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Cradle-to-Gate Life Cycle Assessment of Fresh and Processed Pineapple in the Philippines

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ABSTRACT

In this work, a cradle-to-gate life cycle assessment is conducted in order to assess the impact of pineapple production in the Philippines to the people and the environment, determine the predominant challenges of all pineapple growers and processors and identify opportunities for further improvement. The cradle-to-gate life cycle assessment includes the analysis of non-renewable energy use (NRE), carbon footprint, acidification potential, ozone creation potential, blue water and total water footprint of pineapple farming, processing, and packaging. With the use of 1 serving of fruit as a functional unit, processed pineapple has the higher NRE and carbon footprint as compared with fresh pineapple and other fruits like fresh apple and orange. Pineapple farming demands less water and the good tropical conditions of the Philippines negates the need for more irrigation. Processed pineapple demands more water than fresh pineapple because of the amount of water required in washing and other manufacturing processes involved. The current manufacturing process has the greatest environmental impact because of the use of bunker fuel. The distance from farm to processing also contribute to the increase in consumption of diesel and the inefficiency in the introduction of fertilizer can increase carbon emission.

INTRODUCTION

Pineapple ranks in the top 10 in terms of worldwide production of fruits and ranks number 6 in the top fruits being exported worldwide. As of 2013, Philippines ranks third in the production of pineapple in the world. It ranks second in export of fresh pineapple, canned pineapple and pineapple juice concentrate. Pineapple is the fourth most produced crop in the Philippines. Comparison to volume produced and the amount of area needed for the fruit, it is the third most efficient crop behind sugarcane and banana, which ranks first and second respectively (BAS 2013). With increasing demand from other countries, pineapple farms are expected to increase in size, to become more efficient to its operation and more conscious to the environment.

This study attempts to characterize the environmental impact that the production of fresh and canned pineapple from the Philippines has caused. The cradle-to-gate analysis is employed as the supply chain is analysed from land preparation up to its production and processing. The aim of the study is to conduct a cradle-to-gate life cycle assessment of the pineapple production in the Philippines. More specifically, this study attempts to assess the environmental impact caused by the production of pineapple in the country and suggest ways on how to minimize this impact, in terms of non-renewable energy (NRE) used, carbon footprint, acidification potential, ozone creation potential, water footprint, and finally investigate avenues for waste mitigation. A full life cycle analysis would give subjective results because the comparison between the method of transportation outside the farming and processing of the fruits would be different, the logistics is diverse and the distance between supplier and producer to the target market is always different.

Fresh and Processed Pineapple from the Philippines

Philippines currently exports pineapples to countries like Japan, Korea and Middle East (Lorenzo 2010). About 88% of the pineapple production in the country is located in the Mindanao island. Philippine pineapple production grew from 1.5 million metric tons to 2.5 million metric tons from 2000-2013, and the area of production expanded by 42.8% from 42,000 to 60,000 hectares at the same time (BAS 2013, FAO 2013). The process of producing fresh pineapple is

Table 1: Life cycle impact assessment categories using TRACI indicators.

Category Indicator	Impact Category	Description	Unit	References
Energy Use	Non-Renewable Energy Use	A measure of the total amount of primary energy extracted from the earth. NRE is expressed in energy demand from non-renewable resources (e.g. petroleum, natural gas, uranium, etc.) Efficiencies in energy conversion (e.g. power, heat, steam, etc.) are taken into account.	MJ	(Guinee et al. 2002) (Frischknecht & Jungbluth 2007)
Climate Change	Global Warming Potential (GWP) or Carbon Footprint Equivalent	A measure of greenhouse gas emissions, such as CO_2 and methane. These emissions are causing an increase in the absorption of radiation emitted by the earth, magnifying the natural greenhouse effect.	kg CO_2 and equiv.	(Sinden 2008) (Guinee et al. 2002) (Colls 2002) (Bare 2014) (Vidal 2008) (Fertilizers Europe 2011)
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 SO_2 and equiv.	(Guinee et al. 2002) (Bare 2014) (Colls 2002) (Mittal 2010)
Ozone Creation in Troposphere	Photochemical Ozone Creation Potential (POCP) or Smog Air (TRACI)	A measure of emissions of recursors that contribute to low level smog, produced by the reaction of nitrogen oxides and VOC's under the influence of UV light.	kg O^3 equiv. kg NOx equiv.	(Guinee et al. 2002) (Bare 2014) (Colls 2002) (Mittal 2010)

