Sustainability of Malaysian smallholder banana farming: an energy efficiency use-based audit

Nordin Onsang[1], Darius El Pebrian[1*], Fivi Anggraini[2]

(1. Faculty of Plantation and Agrotechnology, Universiti Teknologi MARA, Melaka Branch, Jasin Campus, 77300 Merlimau, Melaka, Malaysia;
2. Faculty of Economics and Business, Universitas Bung Hatta, Padang, West Sumatra 25133, Indonesia)

Abstract: Banana (*Musa* spp.) is one of important food crops that contributes to the Malaysia's economy from agro-based industry sector. This study aims to inspect the sustainability of banana cultivation by smallholder in Malaysia based on auditing the energy efficiency use and carbon footprint on its crop upkeep operation. Data were collected based on oral interviews with the owner of smallholder banana farming at Labuan, off the coast of the state of Sabah in East Malaysia, Malaysia. The findings showed total energy input use for crop upkeep in banana cultivation was 17998.50 MJ ha^{-1}. The ratio of energy output/inputs was equal to 1.002, which means crop upkeep operation in the study area is not therefore gaining energy, and it is not losing energy. Total carbon footprint was 551.35 kg CO2-eq ha^{-1} or equal to 58.11 g CO2-eq kg^{-1} banana. In general, the value reflects the sustainability of smallholder banana farming in the study area was mediocre. Thus, sustainable cultivation techniques should be enhanced in the banana farming to lift-up the energy efficiency use, and furthermore meet the relevant points in the Sustainable Development Goals (SDGs).

Keywords: banana cultivation, carbon footprint, energy utilization, input, output

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1 Introduction

Banana (*Musa* spp.) is a non-seasonal main fruit crop that has been identified to become an important source of income from agricultural sector of Malaysia. The DOA Malaysia (2018) reported that the banana planted areas in the country has been expanding rapidly from 28036 ha in 2016 to 30455.45 ha in 2018. For such areas, the banana occupied 17.5% of 174104.47 ha total fruits planted areas in the country. At the portion, the banana fields were the second largest fruit planted areas in Malaysia after the durian fields. In fact, based on banana exports in year 2020 reported by FAO (2021), Malaysia is among the main countries producing banana in Asia, after Pakistan, India, Vietnam and Philippines. The increase in planted areas had effect on the increasing of banana production from 309508 metric tonnes to 376690 metric tonnes. The production exceeded the demand for local consumption, and made banana achieves a self-sufficiency ratio (SSR) at 103.2 % (DOSM, 2018). With the SRR achievement also enabled Malaysia's exports more than 20000 metric tonnes of bananas or about 8% of production to Singapore, which valued at RM40.1 million (DOA Malaysia, 2018; KRI, 2019).

Banana is also a popular fruit in the diet of many Malaysians. Various parts of this plant are also consumed or utilized to serve various types of Malaysian food. According to DSOM (2018),

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***Corresponding author: Darius El Pebrian,** PhD, Senior Lecturer, Faculty of Plantation and Agrotechnology, Universiti Teknologi MARA, Melaka Branch, Jasin Campus, 77300 Merlimau, Melaka, Malaysia. E-mail: darius@uitm.edu.my, Tel: +6062645297. Fax: +622645248.

Malaysia's bananas consumption per capita was 10.0 kg per person in 2017 or more than that of the pineapples (7.6 kg per person) and durians (6.4 kg per person). This amount has also positioned banana in the second most consumed fruit after coconuts (19.4 kg per person). KRI (2019) also added that Malaysia's bananas consumption per capita was slightly lower than the European Union (11.6 kg per person) and the United States (12. 6 kg per person).

Additionally, as a cash crop, banana is suitable to be integrated in intercropping system with oil palm that has been branded as the top crop on Malaysia's agricultural land. Ismail and Khasim (2005) said that the banana can be integrated for a period of 1.5 to 2.0 years (two planting seasons) after planting of the oil palm, and even can be extended for another 2 to 3 years under double avenue planting system. The integration of the crops maximizes land use, increases land productivity and generates an additional income to oil palm growers especially during the immature phase of oil palm. It is also considered as a potential sustainable approach to create a better environmental and socioeconomic values. In fact, Zainal and Omar (2020) mentioned that combining oil palm with banana generate lucrative income and lessen dependency on the fluctuating world market price for oil palm.

