Evaluation of the Carbon Footprint of Fresh Durian Grown in an Agroforestry System in Uttaradit Province, Thailand

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Abstract

The calculation of carbon footprint (CF) as an estimate of greenhouse gas emissions is one method used to measure environmental impact. Including carbon labeling on a product informs consumers of the environmental cost of that product during every stage of its life cycle (PLC), from acquisition and processing of raw materials to manufacturing, distribution and ultimate use. The purpose of this study was to estimate the CF of durian grown within an agroforestry system, including the removal of unconsumed portions of the fruit, in Ban Dan Na Kham, Uttaradit province, Thailand. Acquiring and processing fresh durian were responsible for 0.355 kg CO_2-eq and 0.00018 kg CO_2-eq, respectively. Distribution of fresh durian had a CF of 0.0359 kg CO_2-eq, and consumption was considered to have a CF of zero. Disposal of the inedible parts of durian constituted the largest CF component (1.9006 kg CO_2-eq), almost 83 % of the total CF (2.30 kg CO_2-eq) for all processes. Reducing disposal of the inedible portion of durian by selling it pre-peeled for consumers or reusing the peel for a variety of packaging purposes may help to reduce the environmental impact of fresh durian production.

Keywords: carbon footprint; durian; agroforestry system; greenhouse gases; Uttaradit province

1. Introduction

Human activity in Thailand, including agriculture, transportation, development, industry and deforestation causes the release of carbon dioxide (CO_2), methane (CH_4), nitrous oxide (N_2O) and chlorofluorocarbon compounds. The release of these greenhouse gases can be mitigated in a number of ways, including encouraging consumers to buy and use products with a reduced carbon footprint (CF). The Thai

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people have become more aware of global warming in recent years. They are interested in producing and consuming environmentally-friendly products and Thailand is ranked 31st in the world of greenhouse gas emissions and is ranked 4th in ASEAN (Pornpun, 2010).

Agroforestry systems (AFSs) have a high potential for climate change mitigation (IPCC, 2000; Fornara *et al.*, 2018) due to their roles in reducing C emissions and promoting C sequestration in soil and biomass. The AFSs have been recommended for Europe through the European Rural Development Council regulation 1698/ 2005 (Mosquera- Losada *et al.*, 2011). Nevertheless, the extent of C sequestration in AFSs depends on a number of site- specific factors, e.g., soil characteristics, especially silt and clay content (Takimoto *et al*., 2009; Haile *et al.*, 2010), species composition, plant age, rotation length, and system management (Nair *et al*. 2009). In fact, estimates of C sequestration in AFSs are highly variable, ranging from less than one to several Mg of C ha^{-1} $year^{-1}$ (Schroeder, 1994; Gordon and Thevatha san, 2006; Udawatta and Jose, 2011).

Uttaradit province in the northeast Thailand has a total area of 7,838,592 km^2, or 4,899,120 rai, and represents 4.62 % of the northern region. It is divided into nine districts, 67 subdistricts and 539 villages, and possesses complex mountainous terrain, low slopes from north to south and a lowland. The economy of Uttaradit is based on descending order of importance, agriculture, industry, fisheries and commerce. Important crops include langsad, durian, rambutan, mangosteen, and pineapple. In the Ban Dan Na Kham subdistrict durian is cultivated in agroforestry systems, areas in which crops are planted in forested environments that allow for the potentially sustainable collection of forest products and maintenance of local wildlife populations. Within an agroforestry system, crops grown in forested areas may only be cultivated at certain times of the year, allowing the forest to periodically return to natural conditions. Agroforestry allows crops to be shaded by tree cover and experience high humidity. Agricultural forms such as Miang gardening (Cha), Makha Wao Taow garden, etc. In the northern region, the cultivation of durian, mangosteen, longkong.

