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I-SEEC 2012

Proceeding - Science and Engineering (2013) 323–331

Proceeding
Science and Engineering

www.iseec2012.com

Science and Engineering Symposium
4th International Science, Social Science, Engineering and Energy Conference 2012

Improving a Canned Lychee Production by a Life Cycle Assessment

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Abstract

This research created an inventory database of material and energy consumption of a canned lychee production. The database was used to assess the environmental impact by a life cycle assessment (LCA) technique in order to improve the production process. The boundary of the investigated system included the cultivation, transportation and manufacturing process. The result showed that the total GHG emission of this canned lychee production is about 813.2 kg CO2-eq/ton. The analysis indicated that the highest GHG emission was released from the manufacturing process followed by the transportation, waste management and cultivation respectively. The raw material played a major role in GHG emission accounted for 65.5% of the whole GHG emitted from the whole life cycle. The alternative options to reduce the GHG were proposed in this research e.g. replacing a tin can by an aseptic box, insulating the exhaust box and hot water tank and renovating the steel rail.

Keywords: Canned Lychee Production; Life Cycle Assessment; Greenhouse Gas Emission

1. Introduction

Global warming becomes a common concern in the international community. Global scientific research showed that the global warming is primarily due to the emission of carbon dioxide (CO_2), methane (CH_4), nitrous oxide (N_2O) and other greenhouse gas (GHG) [1]. GHGs are emitted from the combustion of fuel, fermentation process, industrial process and etc. International Standard Organization provides the standard for quantifying GHG emissions over the life product's life time as called a carbon footprint label [2]. Food industry is one of the largest industrial sectors in Thailand. Food production requires a large amount of recourses, causing several environmental effects [3]. Fertilizer and insecticide are commonly used in an agricultural process; its product is transported to the factory, utilizing fossil fuel. Food processing consumes electric power, natural gas or fuel oil, and releases GHG [4]. The Life Cycle Assessment (LCA) methodology is widely used as a tool to

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evaluate an environmental impact. A few researches attempted to cover the entire life cycle of Thai food products by a LCA method e.g. the environmental evaluation of canned beverage: life cycle assessment approach [5] and the environmental evaluation of canned fruit [6].

This research adopted the LCA method to evaluate the environmental impact of a canned lychee production in Chieang Mai Province. This product is locally produced in the north of Thailand and it is one of the common brands sold in the country. The entire life cycle of this product was studied. The inventory database of the lychee cultivation and the manufacturing process of a canned lychee were created. The energy consumption and GHG emission of each process were analysed; the technologies which can be used to reduce GHG emission were investigated and proposed in this work.

2. Methodology

This project aims to improve the production process of a canned lychee for reducing GHG emission. The study applied the LCA methodology, proposed by the International Organization for Standard (ISO) 14040 [7]. The four major stages were applied including: (I) the determination of the scope and boundary, (II) the creation of inventory database of outputs and inputs, (III) the assessment of environmental impact from the inventory database and (IV) the interpretation of results and suggestions for improvement.

2.1 Goal and Scope Definition

The principal goal of this study is the investigation of the GHG emission from the canned lychee production and the improvement of production process. The functional unit was defined as a ton of canned lychee, weighting 565 grams per a can. Fresh lychees used in the process were grown in two farms located about 1 and 1.5 km from the factory. The canned lychee was processed in the factory located in Chieang Mai Province. Then, the product was packed, transported to the retailers. Figure 1 showed the canned lychee process. The system boundary of this research included the cultivation, transportation, manufacturing process and waste management. The dashed line in Figure 1 indicates the system boundary. The boundary of the investigated system was called the cradle to gate LCA model [8].

2.2 The Data Collection

2.2.1 Cultivation (Fresh Lychee Production)

The fresh lychee data was collected from the farms which supplied the fresh lychee to the factory. Both farms located in Mae Ngon, Fang, Chieang Mai, Thailand. The water for cultivation was distributed to the farm from the local irrigation channels. The herbicide and synthesis fertilizer were utilized about 2 times per year. The herbicide was spread out by a 4 – stock gasoline engine.