similar in most pineapple industry. After harvest, the fruit is washed, then packed in boxes and stored at a temperature of about 6-8°C. The pineapple is transported by container trucks and shipped to its destination. Unlike bananas (where the fruit is raw when harvested), pineapples are already ripe from picking, and it has a window of 8 weeks from harvesting to the customer. Processed pineapple can have 2,000 different sub products, but can be narrowed down to pineapple preserves (canned), pineapple juice and other variants such as dried pineapple, etc. These products can be stored at room temperature for up to 3 years.

Scope and Limitations

The study would be using the cradle-to-gate approach in life cycle assessment and focusing on production of pineapples up to finished goods. Transportation outside the manufacturing facility after it has been produced would not be included. Manufacturing inputs, especially fuel, fertilizers and pesticides before it was used were not also included, which would include the impact on how it was extracted and manufactured. Farms chosen were from the Southern Mindanao, Philippines. Other farms also exist in other regions of the country, but being one of the oldest producers and due to location factors, the region was chosen to be the area of the study. Weight of pineapple fruits would always be subjective since there would be a lot of factors to consider (planting schedule, maturity in harvest, first stem or ratoon). Production in farms is computed based on the Philippine government data estimate (BAS 2013, FAO 2013). The selected farms produce two variants of smooth cayenne pineapple. Since the difference in their whole crop cycle is very minimal (1-2 weeks compared to harvesting time of up to 8 weeks), the crop cycle and harvesting times for the two variants are considered equal. Since the weight of the fruit is used for calculation of its servings, all goods can be served by the total weight of the pineapple, regardless of its output (juice, pulp in can or pack, fresh fruit, etc.). The number of serving/weight of fruit is used for the analysis in NRE, carbon emission, acidification potential, ozone creation potential and water footprint. Geographic data relating to weather (rainwater) gathered in the Southern Mindanao area is chosen to represent the data in pineapple farming. It has been observed that fertilizer and pesticide application is done both, by farm managed farms and grower (other) farms. In this case, application of the chemicals is treated as the same on all farms. About 50% of the power of Mindanao island is produced by coal fired power plants (DOE 2013), while the other 50% is renewable energy which is produced by hydroelectric plants. Rainwater is the only source of water for the pineapple farms. Thus, water footprint only includes green (rainwater) and blue (processing). It does not include gray water (water subjected for treatment).

MATERIALS AND METHODS

Data on the year 2013-2014 was collected both in the farm and local government units and agencies. All the inputs for fresh fruit farming operation were taken into consideration for this study. From farming, fruits are taken either to fresh

Table 2: Summary of pineapple farm data.

Category	Item	Unit	Average
Product	Yield	kg/ha/harvest	45545.83
	Plant cycle	year	2.75
	Number of harvest in one cycle	unit	2.00
	Harvest frequency	harvest/year	0.72
	Annual yield	kg/ha/year	32793kg/ha/year
	Pineapple mass	kg/pineapple	1.7kg/pineapple
	Pineapple area	ha	24580
Fuel	Diesel (3d)	kg/ha/year	367.356
	Gasoline (a)	kg/ha/year	1.661
	Bunker fuel or fuel oil #6	kg/ha/year	356.697

Table 3: Environmental impacts of 1 serving of pineapple.

Impact category	Fresh Pineapple	Processed Pineapple	Weighted Average	Unit
Non-renewable energy	0.14895	0.5322	0.3252	MJ
Carbon footprint	0.03734	0.0794	0.0567	kg CO_2
Acidification potential	0.00001	0.0003	0.0001	kg SO_2
Ozone creation	0.00011	0.0005	0.0003	kg O^3
Blue water footprint	0.22577	2.3754	1.2146	L
Total water footprint	183.19	185.34	184.18	L

pineapple products or processed pineapple products.

Data Collection

Energy used was first divided to renewable and non-renewable in source. Energy content for diesel, gasoline and gas used was estimated based on carbon emissions of fuel database (Engineering toolbox 2015a). Bunker fuel energy content was based on the geography of transport systems (Rodrigue 2015). Specific gravity for diesel and gasoline used was estimated based on specific gravity of liquids database (Engineering toolbox 2015b). Electricity used by the area was from a local electric station in Southern Mindanao.

