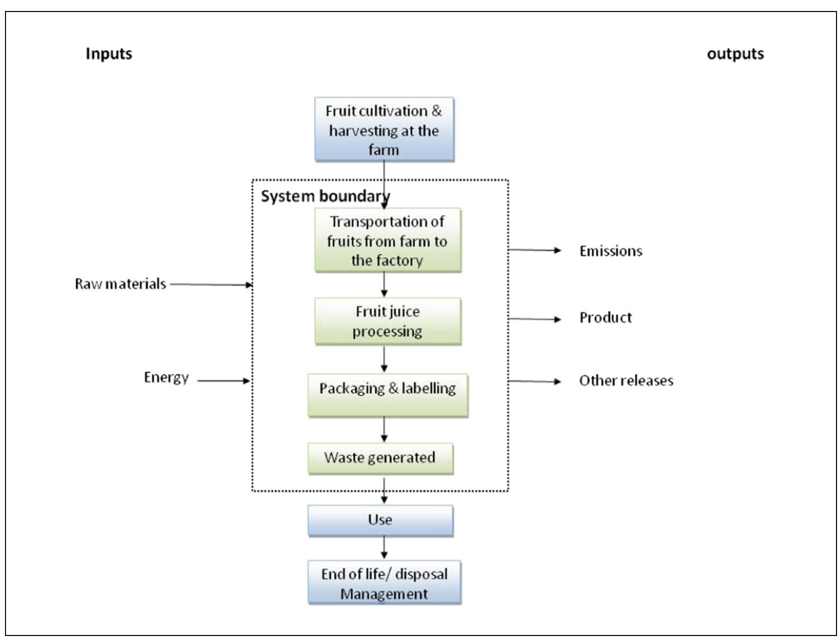

Fig. 1 Flow diagram showing life cycle stages during the production of fruit juices

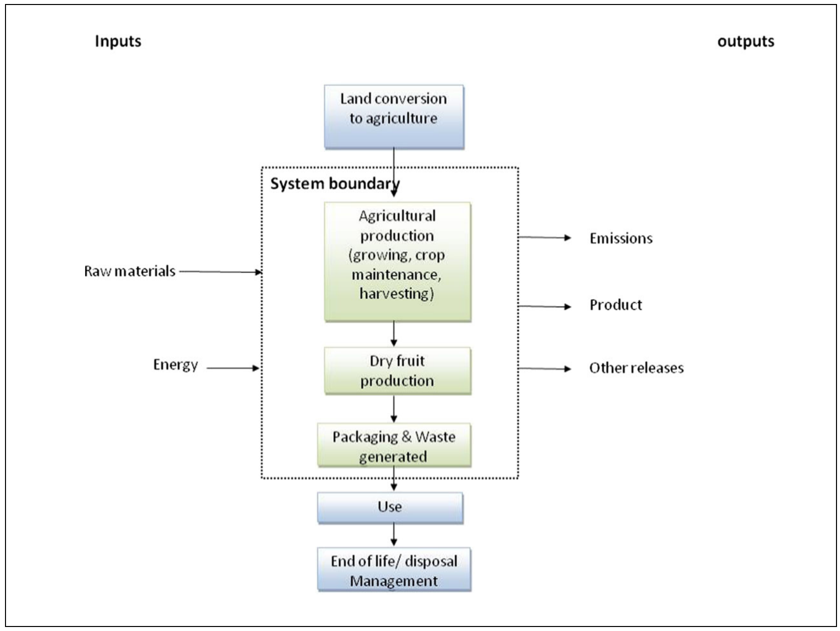

Fig. 2 Flow diagram showing life cycle stages during the production of dried fruits

Among all products chosen from the three sites for this LCA study, dried pineapples were the only product produced at all these sites. Thus a single entity was obtained as an average for the values from the three sites after normalizing pineapple inventory values to the functional unit.

During this study, the main cause of uncertainty in the data collected was the assumptions and estimations made especially at the farms. For example, there were no records on the amount of fuel used and so it had to be estimated. Other assumption include land transformation (from the initial vegetation cover to the current) was based on only the change in the vegetation cover type, and traveling of employees to and from their place of work was excluded.

2.3 Impact assessment

The impact assessment includes the selection of impact categories, classification, and characterization based on ISO 14044 (2006b). Impact categories considered during this study for 1 l of packaged juice and 1 kg of packaged dried pineapple are global warming, human toxicity, ecological toxicity, photochemical oxidation, and abiotic depletion. Also for dried fruits, greenhouse gas (GHG) emissions as a result of land use change are considered.

2.3.1 Assessment of environmental impacts of various inputs and outputs at the different stages of the product life cycle

Emissions from agriculture Estimation of Net emission from land cover changes is based on the tier 1 approach as developed under the 2006 IPCC Guidelines for National Greenhouse Gas Inventories using the following equation. $\Delta C =$ (activity data * emission factor) (Agus et al. 2013).