2.2.2 Manufacturing Process

The canned lychee was processed for 6 weeks per year. The data was collected from the second week of the production period. The material procurement data, the energy and water consumption were recorded. Both soft water and tap water were used in the process. The soft water was produced from the tap water via a resin treatment process. The soft water was used for preparing syrup, washing cans and sterilizing product. The tap water was used for soaking and washing raw material, washing floor and cooling product. The water that used for washing and soaking was sent to the waste water treatment unit inside the factory; the rest of the water became a part of the product. The electricity was used for lighting and driving machine. The thermal energy for heating the product was obtained from the combustion of the liquid petroleum gas (LPG).

2.2.3 Transportation

The fresh lychees were transported from two farms by lorries. Eighty percent of the fresh lychee supplied from the first farm (located 1 km from the factory) and the rest supplied from the second farm (located 1.5 km from the factory). Other raw materials were transported from Bangkok. Most of the data were recorded by the purchasing department.

2.2.4 Waste Management

Waste from cultivation e.g. trimmed grass was burned in the open air. The number of wasted can was counted by the factory's staff. Wasted cans were disposed in the municipal landfill of Fang district (located 30 km from the factory). The GHG emitted from wasted can transportation was also considered. Waste water from the process was treated by an Anaerobic Baffled Reactor (ABR).