Impact Assessment

The environmental impact was estimated using the indicators which are based on cumulative non-renewable energy, carbon footprint, acidification, ozone creation and water footprint. These indicators were used because they are the basis for all other minor assessment (soil erosion, human and freshwater toxicity, etc.). Energy use is based on the potential energy that can be generated by using a unit of fuel in terms of metric joules (MJ). Global warming potential is measured by amount of CO_2 or its equivalent. Acidification is the amount of SO_2 or its equivalent emitted by burning fossil fuel. Nitrous oxide is the amount of NOx created by using fossil fuels. The categories were based on TRACI 2.1 2014 database given in Table 1.

Water consumption of pineapple in the farm was based on the maximum consumption of commercial pineapple, since the only source is rainwater (Medina & Garcia 2005). Included in the calculation was the weather and amount of precipitation in the Southern Mindanao area based on the weather report from the local government (Accuweather 2014). Computation on the amount of precipitation from mm to litres was based from an online rainfall calculator to compute the amount of rainwater in an area into litres (Calctool 2015). The USDA recommends 1 to 2 servings of fruit per day depending on age and gender (USDA 2011). The USDA defines a serving of fruit as 1 cup of fresh fruit, which for pineapple is 165g (USDA 2015). Weight percent composition of a typical *Cayena Lisa* pineapple is: pulp (33%), core (6%), peel (41%) and crown (20%) or roughly 50% of the whole fruit is considered to be edible (Medina & Garcia 2005). This amount is used for computation of the number of servings per kg of pineapple fruit. Since the pulp (fresh and processed), core (juice) and part of the peel (juice) are the parts of the pineapple that is edible, the formula to get the amount of servings per kg of fruit is:

$$\text{Servings/kg} = 1\text{ kg} \times \text{edible part }\%/0.165\text{ kg} = 3.03\text{ servings/kg} \quad ...(1)$$

The assessments were used because the data for comparison with other fruits are available for benchmarking. Fresh fruit farming inputs as well as fresh and processed pineapple product inputs were included in the model. The two stages covered in the model can provide the data needed

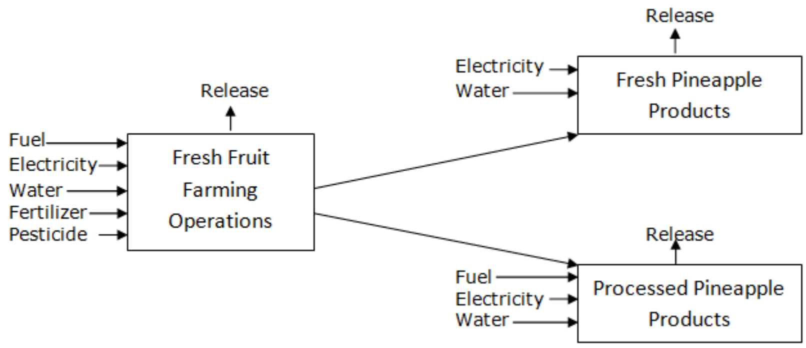

Fig. 1: Simple farm to gate diagram of pineapple production.

to assess the operations thoroughly (Fig. 1).

RESULTS

Table 2 summarizes all the inputs needed for the farm in the year 2014. Fertilizer consumption was divided into two types of pineapples produced, the variant 1 and variant 2. Pesticide use was averaged in both the variants, since it is dependent not on the variety of pineapple, but on the land area. Diesel and gasoline are used primarily for trucks transporting goods in and out of the production facility and for the vehicles used by workers. Bunker fuel is used in some of the machinery in the processing of pineapples.

Variant 1 is produced for fresh pineapple. Variant 2 is for further processing for canned, dried, fruit juice, etc. 54% of the pineapple produced in farms are variant 1 and 46% are variant 2. On average, pineapple farms harvests twice in a 33 month cycle. Data being presented are already converted into a per year basis for easy comparison and benchmarking. Diesel and gasoline for farm and transportation are divided according to amount being produced which is 54% and 46% respectively, but bunker fuel is exclusively used for pineapple processing. Blue water (sourced from local water station) and electricity is divided for fresh production and processed pineapple.