Study and analysis of greenhouse gas emissions in agroforestry systems has been studied in traditional agroforestry systems under rainfed and irrigated ecosystems (Doddabasawa *et al.*, 2019), such as carbon footprint assessment for irrigated and rainfed maize (*Zea mays* L.) production on the Loess Plateau of China (Wushuai *et al*., 2018), and carbon footprints of food crop production of different crops (e.g. legumes, winter and spring cereals, oilseed rape, potato) and farming practices (conventional, integrated and organic) (Jonathan *et al*., 2008).

The purpose of this study was to determine the CF of the planting, harvesting and distribution portions of the life cycle of fresh durian grown in an agroforestry system in Uttaradit province, Thailand.

2. Materials and Methods

2.1 Study scope and goals

The CF of fresh durian was determined by calculating carbon dioxide equivalents (kg CO_2- eq) . (Greenhouse Gas Management Organization, 2011) of each stage in the production and distribution process. The production steps are represented in Figure 1. Product together with the production guidelines of the community products that received the carbon label and the life cycle database of products in Thailand are shown in Figure 1. The functional unit of fresh durian in this study is one kilogram.

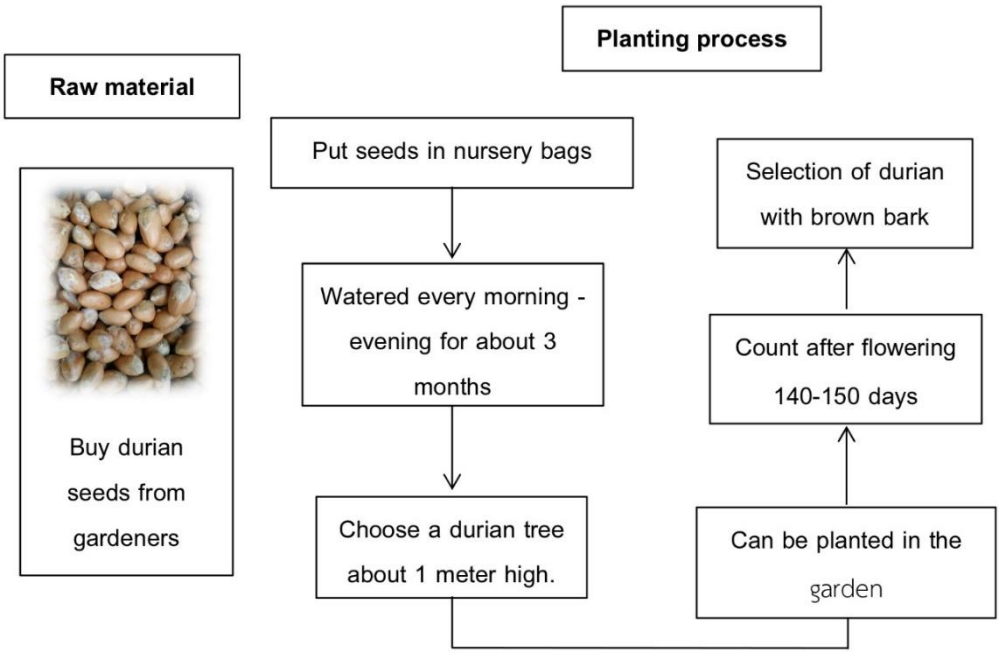

Figure 1 The steps included in calculation of CF in durian planting systems

2.2 Environmental accounting analysis

Analysis of environmental accounting was performed using primary data including resource usage, energy consumption and the amount of waste, and secondary data such as calculating the emission factor coefficient (EF).

The amount of greenhouse gases from activities (kg CO_2-eq)	=	Activity data (Unit)	x	emission factor coefficient (EF) (kg CO_2-eq /unit)

2.3 Carbon Footprint Analysis

The CF of fresh durian was calculated using the following general equation (Greenhouse Gas Management Organization, 2011).