Where ΔC is the change in carbon stock, Activity data is the area undergoing a specific type of land use change that emits carbon, and Emission factor is the total loss of carbon stock per unit land area during the specific type of land use change. For this study, FAO emission factors are used (http://www.fao.org/docrep/019/i3671e/i3671e.pdf).

Calculations of N_2O from manure management are obtained using the IPCC tier 1a method $N_2O = N_{ex} \times FRAC_{GASM} \times EFA$, where: N_2O = emission due to NH_3 and NO_X losses from manure (kg N/Y), N_{ex} = Total N excreted by animal in the country (for this study, default IPCC values were used) (kg N/Y), $FRAC_{GASM}$ = Fraction of total nitrogen excretion that is emitted as N0x or NH_3 (kg/N/kg), EFA = IPCC default emission factor (EEA 2000).

Manufacturing stage (factory) (a) CML 2001 method

The Center of Environmental Science of Leiden University methodology, CML 2001 (Guinée et al. 2002) together with characterization factors of CML-IA, April 2013 database (https://www.universiteitleiden.nl/en/research/research-output/science/cml-ia-characterisation-factors accessed on 14/May/2014) are used to get impact category indicator results.

Midpoint impact categories considered using this method are global warming, ecological toxicity, human toxicity (considering poly-ethylene as an input), photochemical oxidation, and abiotic depletion.

(b) USEtox method

Besides poly-ethylene (PET), poly-vinyl chloride (PVC) also causes human health impacts. USEtox method (Rosenbaum et al. 2008) was used to get characterization factor value of PVC so as to get the results of human toxicity.

Characterization factors for calculating human toxicity and freshwater ecotoxicity for the case of PET were obtained using CML-IA, April 2013 database.

To calculate environmental impact assessment results of global warming, human toxicity, ecological toxicity, photochemical oxidation, and abiotic depletion impacts, the following formula was used:

Inventory data × characterization factor = characterization value.

Quantifying energy use Quantity of fuel; hydroelectric power (kWh), diesel (liters), petrol (liters), fuel wood (kg), and charcoal (kg) used were converted (using FAO conversion factors) into energy and results recorded in mega joules.

Wastes generated During fruit product manufacture, there are products (according to PCR 2012:07 CPC 013 Fruits and nuts together with PCR 2011:08, CPC 2143 Fruit juices documents) that are not consumed by humans. These were recorded as wastes (either non-hazardous or by-products).

3 Results

The assessment results on global warming, ecological toxicity, human toxicity, photochemical oxidation, and abiotic depletion impacts of the production of packaged juices and packaged dried fruits are shown in Table 1.

3.1 Energy consumption

Results from assessment and quantification of energy use are shown in Fig. 3. The results show that, as was expected, more energy was being consumed during the production of dried fruits than for production of juices. Dried pineapples consumed more energy at the agricultural stage compared with dried pineapples. At the manufacture/production stage, sweet bananas consumed the highest amount of energy (Fig. 3).

3.2 Global warming

Global warming impact was highest during the production of dried fruits than juice. Production of dried sweet bananas contributed the highest value of this impact.

3.2.1 Vegetation cover change emissions

Production of dried fruits included the agricultural stage. During land clearing to grow fruits (pineapples and sweet bananas), some of the forest land, grassland, cropland (coffee), and shrubland was converted into agricultural land. Results for carbon dioxide emissions quantification from change in the land cover are shown in Fig. 4. Loss of forest/ tree land cover contributed the highest amount CO_2 emission to the atmosphere (Fig. 4) especially at the agricultural stage of dried pineapples.

3.3 Human toxicity, ecological toxicity, photochemical oxidation, and abiotic depletion

Charcoal burning during the production of dried pineapples and mango juice caused photochemical oxidation with dried pineapples production having the highest recorded value of this impact. The use of PET packaging material also caused this impact (photochemical oxidation). Ecological toxicity, human toxicity, and abiotic depletion impacts also resulted from the different types of packaging material as presented in Table 2. Ecological toxicity, human toxicity, and photochemical oxidation (all from the use of PET packaging material) were recorded the highest during mango juice production. Dried pineapples were the only fruit product with a record of human toxicity impact due to the use of PVC. This happened since none of the other fruit products used this type of packaging material. Abiotic depletion impact category was observed only during mango juice production (Table 2).

3.4 Wastes and waste management practices

These were products not consumed by humans but were generated along with the main product. These were grouped into non-hazardous wastes and by-products. Non-hazardous wastes included waste water, old generators oil, spilled diesel/ juice, PET packaging material, and broken glass. By-products were peels, pulp, suckers, banana stalks, and mango seeds (Table 3).

3.5 Challenges and limitations

The challenges and limitations of this study were mainly associated with absence of related background data and information at the study sites level, and in Uganda as a whole. Similarly, there was lack of expertise and technical support at all levels considered by the study. Specific challenges at farm and transport levels are presented next under the respective headings.