Non-Renewable Energy

As a whole, NRE can be largely attributed to diesel (44%) which is used for transporting raw materials, finished goods and personnel. Bunker fuel (41%) comes in second which is used for equipments in the processing of pineapple. About 75% of the NRE used by pineapple grower is on the processing of pineapple for canning, dried and juice. Fresh pineapple export (25%) accounts for a small amount of NRE. Majority of the NRE used for processing of pineapple is the use of bunker fuel (54%), diesel fuel (27%) comes in second while electricity (19%) comes in third. 97% of the NRE used in fresh pineapple production is because of the use of diesel fuel. This is exclusively because of transportation of materials (farm to packaging).

Carbon Footprint

Nitrogen for fertilizer (45%) accounts for the largest contribution of carbon emission. Electricity (22%) and diesel fuel (19%) comes in second and third, respectively. Application of nitrogen to farms as a fertilizer would account for equipment used and releasing of N_2O (Ingwersen 2012). Although variant 1 accounts for a bigger chunk of total production, the process of producing canned, dried and pineapple juice contributes 64% of the total carbon emissions. This would be largely attributed to the additional machinery used for the production. Electricity (33%) is still the largest contributor of carbon emission for processed pineapple production while nitrogen from fertilizer (32%) comes in second. Nitrogen (68%) from fertilizer still is the largest contributor of carbon emission for fresh fruit production, second would be the use of diesel for transportation (29%).

Acidification Potential

Electricity (63%) accounts for the largest contribution of acidification potential. Bunker fuel (36%) comes in second overall. Although variant 1 accounts for a bigger chunk of total production, the process of producing canned, dried and pineapple juice accounts for 97% of the total acidification potential. This would be largely attributed to the additional machinery used for the production. Electricity (63%) is still the largest contributor of acidification potential for processed pineapple production, while bunker fuel (37%) comes in second. Electricity (89%) still is the largest contributor of acidification potential for fresh fruit production, second would be the use of diesel for transportation (11%).

Ozone Creation Potential

Bunker fuel (58%) accounts for the largest contribution of

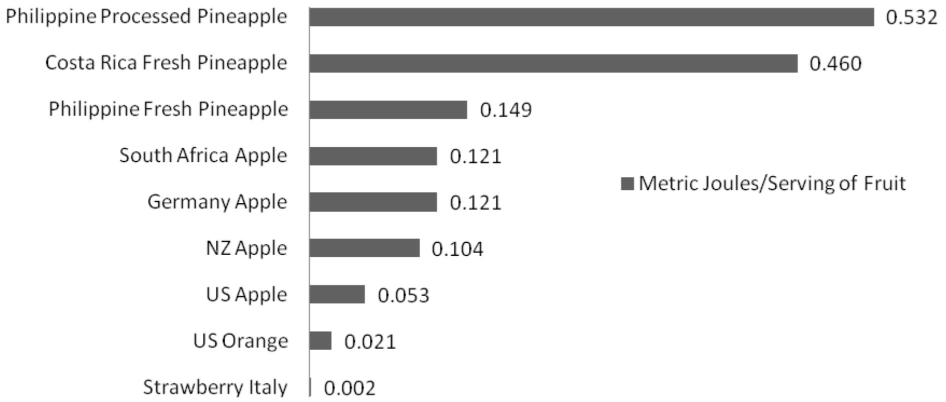

Fig. 2: Comparison of non-renewable energy demand. Sources of data for other fruits: energy consumption, carbon footprint and water footprint of pineapples from Costa Rica (Ingwersen 2012), energy consumption of apple from Germany, New Zealand and South Africa (Blanke & Burdick 2009), energy consumption of oranges and apple from US (Pimentel 2009) and non-renewable energy and carbon footprint from Italy (Girgenti et al. 2013).