The above literatures remarked that the banana plays crucial roles, not only as an important food crop, but also as an agro-based industry contributor to Malaysia's economy. Most importantly, banana is a well-potential crop for eradicating poverty among rural smallholders. Therefore, sustainable banana cultivation in the country should be always given a high priority by all the parties involved in the farm business in order to ensure its production continuously competitive in boosting the economic development from agricultural sector while offering sustainable environment at the same time. This is agreeing with Carruthers (2017) who mentioned that communities want public assets such as natural resources, soil and water quality and biodiversity are protected from the impacts of business operations including agriculture. According to Carruthers (2017), the farmers must balance their own business requirements and customer expectations for food quality and safety, and public expectations for land management when running their agriculture enterprises. He also emphasized that there is a strong trend now that consumers demand for sustainable production, and are increasingly skeptical about unsubstantiated "green" claims regarding production practices.

In response to these issues, sustainable production of banana through auditing the energy use in banana cultivations is a prime interest to be explored because energy is required as production inputs at every level of the crop cultivation. As far as we know, study on analysis of energy use in banana production has been reported by several researchers in past research literatures. Sarath et al. (2017) carried out a study on energy use pattern for banana production in Erode District of Tamil Nadu, India. However, there is no study on the energy utilization in banana cultivation in Malaysian farms. The aforementioned published findings could not be adopted to the Malaysia's banana farms since the differences farm characteristics, cropping system, climate and environment between Malaysia and the country mentioned in the past study.

Thus, this study aims to explore the sustainability of smallholder banana farm in Malaysia based on energy efficiency use to its crop upkeep operation. Crop upkeep operation was given emphasis in this study since the operation has been identified as an operation with high-consuming energy inputs in some crops cultivations in Malaysia (Azwan et al., 2016; Nazri and Pebrian, 2017; Zulekipli and Pebrian, 2019; Liyana and Pebrian, 2020). The crop upkeep operation in banana cultivation include fertilizing, spraying herbicide, irrigation system, pruning and harvesting.

The output of the study can give understanding on when, where and how much energy inputs consumed on each stage of crop upkeep operation in banana cultivation, which is useful for assessing the sustainability of banana cultivation in smallholder farm in Malaysia. Besides that, the output is useful in supporting the relevant agencies to enhance policy that meet the Sustainability Development Goal (SDG) 12, namely "responsible consumption and production".

2 Materials and methods

2.1 Data collection

The data for this study was collected through a case study at Kampung Durian, Tunjung, in Labuan, off the coast of the state of Sabah, Malaysia. The study area was 4.0469 hectares of mineral soil that was planted with the *Musa acuminate balbisiana* species (Figure 1). The area consisted of 4 (four) plots. The plots were treated as number observational plots; hence, four sets data were taken from the entire study area. The farm in the study area was supervised by the Farmers' Organization Authority of Labuan federal territory, near the coast of Sabah state of Malaysia. The reason of selecting the study area is that the Sabah state and its surrounding areas are among the top three states in Malaysia that produce banana. According to the DOA Malaysia (2018), Sabah produced 53361 metric tons' bananas in 2017. Such production has ranked Sabah as the third largest state producing banana, after Pahang and Johor states in Malaysia.

Figure 1 Typical planted banana in the study area

A total of 4000 stacks for planting spots were prepared on the study areas. Each stack was planted with 4 trees. As previously mentioned, the data of study was the energy inputs use for crop upkeep operations in the banana cultivation, which comprised of fertilizing, spraying herbicide, irrigation, pruning, and harvesting. The total yield of bananas for 1 year's harvesting cycle was recorded for use in the computation of energy output. Survey method thru face-to-face interview with farm owner was employed to collect the information in regard with the description of field operation used by the owner, and quantity energy inputs applied such as human, machinery, fertilizers, herbicide, and irrigation.