Table 1 Results per functional unit of fruit products from agro-based companies in Uganda

Mango juice					
Life cycle data: mango juice manufacture					
Inputs	Quantity (per liter)	Unit	Outputs	Quantity (per liter)	Unit
Diesel (for transportation of mangoes to the factory)	0.0320	lt	Mango juice	1.0	lt
Sorted mangoes (at the factory)	0.7786	kg	CO from burning charcoal	0.0758	kg
Water for fruit washing	0.7576	lt	Total CO2 emitted	0.7924	kg
HEP during fruit washing	0.0051	kwh			
Water (ingredient)	0.4419	lt			
White sugar (ingredient)	0.1263	kg			
Lemon juice (ingredient)	0.0061	lt			
Mango extract (ingredient)	0.4419	lt			
HEP (for pulping)	0.0013	kwh			
Wood (for sterilizing bottles)	0.4293	kg			
Charcoal (fuel)	0.0758	kg			
Life cycle data: mango juice packaging and waste generated					
Inputs	Quantity (per liter)	Unit	Outputs	Quantity (per liter)	Unit
Poly-ethylene (packaging material)	0.0028	kg	Packed mango juice	1.0	lt
Silicon packaging material (from glass)	0.2121	kg	Waste (by-product-peels)	0.0568	kg
			Waste (by-product-seeds)	0.0589	kg
			Waste (non-hazardous-broken glass; silicon)	6.629E-05	kg
			Waste (non-hazardous-waste water)	0.2946	lt
			Waste (non-hazardous-spilled juice)	0.0025	lt
Pineapple juice					
Life cycle data: pineapple juice manufacture					
Inputs	Quantity (per liter)	Unit	Outputs	Quantity (per liter)	Unit
Diesel (to transport pineapples to the factory)	0.0003	lt	CO2 (from diesel)	6.93E-04	kg
Sorted pineapples	4.0000	kg	Pineapple juice	1.0	lt
Water for fruit washing	0.4800	lt			
HEP for pumping water	0.0006	kwh			
HEP for juice extraction	0.0036	kwh			
Life cycle data: pineapple juice packaging and waste generated					
Inputs	Quantity (per liter)	Unit	Outputs	Quantity (per liter)	Unit
Poly-ethylene (packaging material)	1.06E-03	kg	Packed pineapple juice	1.0	lt
HEP	0.0006	kwh	Waste (by-product-peels)	0.56	kg
			Waste (by-product-suckers)	1.35	kg
			Waste (non-hazardous-PET)	6.0E-07	kg
			Waste (non-hazardous-waste water)	0.4809	lt
Dried pineapples					
Life cycle data: dried pineapples production					
Inputs	Quantity (per kg)	Unit	Outputs	Quantity (per kg)	Unit
Planted banana suckers	10.3812	kg	N2O from animal manure	0.3292	kg
Diesel used during cultivation	0.0127	lt	Dried pineapples	1.0	kg
Animal manure	0.9797	kg	CO emitted from charcoal	0.1911	kg
Compost household waste	0.0653	kg	Total C02 emitted	4.5802	kg
Diesel to transport suckers	0.00295	lt			
Harvested and delivered pineapples (factory)	19.7567	kg			
Diesel used to deliver fruits	0.0151	lt			
Petrol used by boat engine to deliver fruits	0.0011	lt			
Sorted pineapples	12.4792	kg			
Water (fruit washing)	2.5427	lt			
Diesel used by water pump	0.0011	lt			
Petrol used by water pump	0.0014	lt			
HEP for water pumping	0.0018	kwh			
Diesel (from the hybrid drier- fruit drying)	0.1618	lt			
Charcoal (fruit drying)	0.1911	kg			
Fuel wood (fruit drying)	2.3590	kg			
Diesel to transport fuel wood	0.0025	lt			
HEP (fruit drying)	0.0108	kwh			
Petrol (from the hybrid drier when power is off)	0.0538	lt			
Life cycle data: dried pineapples packaging and waste generated					
Inputs	Quantity (per kg)	Unit	Outputs	Quantity (per kg)	Unit
Diesel used by packing machine	0.0189	lt	Packed dried pineapples	1.0	kg
Poly-ethylene packaging material	0.0037	kg	Waste (by-product-peels)	1.9165	kg
Poly-vinyl chloride packaging material	0.0016	kg	Waste (by-product- pulp)	0.2035	kg
HEP	0.0014	kwh	Waste (by-product-suckers)	2.7107	kg
			Waste (non-hazardous-ethylene)	0.0011	kg
			Waste (non-hazardous-waste water)	2.5324	lt
			Waste (non-hazardous-spilled diesel)	0.0108	lt

Table 1 (continued)