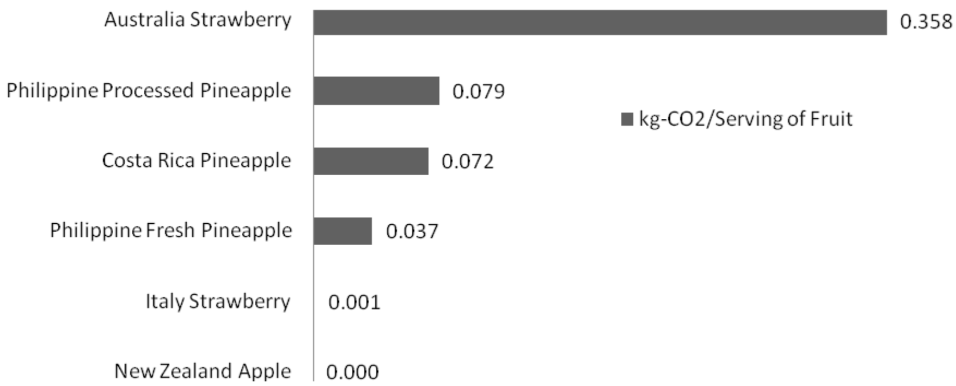

Fig. 3: Comparison of carbon footprint. Sources of data for other fruits: energy consumption, carbon footprint and water footprint of pineapples from Costa Rica (Ingwersen 2012), carbon footprint of apple from New Zealand (Canals 2003), carbon footprint of strawberry from Australia (Gunady et al. 2012) and non-renewable energy and carbon footprint from Italy (Girgenti et al. 2013).

acidification potential. Diesel (32%) and electricity (10%) comes in second and third respectively. Although variant 1 accounts for a bigger chunk of total production, the process of producing canned, dried and pineapple juice accounts for 82% of the total ozone creation potential. This would be largely attributed to the additional machinery used for the production. Bunker fuel (71%) is still the largest contributor of ozone creation potential for processed pineapple production while diesel (17%) and electricity (12%) comes in second and third respectively. Diesel (97%) still is the largest contributor of ozone creation potential for fresh fruit production, second would be the use of electricity (3%).

Life Cycle Analysis Results

Most of the non-renewable energy source were from diesel (44%) and bunker fuel (41%). Gasoline and ethylene gas also contribute to non-renewable energy use, but is considered to be minimal compared to other contributors. Fresh pineapple production use less non-renewable energy (0.149 MJ) compared to processed pineapple (0.532 MJ). The main reason for this is the use of bunker fuel in the processing equipment. The difference between using bunker fuel in the use of non-renewable energy is significant that only 25% of the NRE is from the fresh fruits and 75% is from the processed stage. NRE use in the fresh fruit is mostly from the diesel gasoline used for transportation (Table 3).

Most of the carbon emissions were from the farm stage, in which nitrogen used for fertilizer is the main contributor (45%). Electricity (22%), diesel (19%) and bunker fuel (14%), arranged from highest to lowest. Gasoline and ethylene gas also contribute to carbon emissions, but is considered to be minimal compared to other contributors. Carbon

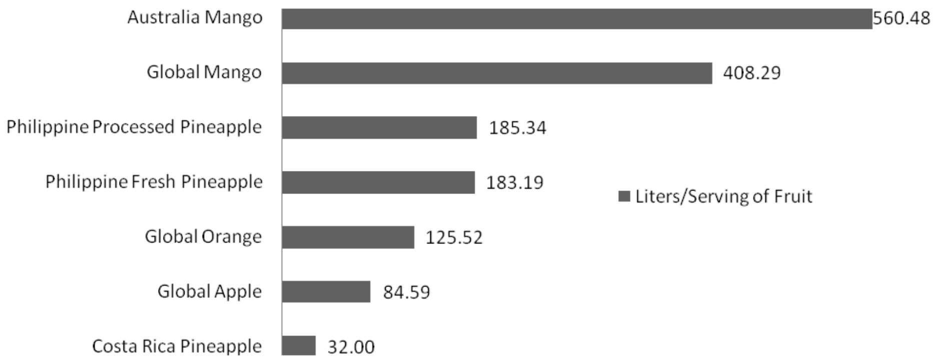

Fig. 4: Comparison of total water footprint. Sources of data for other fruits: energy consumption, carbon footprint and water footprint of pineapples from Costa Rica (Ingwersen 2012), global water footprint of mango, apple and orange (WFN 2015) and water footprint of mango from Australia (Ridoutt et al. 2010).

emission is dominated by nitrogen application during farming with 68% of carbon emission in fresh pineapple production and total electricity with 33% from processed pineapple. Bunker fuel also contributes largely to the carbon emissions in processing of pineapples (26%), which results in higher carbon footprint of processed pineapple of 0.0794 kg CO_2 compared to fresh pineapple 0.03734 kg CO_2 (Table 3).