2.4 Variation of data

The CF analysis of fresh durian can identify the processes that emit significant greenhouse gases and allow for assessment of

how to reduce energy consumption and waste materials in the production and distribution processes (Tumrongrat, 2007).

3. Results and discussion

3. 1 Carbon footprint assessment of fresh durian

3.1.1 Selection of fresh durian

One fresh durian fruit weighs approximately 4.07 kilograms. The functional or reference unit used for calculation is CF per one kg of durian.

3.1.2 Preparation of life cycle map of durian, fresh fruit

The scope of the assessment including the planting, harvesting, processing, distribution, consumption and disposal of durian, is depicted in Figure 2.

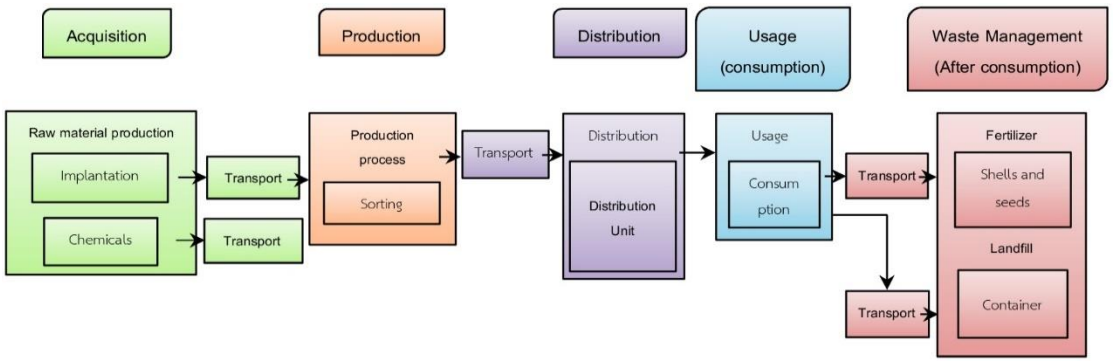

Figure 2 Life cycle of fresh durian in an agroforestry system in Uttaradit province, Thailand

3.2 Fresh durian production

To facilitate calculation of the fresh durian CF, the production process diagram identifies the inputs and outputs of energy, resources and waste (IPCC, 2006).

Inputs: raw materials, packaging and electricity

(1) Fresh durian: 5,924 kg, and as the average weight per fruit is approximately 4.07 kg. This represents approximately 1,455 fresh durians.

(2) Durian packaging: each package of 300 labels weighs 0.3 kg, so the weight of 1,455 durian labels was calculated as (1,455 x 0.3 kg/300 labels), or 1.455 kg.

(3) Electricity for sorting and labelling durian: sorting 300 kg of fresh durian requires two hours using 40-watt light bulbs. Electricity use for sorting 5,924 kg of durian was calculated as (2 hours x 4 tubes x 0.04 kWh x 5,924 kg/300 kg), or 6.32 kWh.

Outputs would include waste from the production process. In this part of the life cycle, there is no waste as farmers who bring the products to send to the manufacturers to sort out the preliminary.

Durian fresh fruit on the way, is the fresh durian that has been labeled in the durian stem. In quantities equal to 5,924 kg.