			Waste (non-hazardous-old generator oil)	0.0009	lt
			CO2 emission from diesel	0.0497	kg
Dried sweet bananas					
Life cycle data: dried sweet bananas production					
Inputs	Quantity (per kg)	Unit	Outputs	Quantity (per kg)	Unit
Planted banana suckers	0.1774	kg	Dried sweet bananas	1.0	kg
Compost manure	2.1079	kg	Total CO2 emitted	58.5539	kg
Petrol used during harvesting	0.0835	lt			
Harvested and delivered sweet bananas (factory)	16.4307	kg			
Fuel (petrol) in transportation	0.0614	lt			
Selected and sorted sweet bananas	5.8968	kg			
Water used during washing	1.5565	lt			
Petrol used by water pump	0.0061	lt			
Diesel to run the drier	0.0501	lt			
Fuel wood used in drying	35.1351	kg			
Diesel to transport the wood	0.0125	lt			
Life cycle data: dried sweet bananas packaging and waste generated					
Inputs	Quantity (per kg)	Unit	Outputs	Quantity (per kg)	Unit
Diesel used by packing machine	0.0307	lt	Packed dried sweet bananas	1.0	kg
Poly-ethylene packaging material	0.00098	kg	Waste (by-product-peels)	0.6143	kg
			Waste (by-product- banana stems)	0.6511	kg
			Waste (non-hazardous-waste water)	10.5283	lt
			Waste (non-hazardous-old generator oil)	0.0154	lt
			Waste (non-hazardous-PET)	3.07125E-06	kg
			CO2 emission from diesel	0.0808	kg

3.5.1 Farm level

During data collection, some farmers were not willing to disclose some of the information about their farms. Tracing the sources of raw materials used by different companies was difficult due to lack of records. Physical access to village farms was also extremely difficult.

3.5.2 Transportation level

At transportation level, there were no records (most especially at the farm level) about the amount of fuel consumed. So, most of the figures recorded were estimates. For the processing level, the main challenge was lack of a national (Ugandan) LCA database/baseline data to compare with the data that were collected.

4 Discussion and recommendation

4.1 Amount of carbon dioxide emitted during land cover transformation

Results from this study clearly show that the single most important impact was global warming directly linked to land cover change. The land covers converted were mainly tree/forest, grassland, and shrubland. As expected, most of the carbon emissions were realized in areas where conversion was from tree cover to crop fields. This is because the carbon that has been stocked in trees over a long period of time is lost during the conversion from tree/forest cover into fruits crop fields with less carbon value. The finding is in line with several other studies that have shown that land cover transformation plays a great role in increasing atmospheric CO_2 (Sitch et al. 2005; Parish et al. 2007; Agus and Subiksa 2008; Pachauri and Reisinger 2008). In a study conducted by Brown et al. (2012), agricultural expansion was found to be a major driver of deforestation in many countries. In their study, they further show that reducing emissions through reduced conversion of forests into farmlands requires increased production on existing lands. Results suggest that there is need to avoid and/or minimize conversion of tree/forest-covered land into agricultural land use because of the high-carbon losses associated with the process that is not easily recaptured.

Whereas the growth of agricultural based industries is seen to be a positive development indicator in Uganda, the growth needs to be matched with sustainable development principles. Moreover, there is a need to ensure that the agricultural products meet regional and international standards which is important in promoting market competitiveness (World Economic Forum et al. 2015). Regional and international recognized standards require measurement of performance based on recognized facts and methodologies that

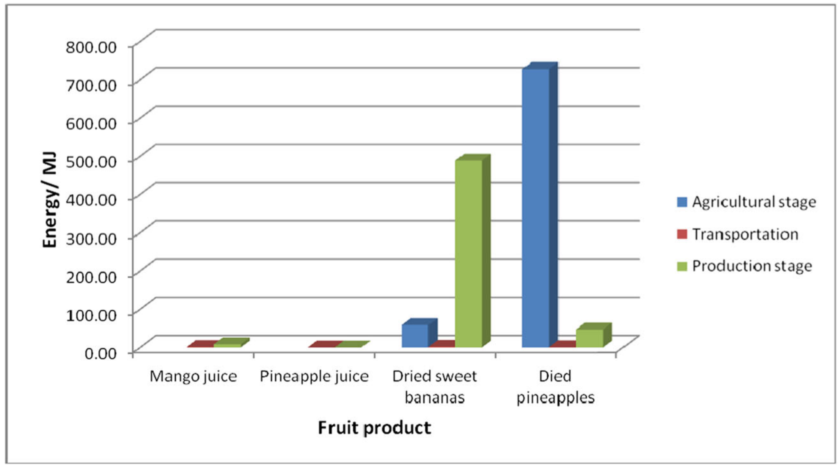

Fig. 3 Energy consumption during the production of 1 l of fruit juice and 1 kg of the dried fruit products (MegaJoules)