2.2 Description of field operation

As mentioned earlier, this study focused crop upkeep operation in banana cultivation, which comprised of fertilizing, herbicide spraying, irrigation, pruning and harvesting (Table 1). The description of crop upkeep operation process at the study area is as follows:

2.2.1 Fertilizing

The material used for fertilizing operation consisted of NPK Blue fertilizer and farmyard manure. The granulated NPK blue fertilizer was dissolved into liquid form. The liquefied fertilizer was placed into a 15-L knapsack sprayer. The worker then carried the fully loaded knapsack sprayer on his shoulder to spread the fertilizer while walking nearby the planting path. The farmyard manure was spread manually by using hand-held tool. The fertilizing operation was carried out for 4 times a year, i.e. on the months of March, June, September, and December. Usually, the operation took 6 days to be completed in each month. In this study, the amount of fertilizer applied along with the time taken in completion of operation were recorded. The recorded data was then converted into total energy equivalent in Mega Joule per hectare (MJ ha^{-1}).

2.2.2 Spraying herbicide

Spraying herbicide was manually conducted by worker using a knapsack sprayer. During the operation, the worker carried the knapsack sprayer to apply the herbicide for weed control. Similar to fertilizing operation, the frequency of herbicide application was also 4 times a year, i.e. on the month of March, June, September, and December. The duration of operation was also 6 days. The amount of herbicide applied and the time used by the worker to complete the operation were documented. The documented data was then converted into total energy equivalent in MJ ha^{-1}.

2.2.3 Irrigation

Like other crops, availability of water supply through irrigation is required by banana to grow. Water is the most important element to maintain the plant structure, and it is necessary in catalysing the chemical process inside the plant cell. Surface irrigation was practised in the study area. A 5-hp Robin EY20 air-cooled gasoline engine was used as a power source to pump water from the reservoir to the banana planted areas. The engine weighs 15 kg and has a 3.8 L fuel tank capacity. The distribution of water in irrigation process was conducted every day with around 3 hours' duration per day. The duration was divided into two sessions; morning and evening times, and each session took time one and half hour. The data collected from the irrigation were the time taken by the worker in completing the assigned area, the fuel consumption of water pump and average amount of water used during irrigation. All the data was then converted into total energy equivalent in MJ ha^{-1}.

2.2.4 Pruning

Pruning was carried out to maintain the cleanliness of the cultivation area so that it prevents the planted banana trees from severe pests and diseases attacks. Apart of that, this activity also improves the quality and quantity of banana yields and provide more accessibility for carrying out the harvesting operation. Pruning was conducted when the fruit on the oldest tree was matured and ready to be harvested. This process lasted one week in each month and was conducted by the worker using sickle and machete. During pruning, unwanted suckers were removed from the stack of banana tree by using wheelbarrow. Only 4 suckers' trees were retained on each stack to prevent the competition of nutrient and space. Pruning also aimed at removing the dead leaf on the banana tree so that it can stimulate new leaf growth. In this study, time taken by the worker to finish the pruning process was documented. This data was then converted into total energy equivalent in MJ ha^{-1}.

Table 1 Field operations aspects for crop upkeep in the study area

Operation	Period of time	Frequency
Fertilizing	March to June September to December	4 times
Spraying herbicide	March to June September- to December	4 times
Irrigation	January to December	720 hours
Pruning	January to December	12 times
Harvesting	January to December	12 times

2.2.5 Harvesting

Harvesting is process of collecting the fruit bunches that has reached about 75% fruit maturity standards. The maturity standards are critical to prevent fruits become over ripening or premature ripening during transporting to the local market. This process will be conducted manually by the worker. The fruits were harvested with a knife or machete and transferred to the collection area using a wheelbarrow. This process will be conducted 1 week for each month before the pruning process.

2.3 Data analysis

Each input use in the crop upkeep operation was recorded as energy input. The recorded energy was then multiplied with the coefficient of energy equivalent from the previous research literature, as is indicated in Table 2. The labor input for fertilizing, herbicide spraying, irrigation, pruning and harvesting operations were recorded based on number of labor and time spent by the labor to complete each operation. It was expressed in hour. Quantity of fertilizer and other agrochemicals were documented in kilogram. These materials were only measured for their active ingredients.