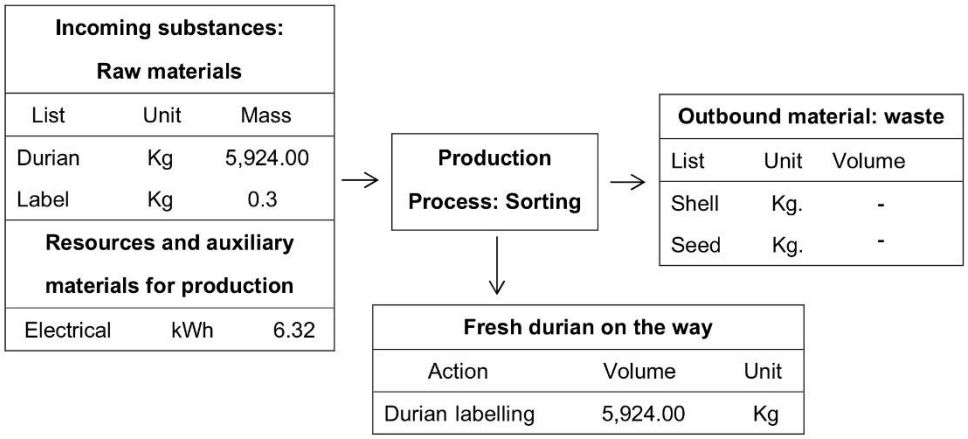

Figure 3 Diagram of the production process of fresh durian in an agroforestry system in Uttaradit province, Thailand

3.3 Calculation of CF

Raw material: Durian CF calculations were completed using survey data of 437 rai of durian cultivation and information on cultivation activities for durian from planting to harvesting.

Inputs included raw materials such as seedlings, fertilizers and chemicals used in growing durian and resources such as electricity. In calculating CF, all raw materials and resources were expressed in terms of the functional unit (one kg of fresh durian) and multiplied by the greenhouse gas emissions coefficient. The emission factor (EF). The total CF of the incoming substance item is 0.1532 kilograms of carbon dioxide equivalent (kg CO_2-eq).

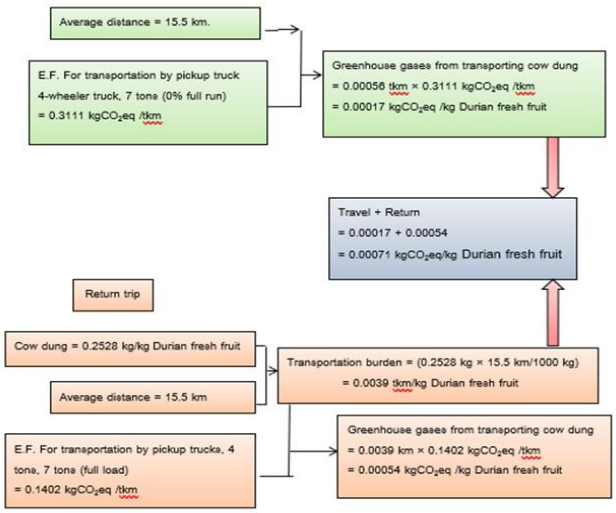

Figure 4 Example of calculating CF for distance-based transport in an agroforestry system in Uttaradit province, Thailand

Durian distribution inputs include transportation via a small four-wheel truck with a maximum load of seven tons, running in normal mode, on-going. When 0% loaded, the EF = 0.3111 kg CO_2-eq/km and when 100% loaded, EF = 0.1402 kg CO_2-eq /km). The average distance travelled is 15.5 km. The total CF of every shipment is 0.1398 kg CO_2-eq.

Durian is grown and transported with other fruits, and only accounts for 65 % of the total production and distribution footprint calculated above. As the CF of the raw material inputs is 0.1532 kg CO_2-eq and the CF of the transport input is 0.1398 kg CO_2-eq and this footprint is shared with other fruits, the CF of raw materials allocated to durian is (0.1532 kgCO_2 equivalent + 0.1398. kg CO_2-eq) x 65 %), or 0.2000 kg CO_2-eq.

The results of calculations of the CF of fertilizers, chemicals, electricity, gasoline and oil were as follows: 19.045 kg CO_2-eq chemical fertilizer 55.70 kg CO_2-eq, organic fertilizers 22.10 kg CO_2-eq, electricity 10.334 kg CO_2-eq, various chemicals 5.7829 kg CO_2-eq, gasoline 3.0988 kg CO_2-eq, and diesel fuel 2.9843 kg CO_2-eq as shown in Figure 5.