promote sustainable principles. Therefore, there is need to develop institutional and human capacity for assessing production compliance to standards and legislation as one of the ways of discovering and promoting competitive advantages for the agro-based industries in Uganda. For the selected companies in this study, there was no deliberate effort for life cycle management in spite of existence of some level of awareness of its importance. There is need for production system specific awareness, training, and technical engagements to promote life cycle management practices that will in-turn promote sustainable agro-based production systems. Related efforts in Uganda are being initiated to support decision-making process toward reduced emissions from forestry and land use including those linked to energy (Basu et al. 2013) and climate smart agriculture (M. A. A. I. F 2011; Ampaire et al. 2015). Such efforts need to include technical guidance on renewable energy from agricultural wastes among other innovations aimed at improving life cycle management. Innovation from business is vital to making progress. In order for life cycle management (LCM) to benefit companies and other interested parties, there is also need to provide clear, consistent, and reliable quantification and communicating environmental impacts using LCA according to established and recognized standards to ensure competitiveness of products on both regional and international markets.

4.2 Global warming

Global warming potential was higher during the production of dried fruits than when juice was produced from the industries. This is attributable to the required use of more energy during the dehydration of the fruits. The energy used for drying fruits was mainly obtained by using petrol and diesel generators and fuel wood which are associated with emission of greenhouse gases especially carbon dioxide that is majorly responsible for global warming (Hoffert et al. 2002). Production of dried sweet bananas produced the highest amount of global warming impact compared with the production of other fruit products. This was surprising because pineapples are more

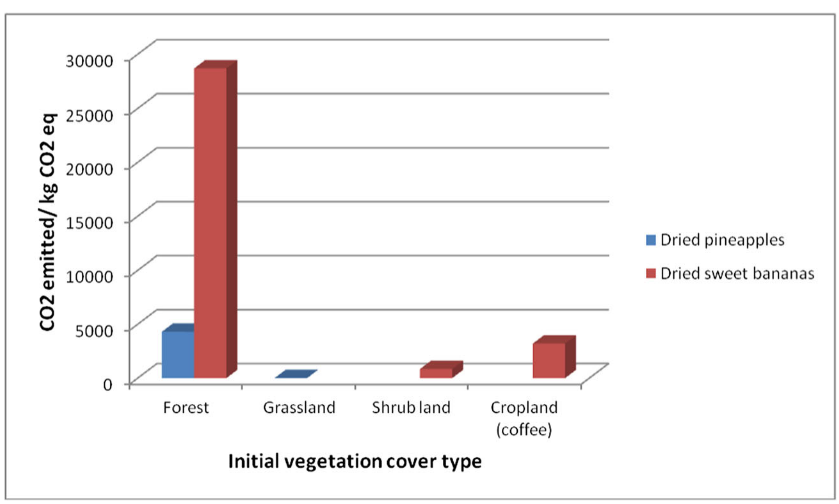

Fig. 4 Amount of CO_2 emitted during land cover transformation to produce 1 kg of packaged dried pineapple fruits including the non-edible parts

Table 2 Environmental impacts associated with the production of 1 l of fruit juice and 1 kg of dried fruits

Impact category	Dried pineapples	Dried sweet bananas	Pineapple juice	Mango juice	Unit
Global warming	4.58 E 00	58.55E 00	6.93 E-04	7.92E-01	kg CO2 eq.
Photochemical oxidation (from CO due to charcoal burning)	5.2E-03	__	__	2.04E-03	kg ethylene eq.
Impacts resulting from the different types of packaging material used					
Ecological toxicity (from PET packaging material)	2.41E-05	6.91E-08	2.38E-05	6.39E-05	kg 1,4-dichlorobenzene eq.
Human toxicity (from PET packaging material)	7.01E-04	2.009E-06	6.93E-04	1.86E-03	kg 1,4-dichlorobenzene eq.
Human toxicity (from PVC packaging material)	8.02E-09	__	__	__	DALY/kg emitted
Photochemical oxidation (from PET packaging material)	1.77E-03	5.19E-06	1.79E-03	4.8E-03	kg ethylene eq.
Abiotic depletion (from glass packaging material)	__	__	__	2.97E-12	kg antimony eq.

Table 3 Waste generated during the production of 1 kg of dried fruits and 1 l of fruit juice

Waste	Management practice	Dried pineapples	Dried sweet bananas	Pineapple juice	Mango juice	Unit
Non-hazardous waste						
Waste water	Soak pit	2.532357	10.52826	0.4809	0.294613	l
Old generator oil	Sold off	0.000885	0.015356	_	_	l
Poly-ethylene packaging material	Open burning	0.001072	3.07E-06	6E-07	_	kg
Diesel spills	Cleaned off from the floor	0.010763	_	_	_	l
Spilled juice	Cleaned off from the floor	_	_	_	0.002525	l
Broken glass	Building material	_	_	_	6.63E-05	kg
By-products						
Peels	Composting	1.91655	0.614251	0.56	0.056818	kg
Banana stalk	Disposed off into the waste pit	_	0.651106	_	_	kg
Pulp	animal feeds	0.203539	_	_	_	kg
Pineapple suckers, mango seeds	Planting material	2.710726	_	1.35	0.058923	kg

hydrated than sweet bananas. As such, the expectation was that there would be more carbon dioxide emissions associated with more energy use during pineapple fruit drying. This is attributed to a lot of fuel used (most especially fuel wood) during sweet banana drying compared with dried pineapples. Wood has a high amount of carbon stock (IPCC 2006), so burning it emits large sums of carbon dioxide to the atmosphere. Therefore, this further calls for the need to invest and promote use of cleaner energies especially hydroelectric power and solar energy for fruit drying since they are associated with far less GHGs emissions to the atmosphere (Hydro Quebec 2009).