Machinery input was calculated with a formula by Moerschner and Gerowitt (2000), in Equation 1. The data used for computing machinery inputs were machinery weight in kilogram, machinery working hours in hour per hectare, and number of application and wear-out life of machinery in hour.

$$E_m = \frac{W_m \times C_m \times H \times N}{W_o} \quad (1)$$

Where E_m is energy of the machine in MJ ha^{-1}, W_m is weight of the machine in kg, C_m is coefficient of energy for the machine in MJ kg^{-1}, H is working hours in h ha^{-1}, N is number of applications in proportion, and W_o is wear-out life of machinery in hours.

Fuel consumption for machinery was estimated based on the formula from ASABE Standards (2009) in Equation 2.

$$FC = PTO \times 0.305 \quad (2)$$

Where FC is fuel consumption in L h^{-1} and, PTO is rated PTO power of machinery in kW. The total inputs equivalent can be computed by summation of energy equivalents of all inputs in MJ units.

Energy ratio (energy use efficiency) and energy productivity were calculated based on formulas by Nazri and Pebrian (2017), Mandal et al. (2002) and Singh et al. (1997) in Equations 3 and 4 by using the computed energy equivalents of the inputs and output.

$$EE=Eo/Ei \quad (3)$$

$$EP=Lo/Ei \quad (4)$$

Where EE is energy use efficiency in proportion, Eo is energy output in MJ ha^{-1}, and Ei is energy inputs in MJ ha^{-1}, EP is energy productivity in proportion, Lo is yield in kg ha^{-1} as energy output, which was recorded in accordance with the total yield of banana for one year of harvesting, which accounted for 9488.74 kg ha^{-1}. The total energy inputs exist in the crop upkeep operation was then categorized into direct, indirect and renewable, non-renewable forms.

Table 2 Energy equivalents for different inputs and outputs in agricultural production

Item	Unit	Energy Equivalent (MJ/Unit)	References
Input			
Human Labor	h	1.96	(Fluck, 1992; Shahan et al., 2008)
Machinery			
Water pump (5 hp)	kg	109.00	(Pimentel, 1992)
Fertilizer			
Nitrogen, N	kg	60.60	(Kuswardhani et al., 2013)
Phosphorus, P	kg	11.10	(Kuswardhani et al., 2013)
Potassium, K	kg	6.70	(Kuswardhani et al., 2013)
Fuel			
Petrol	L	46.30	(Safa and Tabatabaeefar, 2008)
Farm Yard Manure	kg	0.30	(De et al., 2001)
Herbicide	L	238.00	(Kuswardhani et al., 2013)
Water for Irrigation	m^3	0.63	(Heidari and Omid, 2011)
Output			
Fruit	kg	1.90	(Singh and Mittal, 1992)

The carbon footprints in form of CO_2 associated with energy use in banana crop upkeep operation was estimated by multiplying the sum of input factors per hectare by the CO2 emission coefficient. A carbon footprint is defined as estimates the total volume of greenhouse gas (GHG) emissions. Equation 5 by Ilyas et al. (2019), Safa and Samarasinghe (2012) was used in the carbon footprint computation.

$$CF = \sum(A_i \times C_i) \quad (5)$$

Where CF is carbon footprints in kgCO2-eq ha^{-1}, A_i is input factors in unit per area (GJ ha^{-1} or kg ha^{-1} or L ha^{-1}) and C_i is CO_2 emission coefficients of the inputs in kg CO2eq $unit^{-1}$. The CO_2 emission coefficients of inputs are shown in Table 3.

Table 3 CO_2 emission coefficient of inputs

Item	Unit	GHG coefficient (kg CO2eq unit^{-1})	References
Machinery	GJ	71	Pishgar-Komleh et al. (2012)
Chemical Fertilizer			
Nitrogen, N	kg	1.3	Lal (2004)
Phosphorus, P	kg	0.2	Lal (2004)
Potassium, K	kg	0.2	Lal (2004)
Farm Yard Manure	kg	0.126	Pishgar-Komleh et al. (2012)
Petrol	L	2.29	NRCAN (2014)
Herbicide	L	6.3	Lal (2004)

3 Results and discussion

3.1 Distribution of energy utilization based on operation

The utilization of the energy inputs for crop upkeep operation in the banana production was allocated according to the field operations as is shown in Table 4. Fertilizing operation utilized 9790.61 MJ ha^{-1} or about 54.40% of the total energy of 17998.50 MJ ha^{-1} and was the highest share of energy in crop keep operation. Fertilizing used the highest share of energy due to banana cultivation required high amount of fertilizer i.e. Nitrogen (112.96 kg), Phosphorus (56.48 kg) and Potassium (25.92 kg) along with high energy equivalent per hectare of the inputs. The main compound in the NPK Blue was mainly contain Pruning and harvesting that contribute about 278.97 MJ ha^{-1} (1.55%) for both of the operation. Both operations were the least share of energy in the crop operation.