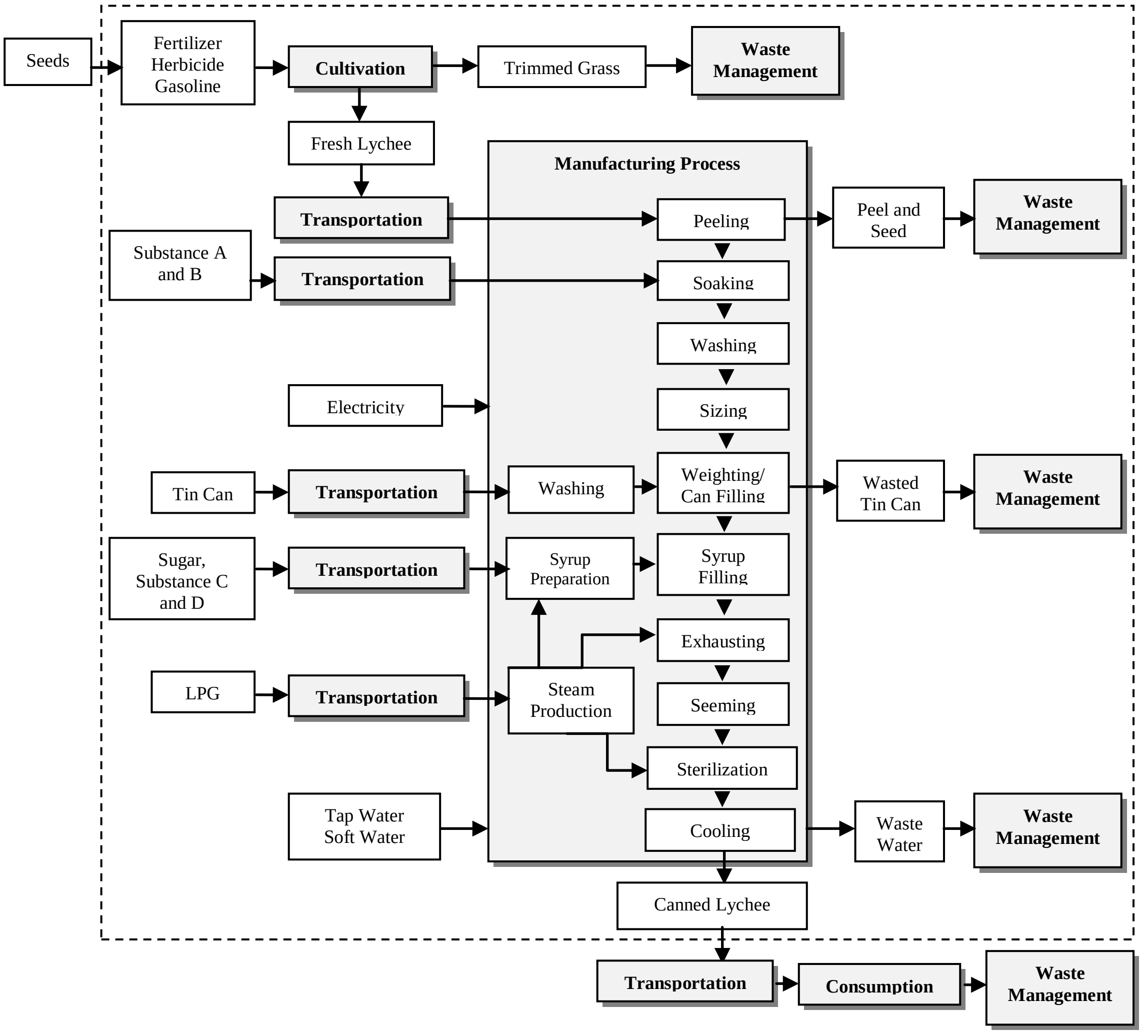

Fig. 1. A Canned Lychee Production Process

2.3 Calculating the GHG Emission

In this research, GHG emission was estimated as the product of Emission Factor (EF) and the process flow unit. The EF represents the quantities of GHG emission released from each activity. These factors were obtained from the Thailand's LCI database and related researches. The equation for evaluating GHG emissions was shown as follows:

$$GHG\ emission = \sum (Q_i \ x\ EF_i) \qquad (1)$$

where Q_i = Quantities of input for a unit process (mass or volume unit)
EF_i = GHG Emission Factor (kg CO_2-eq/unit process)

The calculation result was reported in a unit of kilogram carbon dioxide equivalent per a ton of canned lychee (kg CO_2-eq/ton). The GHG' EFs which used in this research were shown in Table 1.

Table 1. Emission Factors

Unit Process	Unit	Emission Factor (kgCO_2-eq/unit)	Source Data
Cultivation			
• Production and Utilization of Fertilizer			
15-15-15 (N-P-K)	kg	2.5018	Thai LCI Database [9]
8 -24 -24 (N-P-K)	kg	2.3569	Thai LCI Database [9]
• Production of Herbicide	kg	3.23	Thai LCI Database [9]
• Production of Motor Gasoline	kg	0.3409	Thai LCI Database [9]
• Combustion of Motor Gasoline	kg	3.0803	IPCC [11]
Manufacture			
• Production of Materials	kg		
Substance A	kg	1.58	Thai LCI Database [9]
Substance B	kg	3.4461	Thai LCI Database [9]
Substance C	kg	1.9	Simapro [10]
Substance D	kg	1.9	Simapro [10]
Sugar	kg	1.08	Thai LCI Database [9]
• Production of Packaging			
Tin Can	kg	3.221	Thai LCI Database [9]
Carton	kg	0.724	Thai LCI Database [9]
• Production of Electricity	kWh	0.561	Thai LCI Database [9]
• Production of LPG	kg	0.4112	Thai LCI Database [9]
• Combustion of LPG	kg	2.9879	IPCC [11]
• Production of Water			
Tap Water	kg	3×10^{-4}	Thai LCI Database [9]
Resin Water	kg	2.58×10^{-4}	Thai LCI Database [9]
Transportation			
• 4 - Wheel Truck			
No Load	km	0.3317	
Full Load	ton-km	0.1820	Thai LCI Database [9]
• 10 - Wheel Truck			
No Load	km	0.6003	
Full Load	ton-km	0.0485	
Waste Management			
• Solid Waste			
Open Burning (Trimmed Grass)	kg	0.22	EPA [12]
Open Burning (Peel and Seed)	kg	0.02	EPA [12]
Land Fill	kg	0.04	EPA [12]
• Waste Water	Eq.(2) - Eq.(5)		IPCC [11]