The greatest CFs were derived from the use of 15-15-15 fertilizer formula (49.1706 kg CO_2-eq), filtered down to 20.2048 kg CO_2-eq. The CF of fertilizer 16-16-16 is 4.8267 kg CO_2-eq and fertilizer 8-24-24 is 1.7033 kg CO_2-eq.

Fresh durian labels are stickers made of PVC, 7×15cm in size with EF = 0.5100 kg CO_2-eq /kg (Greenhouse Gas Management Organization, 2013): A, which produces fresh durian. Using labels on 5,924 kg of durian and recalling that the reference product is 1 kg fresh durian, the label sticker (1 kg × 1.455 kg/5,924 kg) is equal to 0.00024 kg. Therefore, the CF of the label (0.00024 kg x EF = 0.5100 kg CO_2-eq /kg) is equal to 0.00012 kgCO_2-eq at the label production site.

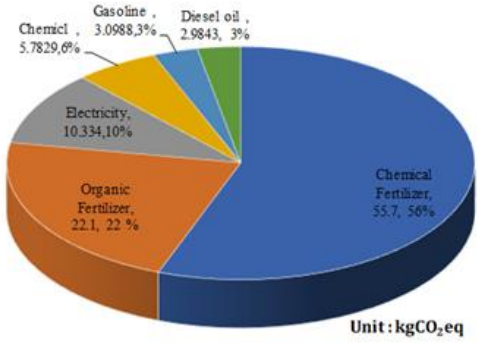

Figure 5 Durian CF Raw Material Inputs in an agroforestry system in Uttaradit province, Thailand

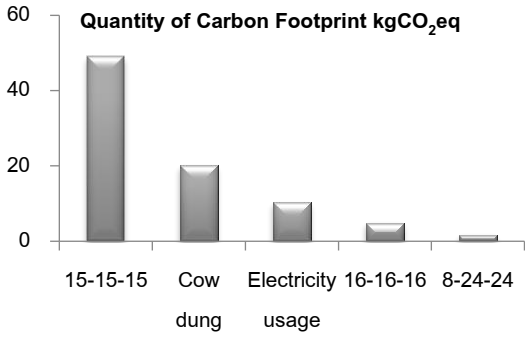

Figure 6 Carbon footprint of largest raw material Inputs for durian production and distribution

Durian is transported from farm to market by a small four-wheel pickup truck with a maximum load of seven tons running on a

regular basis at full-capacity transportation (100 % loaded) (EF = 0.1402 kgCO_2 equivalent /km) and an empty return leg (0 % loaded) (EF = 0.3111, kg CO_2-eq /km) an average distance of 40 km, resulting in CF of raw material transportation (durian effect) equal to 0.155.kgCO_2eq. When combined with the CF of the raw material (durian effect) equal to 0.2000 kgCO_2 equivalent at the durian plant, the durian CF of 0.355 kgCO_2 equivalent at the point of sale.

The CF of transportation of durian labels using the same small truck already described at full transport capacity (EF = 0.1824 kg CO_2-eq /tkm) and empty return (0 % loading) (EF = 0.3342 kg CO_2-eq / km) with an average travel distance of 40 kilometers was determined to be 0.137 kg CO_2-eq.