4.3 Environmental impacts resulting from packaging material used

Packaging material used included poly-ethylene (PET), polyvinyl chloride (PVC), and glass. PET and PVC contribute to ecological and human toxicity respectively (Lithner 2011). It was also noted that besides PVC, the use of PET also contributes to human toxicity (Table 2). The recorded values of this impact from these two types of packaging material were not combined since they have different units of measurements. Impacts from the use of PET were highest during mango juice manufacture because of the higher amount of this packaging material used than in the production of other fruit products. Mango juice was the only fruit product packed in glass. This resulted in the observation of abiotic depletion impact at only this fruit product.

4.4 Energy consumption

Results also showed that high values of energy consumption were recorded at the agricultural and production/factory stages of dried pineapple production and dried sweet bananas respectively. At the agricultural stage, most of the energy was in form of charcoal burning and fossil fuel (diesel) while at the factory energy consumption was mainly in form of fossil fuels used to run generators. The patterns of energy use and the related global warming potential as quantified during the study further points to the need to explore options for reducing environmental impacts and costs associated with using fossils fuels. The apparent option is resorting to renewable energy sources which are available in Uganda. This will include provision of reliable hydroelectricity and efficient use readily available bioenergy options including use of agricultural waste which was available at the case study factories, but was not utilized for energy generation. The results are another pointer to the current general global need to transition from fossil fuels to other sources of energy. Again, use of the organic wastes generated during agro-processing for bioenergy generation might be a good beginning point. It will also be important in promoting efficiency in the production system and diversification of energy sources. Such efforts are essential in supporting reduction of energy consumption and increasing the share of renewable energy and other important energy-related sustainable development targets. It also supports the global efforts aimed at reducing greenhouse gas (GHG) emissions linked to the agriculture sector which contribute about 30% of the global emissions (IEA Bioenergy 2010). Whereas the agricultural products from developing countries like Uganda still enjoy global market access because they are predominantly organically produced, there is need to pay attention to issues related to sustainable production partly for purposes of ensuring market competitiveness and sustainability. The consumers' expectations have changed in the recent past with indications that they are willing to pay more for sustainable products most especially in developed countries. As such, more and more retailers/wholesalers give preference to growers/suppliers that produce sustainably and/or have implemented strategies to gradually improve their sustainability performance (Yue et al. 2010).

Whereas the sustainable development benefits offered through LCA are undisputable, the experiences from this study show that there are quite a number of challenges that need to be addressed in the process of seizing those benefits. The lack of records challenge encountered in the course of this study will require establishment and development of a national database to support LCA and LCM efforts (Sonnemann et al. 2016). Such database should clearly reflect local, regional differences in the life cycle systems. The clear lack of local technical expertise will require investment in technical capacity building through institutions such as universities, environmental management agencies such as the National Environment Management Authority (NEMA), and standards agencies such as UNBS. Without technical assistance from international expatriates through the support by Swedish International Development Cooperation Agency (SIDA) through SIS, implementation of this LCA activity would probably have not happened.

4.5 Challenges and limitations

The technical challenges and limitations experienced through this study including methodological and data constraints remain a critical consideration for better LCA studies in Uganda. However, this is a general problem in developing countries where information and technical capacity on LCA is generally inadequate most especially on crops like fruits (Ruviaro et al. 2012). This is in part due to the generally low levels of development in life cycle management in particular and environmental management in general. In some of these countries, where efforts have been made to develop and implement life cycle management policies and interventions, food products such as fruits are generally considered to cause lower environmental impact than most of other food products, hence given less attention (Notarnicola et al. 2014). Key to addressing this problem will involve capacity building programs and investing in efforts to undertake baseline studies and establishment of databases to support LCA efforts.

Acknowledgments We also thank Raul Carlson for the technical support and training in preparation and during the study. We are also grateful to Makerere University, the agro-based companies and Uganda National Bureau of Standards for institutional support that was very crucial for this study.

Funding information We thank Swedish Standards Institute for the funding that enabled us to carry out this study under the "Trade Promotion through Standardisation in the East African Region" project.