Although fertilizing was the highest share of energy input in crop upkeep operation by banana smallholder, however, the kind of share was still lower than that of the cultivation of other several main crops in Malaysia such as pineapple, oil palm, rock melon and rubber. In pineapple collation for instance, Nazri and Pebrian et al. (2017) reported that fertilizing contributed 54.61% of the total energy inputs use in the crop production. In oil palm cultivation, Azwan et al. (2016) reported that the energy consumed was dominated by chemical fertilizer for crop upkeep. More than 66% of the energy inputs was contributed from chemical fertilizer application. Whereas similarly, another study on rockmelon production by Liyana and Pebrian (2020) also found that fertilizing accounted for 73.29% of the total energy inputs. Zulekipli and Pebrian (2019) also mentioned that fertilizing paid 65.93% of total energy use in the rubber cultivation. Generally, these results indicated that the crops cultivations in Malaysia rely on heavy use of chemical fertilizers based-energy to achieve the intended yield and farms productivity. The consumption volume of mineral fertilizers i.e., nitrogen, phosphorus, potassium by Malaysia's agriculture remains high.

Table 4 Distribution of energy utilization in crop keep operation based on type of operation in banana cultivation

Field Operation	Energy Used (MJ ha^{-1})	Portion (%)
Fertilizing	9790.61	54.40
Herbicide application	1739.94	9.67
Irrigation	5910.02	32.84
Pruning	278.97	1.55
Harvesting	278.97	1.55
Total	17998.50	100.00

3.2 Distribution of energy utilization by energy input source

Table 5 shows the total energy input used for crop upkeep in banana cultivation was 17998.50 MJ ha^{-1}, while total energy output produced in the banana cultivation was 18028.61 MJ ha^{-1}. The energy output came from the banana yield amounting to 9488.74 kg ha^{-1}. Based on the inputs source, it was found that the fertilizer indicated the highest share of input, which made up of 53.88% contribution of the total energy used in the crop upkeep operation. Water for irrigation was the second highest share of 29.17% of the total energy input, followed by herbicide (9.15%), human labor (7.04%) and fuel (0.51%). While machinery with 0.24% donation of total energy input was the least share energy input.

As mentioned earlier, fertilizer was in the top rank among the energy inputs share in the banana crop upkeep operation. Similar situation of ranks also happened on the share of fertilizer use in pineapple, oil palm, rock melon and rubber cultivations in Malaysia as reported by past studies (Nazri and Pebrian, 2017; Azwan et al., 2016; Liyana and Pebrian; 2020; Zulekipli and Pebrian, 2019).

Table 5 Distribution of energy utilization by energy input source

Input	Unit	Quantity per unit area (ha)	Energy equivalent (MJ unit^{-1})	Total energy equivalent (MJ ha^{-1})	Percentage (%)
Human labor (h)				1266.96	7.04
Fertilizer application	h	47.44	1.96	92.98	
Herbicide application	h	47.44	1.96	92.98	
Irrigation application	h	266.87	1.96	523.07	
Pruning	h	142.33	1.96	278.97	
Harvesting	h	142.33	1.96	278.97	
Machinery (kg)				43.63	
Water pump (5 hp)	kg	266.87	109.00	43.63	0.24
Fertilizer (kg)				9697.63	53.88
Nitrogen	kg	112.96	60.60	6845.38	
Phosphorus	kg	56.48	11.10	626.93	
Potassium	kg	225.92	6.70	1513.66	
Farm Yard Manure	kg	2372.10	0.30	711.66	
Fuel (L)				92.60	0.51
Petrol	L	2	46.30	92.60	
Herbicide (L)	L	6.92	283	1646.96	9.15
Water for Irrigation (m^3)	m^3	8334.48	0.63	5250.72	29.17
Total Energy Input (MJ ha^{-1})				17998.50	100
Yield (kg ha^{-1})		9488.74	1.90	18028.61	
Ratio of Energy Output/Input				1.002	
Energy Productivity (kg MJ^{-1})				0.53	