In the cultivation step, the production of synthesis fertilizer, herbicide and gasoline also contributed the GHG emission. Besides, the GHG emitted from the gasoline motor was also considered. GHG from burning the trimmed grass was considered in the waste management step. The emission of GHGs from the production of raw materials, substances, packaging, LPG and electricity were taken into account. The GHGs from transportation were calculated by eq. (1) using the Thai LCI database [9].

The waste in this work included the waste from the agriculture and production process. The value of EF for the open burning waste obtained from the EPA [12]. The GHG emitted from the waste water treatment was estimated base on the IPCC data [11]. The amount of CH_4 was reported in a unit of kilogram carbon dioxide equivalent per day. The equations for evaluating GHG emission from the waste water treatment were described as follows:

$$\text{Total COD (kg COD/d)} = \text{Wastewater Vol. (l/d)} \times \text{COD inlet (kg/l)} \times \text{Digester Eff. (\%)} \quad (2)$$

$$CH_4 \text{ emission (kg } CH_4\text{/d)} = \text{Total COD} \times Bo \times MCF \quad (3)$$

$$\text{Leakage } 15\% = CH_4 \text{ emission} \times 15\% \quad (4)$$

$$CO_2 \text{ emission (kg } CO_2\text{/d)} = CH_4 \text{ emission} \times GWP\ 100\ (CH_4) \quad (5)$$

Where *Bo* = Maximum Methane Production Capacity = 0.21 $kgCH_4$ / kg COD

MCF = Methane Conversion Factor = 0.738

GWP100 = Global Warming Potential of Methane = 21 $kgCO_2$/ $kgCH_4$

2.4 Technology Improvement

Results from the inventory database was analysed in order to investigate the process improvement. The method was described as followed. Firstly, the sensitivity analysis was performed. The results of the sensitivity analysis showed the impact of material reduction on the GHGs emission. Then, a few processes that emitted GHG higher than other process were selected for further study in details. Alternative options for reducing GHG emission were proposed at the end of the study.

3. Results

3.1 Inventory Database

The inventory database was the data for the production year 2012. The inventory data for the canned lychee production was presented in Table 2.

Table 2. Inventory Data for Fresh Lychee Production

Inputs	quantity	unit	Outputs	quantity	unit
Synthesis Fertilizer					
• 15-15-15 (N-P-K)	7.2×10^{-4}	ton	Product : Canned Lychee	1	ton
• 8-24-24 (N-P-K)	7.2×10^{-4}	ton	Solid Waste		
Herbicide	7.2×10^{-6}	ton	• Yard trimmings	1.1×10^{-5}	ton
Gasoline	3.5×10^{-5}	ton	• Peel and Seed	0.158	ton
Raw Materials			• Tin Can	4.31×10^{-4}	ton
• Fresh Lychee	0.36	ton	Waste Water	7.99	ton
• Sugar	0.15	ton	• COD[b]	1256	mg/l
• Substances [a]					
Substance A	1.79×10^{-5}	ton			
Substance B	1.61×10^{-4}	ton			
Substance C	7.39×10^{-4}	ton			
Substance D	2.65×10^{-5}	ton			
Package					
• Tin Can	0.11	ton			
• Carton	0.02	ton			
Water					
• Soft Water	4.84	ton			
• Tap Water	8.55	ton			
Energy					
• Electricity	61.6	kWh			
• LPG	0.065	ton			