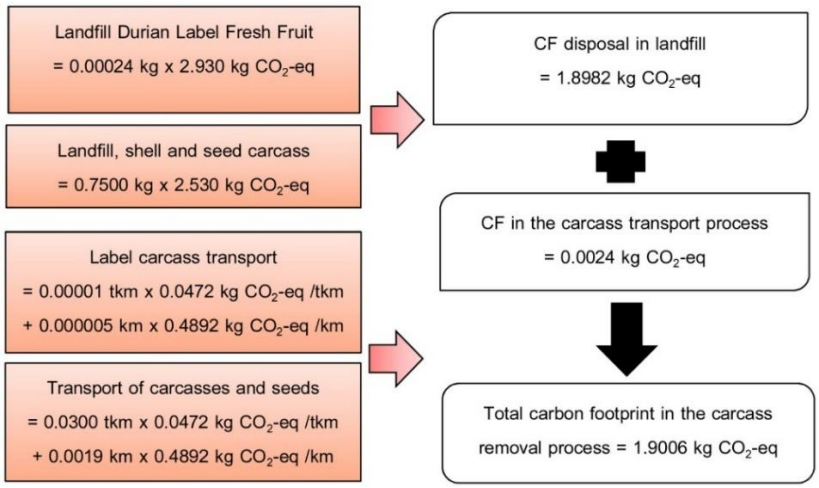

Figure 7 Calculation of CF in the carcass removal process

The acquisition, production, distribution, consumption and decomposition of fresh durian was determined to be 0.355 kg CO_2-eq, 0.00018 kg CO_2-eq, 0.0359 kg CO_2-eq, 0 kg CO_2-eq and 1.9006 kg CO_2-eq, respectively, for a total CF of 2.30 kg CO_2-eq.

Table 1 Carbon footprint of one kg of fresh durian

Life cycle	Carbon Footprint (kg CO_2-eq)	Percentages of greenhouse gas emissions
Acquisition of raw materials	0.355	15.49
Production process	0.00018	0.01
Product distribution	0.0359	1.57
Consumption	0.0000	0.00
Carcass removal	1.9006	82.93
Total	2.30	100.00

3.4 Guidelines for reducing CF of fresh durian

Based on the CF analysis of one kg of fresh durian, carcass disposal is responsible for the emission of 1.9006 kg CO_2-eq or 82.93 percentages of the CF of durian. This is due to inedible large part (75 %) of the fruit. The reduction of shell disposal could result in a substantial reduction of CF. Two scenarios were used to determine the potential impact of carcass disposal reduction. Scenario one modelled 50 % reuse of durian peel, and scenario two modelled 100% reuse of durian shell. Simulation results are presented below in section 4.1.

3.4.1 Scenario 1: Reusing 50 % of durian shell

In the process of 50 % carcass reuse, the CF was reduced to 0.9503 kg CO_2-eq from 1.9006 kg CO_2-eq. For one kg of fresh fruit, the CF was reduced to 1.15 kg CO_2-eq, or a 41.47 % decrease.