Acidification potential is mostly contributed by electricity (63%) followed by the use of bunker fuel (36%). Most of the acidification potential is on the processed pineapple (97%) because of the heavy use of electricity and bunker fuel. Electricity (63%) dominates the processed pineapple acidification potential, followed by the use of bunker fuel (37%). Fresh pineapple acidification potential is led by electricity (89%) followed by the use of diesel (11%). Acidification potential is larger on processing of pineapples (0.0003) than fresh pineapple production (0.00001) per serving (Table 3).

Ozone creation potential is mostly created by the use of bunker fuel (58%), followed by the use of diesel (32%). Most of it comes from processing of pineapple (82%). The use of bunker fuel has the highest ozone creation potential for the processing of pineapple, followed by diesel (17%) and electricity (12%). Fresh pineapple production ozone creation potential is mostly due to the use of diesel (97%). With the use of more bunker fuel, acidification potential for processing of pineapple (0.0005) is higher than fresh pineapple production (0.00011) per serving (Table 3).

Water footprints were divided into two parts, rainwater used and water based on a local water source. An average of 2.937 million cubic meters of water is used in the processing and operations and is sourced from a local station, and 442.44 million cubic meter of water from rain (Calctool 2015). The amount of water used by processing of pineapple is higher (2.38L) compared to fresh pineapple (0.23L) per serving (Table 3).

DISCUSSION

In order to benchmark the non-renewable energy, carbon footprint and water footprint, it would be best to compare it with manufacturers of pineapple and with other fruits. Comparison of different fruits from different countries, given servings per kg fruit are 3.09 for pineapple, 8.26 for apples, 4.06 for oranges, 4.10 for mango and 6.25 for strawberry (Ingwersen 2012).

Non-renewable energy demand for Philippine fresh pineapple (0.149 MJ) is lower in comparison to Costa Rica fresh pineapple (0.46 MJ). But processed pineapple has the highest NRE use in all fruits (0.532 MJ). In comparison to other fruits would prove that pineapple needs more fuel input to produce. This is because of the number of fruits contained per hectare that needs to be simultaneously nurtured and harvested (Fig. 2).

Carbon footprint from Philippine fresh pineapple (0.037) is lower than in Costa Rica (0.072 kg CO_2), but Philippine processed pineapple (0.079 kg CO_2) is higher than Costa Rica. The fruit with the highest carbon emission is the Australian strawberry (0.358 kg CO_2). In comparison to other fruits, pineapples use a lot of nitrogen fertilizer which would explain the higher carbon emission (Fig. 3).

Total water footprint shows that Philippine processed pineapple (185.34 L) and Philippine fresh pineapple (183.19 L) consumes water on an average in comparison to other fruits. The fruit with the highest consumption would be the Australian mango with a water footprint of 560.47 L (Fig. 4).

Blue water footprint would reveal that Philippine processed pineapple (2.37 L) consumes more water than Philip-

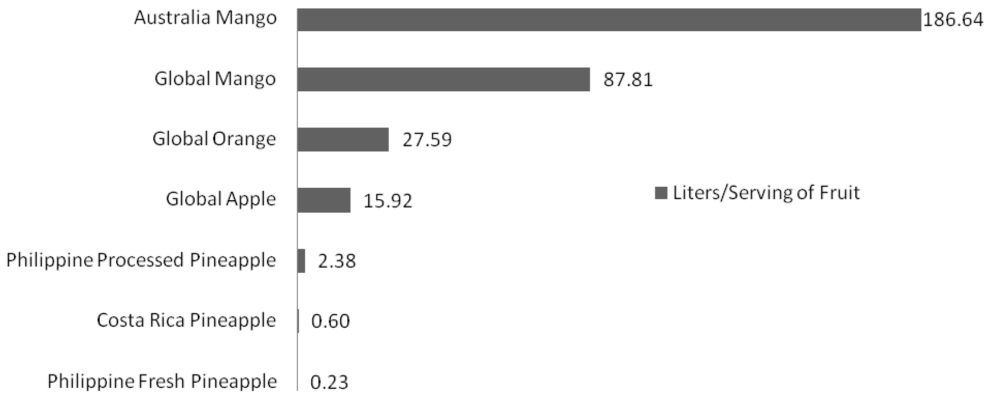

Fig. 5: Comparison of blue water footprint. Sources of data for other fruits: energy consumption, carbon footprint and water footprint of pineapples from Costa Rica (Ingwersen 2012), global water footprint of mango, apple and orange (WFN 2015) and water footprint of mango from Australia (Ridoutt et al. 2010).

pine fresh (0.22 L) and Costa Rica pineapple (0.6 L). The increase in consumption of water in processed pineapple would be for operations used (washing). Unlike other fruits which are from trees, both total water footprint and blue water footprint shows that pineapple does not need elaborate water systems like irrigation for its growth (Fig. 5).