References

Agus F, Subiksa IGM (2008) Lahan Gambut: Potensi untuk Pertanian dan Aspek Lingkungan (peat soil: potential for agriculture and the environmental aspects). Indonesian Soil Research Institute and World Agroforestry Centre (ICRAF), Bogor

Agus F, Gunarso P, Harris N, Schrier-Uijl AP, Malik ARH, Henson IE, Sahardjo BH, Hartoyo ME, Noordwijk M, Brown K, Netzer M, Killeen TJ, Hamzah KA, Joseph KT, Silvius M, Parish F, Lim KH, Rosediana S, Anshari GZ (2013) Reports from the Technical Panels of the 2nd Greenhouse Gas Working Group of the Roundtable on Sustainable Palm Oil (RSPO) Ed: Timothy J. Killeen & Jeremy Goon. Available at: https://rspo.org/publications/download/a2ac85181ed4501. Accessed 8 Jul 2014

Ampaire E, Van Asten JAP, Happy P, Radeny M (2015) The role of policy in facilitating adoption of climate-smart agriculture in Uganda. CGIAR research program on climate change, Agriculture and Food Security (CCAFS), Copenhagen

Basu A, Blodgett C, Müller N (2013) Nationally appropriate mitigation action study on sustainable charcoal in Uganda. United Nations Development Program, New York

Brown S, Grais A, Ambagis S, Pearson T (2012) Baseline GHG emissions from the agricultural sector and mitigation potential in countries of East and West Africa. CCAFS Working Paper no. 13. CGIAR Research Program on Climate Change, Agriculture and Food Security (CCAFS), Copenhagen Available online at: www.ccafs.cgiar.org

Chanaron JJ (2007) Life cycle assessment practices: benchmarking selected European automobile manufacturers. International Journal of Product Lifecycle Management (IJPLM) 2(3):290–311

DEFRA (2006) Environmental impacts of food production and consumption. A research report completed for the Department for Environment, Food and Rural Affairs. Manchester Business School, Manchester

ECA (European Commission for the Environment) (2014) European platform on life cycle assessment (LCA) [online]. Available at: http://ec.europa.eu/environment/ipp/lca.htm. Accessed 06 July 2014

EEA (2000) Emission inventory guidebook: agriculture. European Environment Agency, Copenhagen

EEA (European Environment Agency) (1997) Life cycle assessment (LCA): a guide to approaches, experiences and information sources. Environmental Issues Series no. 6. http://www.epa.gov/nrmrl/std/lca/pdfs/Issue20report20No206.pdf

FOWODE (2012) Gender policy brief for Uganda's agriculture sector. Forum for women in democracy (FOWODE). United Nations Joint Programme on Gender Equality Availabe at http://www.womankind.org.uk/wp-content/uploads/downloads/2013/06/FOWODE-Gender-policy-brief-for-Ugandas-Agriculture-sector.pdf

Guinée J (2001) Handbook on Life Ccyle Assessment — Operational Guide to the ISO Standards. Editorial in Int J LCA 6(5):255

Guinée J, Gorree M, Heijungs R, Hup-pes H, Kleijn R, de Koning A, van Oers L, Wegener SA, Suh S, Udo de Haes H, de Bruijn H, van Duin R, Huijbregts M (2002) Handbook on life cycle assessment, operational guide to the ISO standards. Kluwer Academic Publishers, Dordrecht

Hoffert MI, Caldeira K, Benford G, Criswell DR, Green C, Herzog H, Jain AK, Kheshgi HS, Lackner KS, Lewis JS, Lightfoot HD, Manheimer W, Mankins JC, Mauel ME, Perkins LJ, Schlesinger ME, Volk T, Wigley TML (2002) Advanced technology paths to global climate stability: energy for a greenhouse planet. Science 298:981–987

Hydro Quebec (2009) Greenhouse gas emissions and hydroelectric reservoirs. Available at: http://www.hydroquebec.com/sustainabledevelopment/documentation/ges.html

IEA Bioenergy (2010) Bioenergy, land use change and climate change mitigation: report for policy advisors and policy makers. IEA Bioenergy:ExCo:2010:03

Ingwersen WW (2012) Life cycle assessment of fresh pineapple from Costa Rica. J Clean Prod 35:152–163

IPCC (2006) Draft 2006, IPCC guidelines for National Greenhouse gas Inventories. Volume 4

ISO (2006a) ISO 14040: environmental management–lifecycle assessment–principles and framework. International Organization for Standardization, Geneva

ISO (2006b) ISO 14044: environmental management–lifecycle assessment–requirements and guidelines. International Organization for Standardization, Geneva

Kaval P (2011) Measuring and valuing environmental impacts. A systematic review of existing methodologies. Network for Business Sustainability, London, Canada

Liamsanguan C, Gheewala SH (2008) LCA: a decision support tool for environmental assessment of MSW management systems. J Environ Manag 87(1):132–138

Lithner D (2011) Environmental and health hazards of chemicals in plastic polymers and products. Ph.D. thesis, Department of Plant and Environmental Sciences. Faculty of Science. University of Gothenburg. ISBN: 978-91-85529-46-9. Available at: https://gupea.ub.gu.se/bitstream/2077/24978/1/gupea_2077_24978_1.pdf