Based on the ratio of output and inputs, it was found that energy efficiency use in banana crop upkeep operation to be 1.002. The ratio showed the total output is just sufficient to cover the total energy inputs use in the operation or means no efficiency or inefficiency energy has been made at the operation. To put it simply, the crop upkeep operation in banana cultivation by smallholder in Malaysia is not therefore gaining energy and it is not losing energy. The energy productivity produced by the banana upkeep operation was 0.53 kg MJ^{-1}, which means that every 1 MJ of energy input produces 0.53 kg banana. This value showed that the energy productivity is still low since one-input energy per unit is only capable to offer less than one-kilogram output. Improving the current practices by introducing technology with less energy intensive such as cost-effective farm machinery and high yielding seeds for cultivation is urgently needed to improve the energy productivity in banana cultivation by smallholder. This is agreeing with Hanania et al. (2021), a service-based economy, tends to be less energy intensive, so has a better energy productivity.

Compared with some other crops cultivations in Malaysia, the ratio of energy output-inputs in banana crop upkeep operation was slightly higher than that of 0.83 in rubber cultivation (Zulekipli and Pebrian, 2019). However, the ratio was lower than that of the ratios of 3.60 in pineapple cultivation (Nazri and Pebrian, 2017), 5.34 in rock melon cultivation (Liyana and Pebrian, 2020), and 4.38 in oil palm cultivation (Hasan et al., 2021). While, compared with some other crops cultivations in other countries, the ratio of energy output-inputs in banana crop upkeep operation had lower energy efficiency than that of 1.10 in apple production (Kizilaslan, 2009), 1.24, 1.31 and 3.37 in apricot production (Gezer et al., 2003; Esengun et al., 2007), 1.25, 1.06 and 1.17 in orange production, lemon and mandarin (Ozkan et al., 2004) in Turkey. Apart of that, the ratio of banana crop upkeep was also lower than that of the ratio of rice production range, i.e. from

1.03 to 1.76 in US (Duke, 1983).

3.3 Energy use pattern

Energy inputs for upkeep operation in banana cultivation by the smallholder in Malaysia was mainly dominated by indirect energy that comprised of 63% of total energy use, or equivalent to 11388.22 MJ ha^{-1} (Figure 2). The indirect energy came from the external inputs, which were acquired from manufacturer like fertilizers, agrochemicals and machinery. Direct energy contributed 37% of total energy use or equivalent to 6610.29 MJ ha^{-1}. The direct energy sources were human labour, fuel (petrol) and water for irrigation. Such energy forms were defined in accordance with Nazri and Pebrian (2017), who said that direct energy is the energy that is invested physically in the farm like labor, fuel and electricity. Chemical fertilizers or synthetic fertilizers (NPK Blue) amounting to 8985.97 MJ ha^{-1} or equivalent to 49.93% of 17998.50 MJ ha^{-1} total energy input, is the main contributing factor that made the indirect energy become higher than the direct energy.

Based on energy resources pattern, the non-renewable energy dominated the energy inputs for upkeep operation in banana cultivation by the smallholder in Malaysia with share of 89% of total energy use or equivalent to 16019.88 MJ ha^{-1} (Figure 3). The resources of non- renewable energy are fuel (petrol), machinery (water pump), herbicide, farm yard manure and chemical fertilizer (NPK Blue). Renewable energy supplied only 11% or total energy input, which is equivalent to 1978.62 MJ ha^{-1}. The renewable energy came from human labour and farm yard manure. In contrast with some other crops cultivations in Malaysia, the use of renewable energy in the study area was much lower than that of 39.33%, 20.68%, 15% and 13% in oil palm, pineapple, rock melon cultivation, and in rubber cultivations, respectively (Hasan et al, 2021; Nazri and Pebrian, 2017; Liyana and Pebrian, 2020; Zulekipli and Pebrian, 2019). Again, higher usage chemical fertilizers or synthetic fertilizers in the study area contributed higher portion of non-renewable energy.