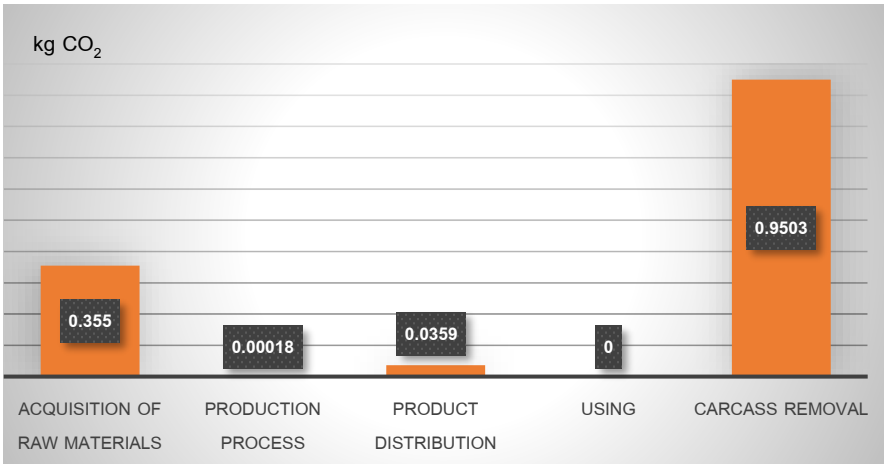

Figure 8 The CF of one kg of fresh durian when 50 % of the shell is used

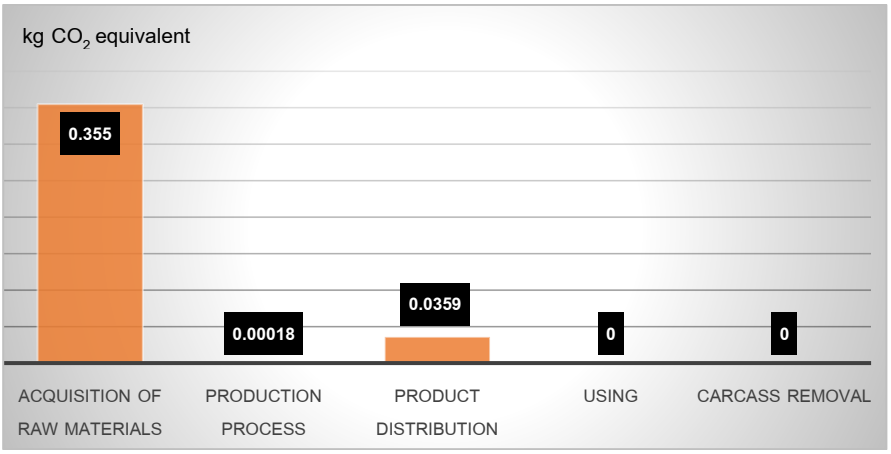

Figure 9 The CF of one kg of fresh durian when 100 % of the shell is used

Table 2 The CF of one kg of fresh durian when 50 % shell is reused

List	Carbon footprint of 1 kg of durian (kg CO_2-eq)
Baseline	2.30
Scenario 1 situation in case of shell carcass 50 % of durian is used	1.15
Percentage change	41.47

Table 3 The CF of one kg of fresh durian when 100 % shell is reused

List	Carbon footprint of 1 kg of durian (kg CO_2-eq)
Baseline	2.30
Scenario 2 situation in case of shell carcass 100 % of durian is used	0.00
Percentage change	97.70

3.4.2 Scenario 2: Reusing 100 % of durian peels

It was found that in the process of carcass removal, the CF was reduced to 0 kg CO_2-eq from the original 0.9503 kg CO_2-eq.

In both simulations, it was found that durian shell utilization resulted in a 100 % CF reduction. These results should be used to manage the discarded durian bark and target it for reuse in such applications as in durian shell fiber trays containing carboxymethyl cellulose or development of bioplastics for use as tea bags, coffee or charcoal briquettes.

The results of CF assessment for acquiring raw materials including durian and the label is equal to 0.355 kg CO_2-eq, derived from fresh durian is 0.355 kg CO_2-eq, 99.97 percent and label is equal to 0.00012 kg CO_2-eq 0.03 percent. Carbon footprint in the production process only slightly equal to 0.00018 kg CO_2-eq, and carbon footprint in the distribution process is equal to 0.0359 kg CO_2-eq. Carbon footprint in the use process of fresh durian is zero. The carcass removal process is equal to 1.9006 kg CO_2-eq. Summarizing the total carbon footprint of durian, 1 kg of fresh fruit, is equal to 2.30 kg CO_2-eq, with the proportion of 82.93 percent. Reducing the durian CF must first focus on reducing the CF accumulated by durian waste (carcass and peels).

The Office of Agricultural Economics, 6th (2015) studied the greenhouse gas inventory of the fresh durian production process in a green agricultural town in Chanthaburi province. The results showed that the CF in acquiring raw materials including durian, labels and chemicals, Durian terminal label is 0.200 kg CO_2-eq from fresh durian, 0.00031 kg CO_2-eq from labels, 0.200 kg CO_2-eq from chemicals and 0.00017 kg CO_2-eq. from terminal labels. To 99.73 percent, 0.18 and 0.09 respectively, carbon footprint in the production process only slightly equal 0.00006 kg CO_2-eq carbon footprint in the distribution process is equal to 0.0460 kg CO_2-eq carbon footprint in the process of using the product is zero and carbon footprint in the carcass removal process, equal to 1.9008 kg CO_2-eq. Summary of the total carbon footprint of durian products, 1 kg of fresh fruit, is equal to 2.15 kg CO_2-eq, with a proportion of 88.41 percent.