[a] Confidential Substances
[b] Chemical Oxygen Demand

3.2 Life Cycle Impact Assessment

The GHG emission in the whole life cycle of the canned lychee was calculated based on the inventory data. The global warming impact potential for each process of the canned lychee production was shown in Table 3. The analysis indicated that the highest GHG emission was from the manufacturing process followed by the transportation, waste management and cultivation respectively. The total GHG emission from the canned lychee production was about 813.20 kg CO_2-eq/ton which was similar to other canned fruit products e.g. canned pineapple (580 kg CO_2-eq/ton) [13], concentrated pineapple juice (796 kg CO_2-eq/ton) [13], canned diced-tomatoes (1,023 kg CO_2-eq/ton) [14], and tomato ketchup (1,220 kg CO_2-eq/ton) [15].

Table 3. The GHG Emission of the Canned Lychee Production

Sub-process	GHG Emission (kg CO_2-eq/ton)
Cultivation	3.64
Manufacturing Process	
• Raw Materials e.g. Tin cans, Chemicals	532.83
• Energy Consumption	255.50
• Water Consumption	2.69
Waste Management	7.88
Transportation	10.66
Total	813.20

3.3 Improvement of the Production Process

From Table 3, the largest portion of GHG was from the raw material production e.g. tin can, carton, sugar and additives; this accounted for about 65.5 % of the total GHG emission from the whole process. Therefore, the GHG emission from each raw material was further analysed. Figure 2 (a) showed the portion of GHG emission from each raw material. The highest GHG emission was from the tin can production followed by the sugar, carton and additives productions respectively. The sensitivity analysis of the raw material consumption was performed in order to investigate the potential of GHG reduction. The result showed that the highest capability of GHG reduction could be obtained by reducing the tin can consumption followed by sugar, carton and additives respectively, as shown in Figure 2(b).

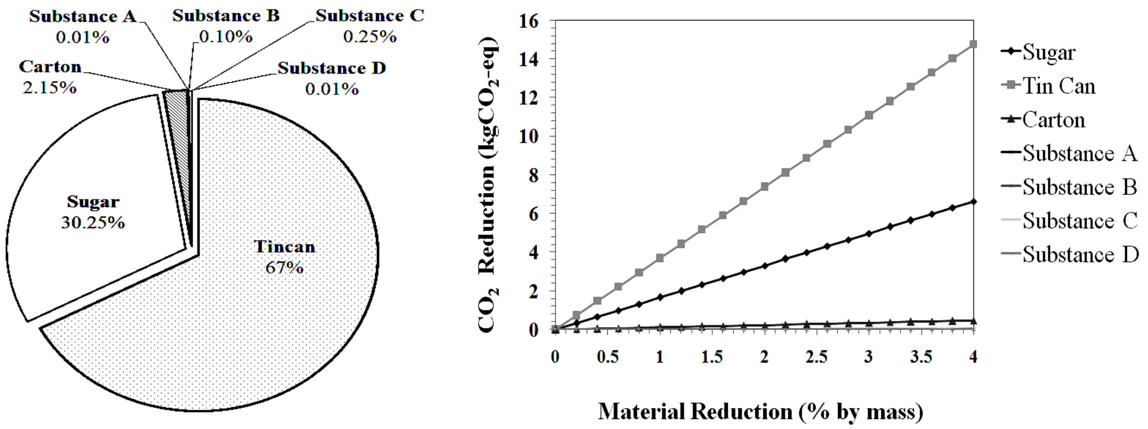

Fig. 2. (a) GHG Emission from the Raw Material Production; (b) The Sensitivity Analysis of the Raw Material Reduction

From the process data, the amount of rejected tin can was about 0.4% of the total tin can input. If the amount of tin can reduces about 0.4%, the GHG emission will decrease about 1.5 kg CO_2-eq/ton. Moreover, an aseptic box can be an alternative option for packing lychee instead of the tin can. The database of the SimaPro UK Ltd indicates that the GHG emission of an aseptic box is less than a tin can about 88.9 % [10]. To replace the tin can by the aseptic box can reduce the GHG emission about 365.28 kg CO_2-eq/ton.