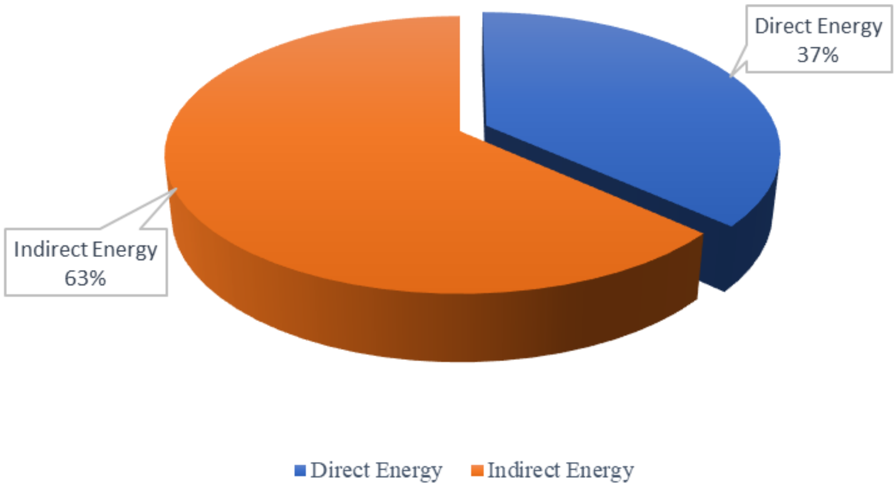

Figure 2 Share of direct and indirect energy use in banana smallholder farming the study area

Commonly, the findings depicted the fertilizer is the most important energy input for crop upkeep operation in banana cultivation in Malaysia. The condition is similar with some other crops cultivations in the country such oil palm, pineapple, rubber, and rock melon as revealed earlier in the past research literatures. NPK compound fertilizer which contains Nitrogen, Phosphorous and Potassium are widely applied for cultivating the said crops in the country. Such fertilizer was synthetic fertilizer obtained from off-farm activity, and its overuse can give implication on economic and environment sustainability of the farm business. Therefore, gradually shifting from the use of off-farm-based fertilizer to the organic fertilizers that are naturally available on the farm should be encouraged in Malaysia's agriculture in order to be capable of alleviating economic and environmental problems associated with. It is highly possible to shift the dependency on synthetic fertilizers to natural fertilizers since the specific functions of agriculture is also an energy producer, besides being an energy user. Hence, the agroecosystem in the farm can regenerate the natural fertilizers, which are important components for sustainable agriculture. This is consistent with Eurostat (2021), who said that the use of mineral fertilizers along with machinery has possibility to increase agricultural productivity and improve yields and the supply of food. However, as an energy user, agriculture promotes to the depletion of non-renewable energy resources and to global warming through energy-related emissions. Shifting the dependency on synthetic fertilizer also can help in reducing out cash flows of Malaysian import bill for fertilizers, which fluctuated within the range of US$749.97 to US$1088.964 million or annually averaged US$925.3805 million during period 2016 to 2020 as reported by the UN Comtrade Database (2022).

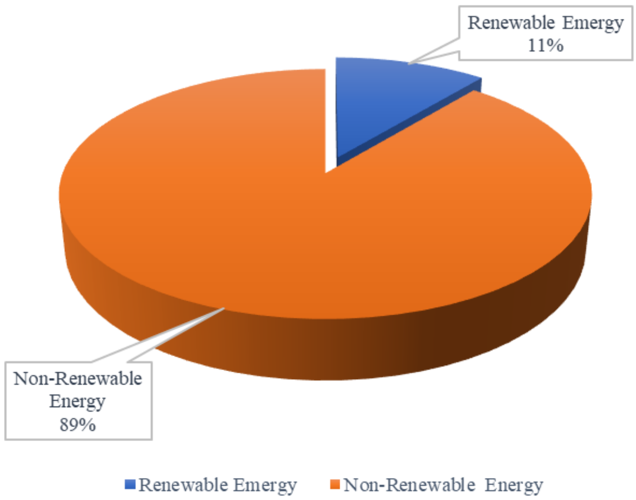

Figure 3 Share of renewable and non-renewable energy use in banana smallholder farming the study area