4. Conclusion

From the study of greenhouse gas emissions from fresh durian in the Ban Dan Na Kham subdistrict, Uttaradit province, an area of major durian production in northern Thailand, we can determine how to reduce the CF in agroforestry systems by using the information to support appropriate policy decisions regarding product labelling.

The CF assessment method is all-encompassing, from birth to death. The scope of the assessment is a business model for consumers. (Business-to-Consumer: B2C) from the interview of 20 durian gardeners.

4.1 Acquisition of raw materials

In the process of acquiring various raw materials. Which is used in the production of this product, namely, durian, fresh fruit and labels, must consider including the impact of raw material production to the transport of raw materials from the raw material source to the production site with the total CF in the process Acquiring raw materials including durian And the scene is equal 0.355 kg CO_2-eq, 99.97 %, and label 0.00012 kg CO_2-eq 0.03 %.

By carbon footprint from durian, fresh fruit is equal to 0.355 kg CO_2-eq comes from all information about the planting and care activities of durian throughout the life cycle. Is a carbon footprint in the process of acquiring raw materials (durian) in the amount of 0.200 kg CO_2-eq at the durian plant, which is caused by the use of chemical fertilizer, the highest is 55.70 kg CO_2-eq, accounting for 56 percent, followed by the organic fertilizer equal to 22.10 kg CO_2-eq. 22 per cent of electricity, 10.334 kg CO_2-eq, 10 per cent of chemicals, 5.7829 kg CO_2-eq to 6 per cent, gasoline 3.0988 kg CO_2-eq, 3 per cent, and diesel 2.9843 kg CO_2-eq, equivalent to 3 per cent and caused by carbon footprint of raw material transportation (durian effect) equal to 0.155 kg CO_2-eq as for the carbon footprint of the durian label transport, the greenhouse gas emissions are very insignificant.

4.2 Production process

In the production process, the impact of the use of raw materials, energy and waste from the production process will be considered, which requires the collection of raw material, energy and waste data. Which the production process of separating durian and sticking to the scene of thousands of durian by using electric light bulbs and in the production of sorting, there are no damaged items Produces a carbon footprint in the production process only as little as 0.00018 kg CO_2-eq.

4.3 Steps for product distribution

The distribution process of durian, fresh fruit of Hai Ha area, Ban Dan Na Kham Sub-district, Uttaradit province requires the use of distance information to transport goods to the store that purchased Most of the vehicles used for transportation are small 4-wheel trucks, maximum load 7 tons, normal run, average distance 30 kilometers. Carbon footprint in the distribution process is equal to 0.0359 kg CO_2-eq.

4.4 Steps to use

There is a requirement for fresh durian consumption without refrigeration, so it does not use energy.

4.5 Steps for carcass removal

In the process of managing debris, fresh fruit after use will consider the impact of the use of energy resources and greenhouse gas emissions from waste management processes. Including transporting the remains of durian from the durian supply to the treatment facility and eliminating waste after eating fresh fruit. Only 25 % of fresh durian is edible and the remainder must be taken to the community landfill and the label must be eliminated using a landfill method that contains carbon elements.

Summarizing the calculation of the total carbon footprint of durian, 1 kg of fresh fruit, is equal to 2.30 kg CO_2-eq, with the highest proportion of 82.93 percent of the removal process, followed by the raw material acquisition process 15.49 percent and distribution process of 1.57 percent, production process 0.01 percent, and the process of using carbon footprint is not released

When comparing the results of the analysis of the two simulations, it was found that the second model in the case of the utilization of the durian shell remains 100%, resulting in a 100 % reduction in carbon footprint.

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