Opportunities to Decrease Impact to Environment Identified in the Life Cycle Analysis

Although total elimination of impact to environment caused by pineapple production is hard to achieve, decreasing it would mean significant reduction in the damage it may cause. Here are some of the opportunities found to be able to decrease the impact caused by farming and processing operations.

Decrease in total consumption of fuel (diesel): The processing of pineapples is located in Southern Mindanao, yet some trucks containing pineapples coming from farms 300 km away, still go to the cannery. A dump truck at that distance can consume 100 litres in a single trip. Satellite processing sites should be developed to be able to decrease the fuel used and therefore decreasing NRE and carbon emissions. Farms management should also be efficient in scheduling to avoid half full trucks going from the farm to the cannery/ processing, therefore decreasing the fuel used. Proper maintenance of the vehicles used for transport would also decrease the consumption of fuel. Efficient engines can decrease the fuel consumption to its minimum, therefore decreasing the fuel used.

Machine upgrade: Some cannery machines use bunker fuel. It is the fuel of choice because it is cheap, but the drawback is it emits harmful gases, like carbon dioxide. Machine upgrade may be able to decrease the NRE use by up to 54% for the processed or 41% as a whole. The carbon emission may decrease up to 21% for the processed or 14% as a whole. Switching to a machine that may use a renewable source maybe a solution. A less drastic approach would be to use electricity as the source which is 50% renewable.

Fertilizer and pesticides management: Regardless of the output per hectare of pineapple, the company uses the same amount of fertilizer and pesticide. By having a better fertilizer and pesticide management and increase the efficiency of harvest, the ratio of fertilizer and pesticide used in comparison to the yield decreases, therefore also decreasing the effect per serving of fruit. The use of nitrogen for fertilizer could also be optimized. By using just in time application to ensure rapid uptake, use of precision farming tools and maintaining good soil structure (proper drainage, avoiding of packing), carbon emission can be mitigated (Yara 2015).

Waste management: Waste cannot be totally eliminated as a by-product in cannery. 20-40 tons of waste (fruit peels, etc.) is being generated by the company, most of which are biodegradable and further reprocessed. To decrease the impact of accumulation of waste, the company must be able to find ways to decrease it or find alternative ways to use it for another product. Proper waste disposal should also be observed so that the water in the surrounding area would not be contaminated.

CONCLUSION

The cradle-to-gate life cycle analysis gives a concrete picture of how pineapple is farmed and processed, together with all the inputs needed for it to be manufactured. The objective would be to quantify the impact that can contribute to global warming, the use of non-renewable energy in relation to renewable energy and the responsible use and disposal of water. Benchmarking with other pineapple producing countries and comparison to other fruits would aid fruit growers, producers and consumers to be aware of the environmental impact of the fruits that they consume, making consumption and production sustainable.

As with pineapple production, non-renewable energy use is higher in processed products than in fresh pineapple products. Consumption of bunker fuel in the processing is the major cause of the problem. Meanwhile in the analysis of carbon footprint, the major contributor is the application of nitrogen fertilizer in the farm. Consumption of non-renewable energy is also a major contributor in carbon emission. By applying modern fertilizer management techniques, decreasing the consumption and finding alternative ways that can eliminate and move to a more renewable source, the NRE and carbon emission can also decrease. Modern alternative processing equipment may entail less non-renewable energy source. Proper selection of new farm site and efficiency of farming methods can reduce the environmental impact.

Accumulation of waste is a problem in pineapple processing. Aside from the pineapple waste, the company has to also look at other fruit waste which is used for the production of its products. Pineapple peels and other waste can be further processed to create a more useful and profitable by product to mitigate the waste generated.

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