The GHG emissions from fuel consumption, thermal process and electricity consumption in each unit process were shown in Fig.3. The total GHG from energy utilization was about 255.5 kg CO_2-eq/ton. The thermal energy played an important role in GHG emission accounted for 91.8 % of the total GHG from energy utilization. The thermal energy used for sugar solution and syrup preparation, syrup filling, exhausting and sterilization processes. The sugar solution is the mixture of sugar and water while the syrup is the mixture of sugar solution and other additives.

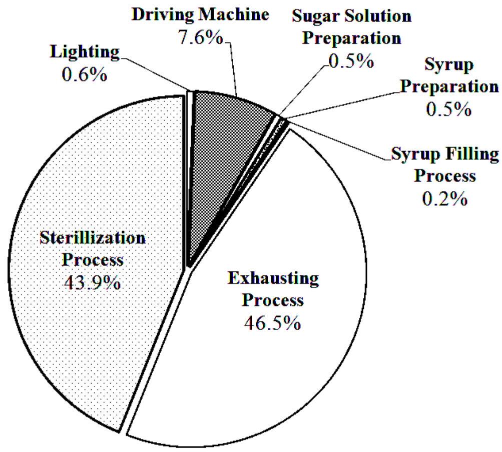

Fig. 3. The GHG Emission from Energy Utilization

From Figure 3, most of GHGs were emitted from the sterilization and exhausting process. Both processes should be improved for reducing GHG emission. The energy efficiency (η), a ratio of the net energy consumption and the net energy input to the process, was calculated. The η of the sterilization and the exhausting process were 10.2% and 8.0% respectively. The η of both processes were quite low because of the heat loss by conduction through the walls and water evaporation. To reduce the heat loss in these processes could increase the energy efficiency and reduce the GHG emission. To insulate the hot water tank and exhaust box could reduce heat loss about 328.9 and 236.2 MJ/d respectively. Furthermore, the GHG emission from both processes could decrease about 7.23 and 36.15 kg CO_2-eq/ton respectively.

Moreover, to improve the production line layout in order to let the process being flowed smoothly could also reduce the energy consumption. For example, the tin can was sometimes stopped in the steel rail before filling the fresh lychee and syrup. To repair the steel rail and let the canned lychee move to exhaust box continuously could reduce the processing time and heat loss. All of the suggested alternatives in this research were summarized in Table 4.

Table 4. Suggested Alternatives to Reduce GHG Emission

Suggested Alternatives	Potential Improvement (kg CO_2-eq/ton)	% GHG Reduction
1. To replace the tin can by an aseptic box	365.3	44.9
2. To insulate the hot water tank	7.3	0.9
3. To insulate the exhaust box	36.2	4.5
4. To repair the steel rail	4.1	0.5

4. Conclusion

This research adopted the LCA methodology to evaluate the GHG emission in the canned lychee production and proposed alternative technologies to reduce GHG emission in the process. The results showed that the total GHG emission was about 813.2 kg CO-eq/ton. The manufacturing process emitted GHG more than the transportation, waste management and cultivation processes. In the manufacturing process, the highest GHG emission was released from the raw materials production followed by the energy consumption and water consumption respectively. There are several alternative options to reduce the GHG e.g. replace a tin can by an aseptic box. In the energy utilization section, the thermal energy played an important role in GHG emission. To insulate the exhaust box and the hot water tank could also reduce heat loss. To renovate and design a steel rail would make the production line flowed smoothly, reducing the heat loss during the process interruption. Although these options were beneficial for the environment but the economic analysis should be further performed before the implementation.

Acknowledgements

The authors would like to thank the School of Energy Environmental and Materials, KMUTT which gratefully acknowledged for using Simapro Software, the National Metal and Materials Technology Center for providing the Thai National LCI Database, and the canned lychee factory for good supporting and allowing to collect the data.

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