M.A.A.I.F (2011) Ministry of Agriculture animal industry and fisheries, Uganda. Operationalisation of the rural development strategy for increased agricultural productivity

Mogensen L, John EH, Niels H, Randi D (2009) Life cycle assessment across the food supply chain: chapter 5. In: Baldwin C (ed) Sustainability in the food industry. Wiley-Blackwell, Ames

MTTI (2008) National Industrial Policy. A framework for Uganda's transformation, competitiveness and prosperity. Ministry of Tourism, Trade & Industry, Uganda

Nilsson K, Sund V, Florén B (2011) The environmental impact of the consumption of sweets, crisps and soft drinks. TemaNord 2011:509 ISBN 978-92-893-2197-6

Notarnicola B, Salomone R, Petti L, Renzulli AP, Roma R, Cerutti KA (2014) Life cycle assessment in the agri-food Sector. Case Studies, methodological Issues and Best Practices: ISBN 978–3–319-11939-7, ISBN 978–3–319-11940-3 (eBook). https://doi.org/10.1007/978-3-319-11940-3

Pachauri RK, Reisinger A (2008) Climate change 2007. Synthesis report. Contribution of Working Groups I, II and III to the fourth assessment report

Parish F, Sirin A, Charman D, Joosten H, Minayeva T, Silvius M, Stringer L (eds) (2007) Assessment on peatlands, biodiversity and climate change: main report. Global environment entre. Kuala Lumpur and Wetlands International, Wageningen

PCR (2011) PCR 2011:08 fruit juices (UN CPC 2143). The International EPD System, Stockholm

PCR (2012) PCR 2012:07 fruits and nuts (UN CPC 013). The International EPD System, Stockholm

Phanchandee W, Sachakamol P (2013) Life cycle assessment of mango and mangosteen in Thailand, Proceedings of the 51st Kasetsart University annual conference

Ridoutt BG, Juliano P, Sanguansri P, Sellahewa J (2012) Onsumptive water use associated with food waste: case study of fresh mango in Australia. Hydrol Earth Syst Sci Discuss 6:5085–5114. https://doi.org/10.5194/hessd-6-5085-2009

Rosenbaum RK, Bachmann TM, Gold LS, Huijbregts MAJ, Jolliet O, Juraske R, Koehler A, Larsen HF, MacLeod M, Margni M, McKone TE, Payet J, Schuhmacher M, van de Meent D, Hauschild MZ (2008) USEtox – the UNEP/SETAC toxicity model: recommended characterisation factors for human toxicity and freshwater ecotoxicity in life cycle impact assessment. Int J Life Cycle Assess 13:532–546

Ruviaro CF, Gianezini M, Brãndao FS, Winck CA, Dewes H (2012) Life cycle assessment in Brazilian agriculture facing worldwide trends. J Clean Prod 28:9–24

Sitch S, Brovkin V, von Bloh W, van Vuuren D, Eickhout B, Ganopolski A (2005) Impacts of future land cover changes on atmospheric CO2 and climate. Glob Biogeochem Cycles 19(2):1–15

Sonesson U, Davis J, Ziegler F (2010) Food production and emissions of greenhouse gases. An overview of the climate impact of different product groups. The Swedish institute or food and biotechnology. SIK-report no 802 2010. Available at: http://www.sik.se/archive/pdf-filer-katalog/SR802.pdf

Sonnemann G, Strothmann P, Weyand T, Valdivia S (2016) Opportunities for national life cycle networks creation and expansion around the world. Life-cycle initiative, United Nations Environment Programme. https://www.lifecycleinitiative.org/wp-content/uploads/2016/10/mapping-publication-9.10.16-web.pdf

UIA (2013) Uganda investment authority. Agriculture sector; fruits and vegetables sector profile. Available at: http://www.ugandainvest.go.ug/index.php/2013-10-24-13-08-51/friuts-and-vegetables. Accessed 28 July 2014

Walakira P, Mwanjalolo JGM, Mfitumukiza D, Kaviiri PHD (2013) Carbon footprint initiative in Uganda. Int J Life Cycle Assess 18:743–744

World Economic Forum, African Development Bank and the World Bank (2015) African Competitiveness Report 2015. Chapter 2.1 transforming Africa's agriculture to improve competitiveness. Geneva: World Economic Forum. Available at: http://citeseerx.ist.psu.edu/viewdoc/download?doi=10.1.1.696.7399&rep=rep1&type=pdf#page=56

Yue C, Hall CR, Behe BK, Campbell BL, Dennis JH, Lopez RG (2010) Are consumers willing to pay more for biodegradable containers than for plastic ones? Evidence from hypothetical conjoint analysis and nonhypothetical experimental auctions. J Agric Appl Econ 42(4):757–772 2010 Southern agricultural economics association