3.4 Carbon footprints

Total carbon footprint in banana crop upkeep operation were 551.35 kg CO2-eq ha^{-1} (Table 6). Based on individual share of energy input contributions to the total carbon footprint, it was found that farm yard manure (54.21%) was the highest, followed by Nitrogen fertilizer (26.63%), and Potassium (8.20%), and water pump (0.17%) was the lowest. Overall, fertilizer (N, P, K) together with farm yard manure contributed 91.09% of GHG emissions was the highest share in banana crop upkeep operation. With recorded yield of 9488.74 kg ha^{-1} banana in the study area, the carbon footprint was found to be 58.11 g CO2-eq kg^{-1} banana. This carbon footprint value was 0.21 times lower to 274 g CO2-eq kg^{-1} of the carbon footprint of Ecuadorian banana farming as reported by Roibás et al. (2015), and also 0.26 and 0.28 times lower to 226 g CO2-eq kg^{-1} and 209 g CO2-eq kg^{-1} of the carbon footprint of Cavendish and Prata bananas, respectively in Brazilian banana farming as stated by Coltro and Karaski (2019).

Table 6 Energy-related carbon footprint of banana crop upkeep operation (kg CO2-eq unit^{-1}) of inputs

Item	Unit	Quantity per unit area (ha)	GHG coefficient (kg CO2-eq unit^{-1})	GHG emissions (kg CO2-eq ha^{-1})	Percentage (%)
Machinery					
Water pump (5 hp)	GJ	0.0134	71	0.95	0.17
Chemical Fertilizer					
Nitrogen, N	kg	112.96	1.3	146.85	26.63
Phosphorus, P	kg	56.48	0.2	11.30	2.05
Potassium, K	kg	225.92	0.2	45.19	8.20
Farm Yard Manure	kg	2372.10	0.126	298.88	54.21
Petrol	L	2	2.29	4.58	0.83
Herbicide	L	6.92	6.3	43.60	7.91
Total				551.35	

Compared to other crop in Malaysia, the carbon footprint of banana crop upkeep operation was 4.24% higher than the rice production in the country, which produced maximum GHG emissions of 527.952 kg

CO_2-eq ha^{-1} in accordance with Elsoragaby et al. (2019). Higher consumption of fertilizer in banana crop upkeep operation caused higher GHG emissions. However, it was lower than that of the wheat agroecosystem in Iran, which was ranged from 553.1 kg CO_2-eq ha^{-1} to 3184.4 kg CO_2-eq ha^{-1} (Mondani et al., 2017) and the greenhouse cucumber production of 82724 kg CO_2-eq ha^{-1} in Yazd province of Iran (Pishgar-Komleh et al., 2013).

4 Conclusion

The sustainability of smallholder banana farming in Malaysia was explored through a case study on its energy utilization audit in crop upkeep operation. Based on the energy calculated, fertilizer with share of 53.88% of total energy input use was the largest portion contributing to energy use for crop upkeep operation in the banana cultivation. Referring the calculated ratio of output/inputs energy of 1.002 for crop keep operation in banana cultivation by smallholder farming in Malaysia, it is not therefore gaining energy and it is not losing energy. In others words, the ratio just achieved a break-even number of energy efficiency use. It can be concluded as a mediocre sustainability.

The carbon footprint of banana crop upkeep operation in the study area was lower than that of the other banana main producing countries such as Brazil and Ecuador. However, the carbon footprint was higher than that of the rice production in Malaysia due to higher energy consumption for fertilizer. Therefore, less energy intensive technology such as cost-effective farm machinery along with high yielding seeds and off-farm fertilizers should be introduced to improve the energy efficiency and energy productivity in banana cultivation by smallholders, later it led an improved sustainability. Overall, the output of the study can give befits in supporting the relevant agencies to enhance the strategy for competitive and sustainable banana farming in Malaysia in line with the relevant points in the SDGs. Besides that, it enriches the literatures on the field of energy for crop production in a specific country.

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