Analysis of Energy Consumption in Rubber Cultivation in Malaysia: A Case Study

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Abstract. Efficient energy use in rubber cultivation is one of the important strategies that can facilitate the sustainability and competitiveness of this crop as one of the main contributors in Malaysian economy from agricultural sector. Therefore, a case study was conducted to analyze the efficiency energy in Malaysian rubber cultivation. Data and other relevant information were gathered through a combination of oral interviews and field observations at rubber plantations located in the Rubber Research Institute of Malaysia Mini Station (RRIMINIS), Jasin, Melaka and Lakai, Negeri Sembilan, Malaysia. Mathematical calculations and computer spreadsheet were used to analyze the collected data. The findings showed that the rubber cultivation in the study areas consumed 16080.86 MJ/ha of energy. The largest amount of this energy, which accounts for 65.93% was consumed by fertilizing operation, followed by planting, weeding, collecting latex, land preparation, spraying hormones, tapping and pruning with share of 15.92%, 9.66%, 4.03%, 3.93%, 0.44%, 0.06%, and 0.04%, respectively. Energy output/inputs ratio in the rubber cultivation was 0.83. Decisively, the energy inputs used in the rubber plantations were less effective since the energy output/inputs ratio is lower than 1. Thus, energy saving-technologies and techniques are highly recommended to be introduced in rubber cultivation in Malaysia in order to achieve sustainability of economics and productivity of rubber planting industry in the country.

1. Introduction

Rubber (Hevea brasiliensis), is one of the major crops in Malaysian agricultural sector. The existence of rubber planting industry has been around in very long and even over a century in this country. With a total of planted areas of 1,007,000.87 ha either run by estates and smallholding as reported by MRB [1], Malaysia is recorded as one of the largest producers of natural rubber (NR) in the world. The total exports natural rubber (NR) amounting to 1,193,891 tons in 2017, which shows an increase of 176,285 tons or 14.77 percent when compared to the year 2016. In addition, Malaysian rubber industry additionally provided about 4.41% contribution rates to the country exports in 2017[1]. With those achievements, this rubber plantation industry continuously forms the backbone and becomes one of the key sectors of the Malaysian economy, which contribute to the prosperity of the country through agriculture sector.

Similar to other sectors, agricultural activities required energy as an important input for its production processes. In fact, agriculture has a close relationship with energy since the farming has functions both an energy user and provider of energy in the form of bio-energy as well. Nowadays, modernization of agricultural production operations has led to increasing energy consumption in agricultural sector.
According to Bekhet & Abdullah [2], among the reasons that may lead to increasing energy consumption in the agricultural sector are labor shortages in the sector in line with the government's policy to reduce dependence on foreign labor and limited available land for agricultural activities due to the rapid development of residential and industrial areas. Efficient use of energy is compulsory for sustaining agricultural production economically and environmentally, because it provides financial savings, preserve fossil resources and reduce air pollution as mentioned by Pervanchon et al. [3] and Pimentel [4]. Therefore, it is important to identify the pattern of energy consumption to help the economics and environmental planning for both agriculture and energy sectors.

In order to sustain its important role in Malaysian agricultural sector, rubber planting industry in the country should be able to maintain its competitiveness through applications of efficient and effective inputs in the cultivation process with the purpose of obtaining the maximum output as possible. Therefore, the efficient use of energy in rubber cultivation has to be looked into seriously to meet these needs. As suggested by Refsgaard [5], among the ways of achieving this goal is through determining the cultivation methods that need smaller energy input with higher energy productivity as suggested by Refsgaard [5]. In other words, rubber has to be cultivated in a manner where the energy inputs are used efficiently and effectively. This is also consistent with Pimentel & Patzek [6], who said that utilizing effective energy in agriculture is one of the conditions for sustainable agricultural production as it leads to financial saving, better fossil fuel preservation and lesser air pollution.

Looking at the past research literature, many studies on the rubber industry in Malaysia have been reported by researchers such as Mustafa et al. [7], Ratnasingam et al. [8], In [9], Othman [10], Ismail [11] and Tugiman [12]. These past studies were focused on processing, economics and future prospect of this crop. Therefore, the findings were not relevant to be acquainted with the understanding of the energy use in rubber cultivation. Special attempts have been made to study energy use in various crops production systems in Malaysian agriculture. Nazri and Pebrian [13], for example, reported energy consumption in pineapple cultivation. Azwan et al. [14] examined energy utilization in Malaysian oil palm mechanization operation. Pebrian et al. [15] reported on workers’ workload in oil palm cultivation. Pebrian et al. [16] also audited human energy inputs for oil palm and rice cultivations in Malaysia. Prior to that research, Gevao et al. [17] investigated energy use in Malaysian rice cultivation. The only one study with regards to energy consumption for rubber industry in Malaysia was reported by Saidur and Mekhilef [18]. They audited and analyzed the energy in the Malaysian rubber producing industries. Again nonetheless, this study was emphasized on energy use in downstream activities which focused on the rubber industry operations including tire manufacturing. Reviewing above-mentioned matter indicated that there is no study aiming at energy consumption on upstream activities such as rubber cultivation in Malaysia that has been published in the research literatures.

Therefore, a study on energy consumption in rubber cultivation in Malaysia is necessary to enrich the understanding on when, where and how much energy inputs are being expended in this crop cultivation in the field, and conclusively to recognize the opportunities to save the energy inputs for economical of operations. This paper initiates to analyze energy inputs-output used in rubber cultivation in Malaysia. Energy inputs-output analysis is employed to assess the effectiveness of energy use for a crop production system. The distribution of energy inputs, energy efficiency and energy pattern in the rubber cultivation were also explored. However, this study was limited to analyze the energy consumption in fields operations only. Energy analysis in nursery stage operations was not included. Specifically, this study could contribute to the development of a database for energy consumption in rubber cultivation in Malaysia, and it can be a guideline in applying related strategies and policies in the rubber planting industry in the country. Generally, this study also would be beneficial to enrich the database of energy consumptions in various crops production systems in Malaysia.
2. Material and Methods

2.1. Data collection

The data was collected through field observations and oral interviews at rubber plantations in RRIMINIS Jasin, Melaka and Lakai, Negeri Sembilan, Malaysia. Both the locations were governed by the Malaysian Rubber Board (MRB). The cultivated areas surfaces were considered as the undulating terrains. Data were obtained from field observations of agronomic practices such as land preparation, planting seedlings, weeding, fertilizing, pruning, tapping, collecting latex at twelve experimental plots. Agricultural inputs used in the operations were recorded. Active ingredient content of agrochemical inputs such as fertilizer and herbicides were also noted. Oral interviews were employed to gather general data from the farm management.

2.2. Field operations description

Field operations observed in rubber cultivation are land preparation, planting seedlings, weeding, fertilizing, pruning, tapping and collecting latex. Land preparation was conducted to remove the debris, plant residues and weeds. Appropriate herbicide such as glyphosate was used to chemically eradicate the growth of the weeds on the land. Planting distance of 6 x 3 m and a planting density of 512 to 555 trees per hectare was applied in planting the seedlings. Prior to the planting seedlings commence, a 37.3 kW tractor mounted with post hole digger was operated to prepare the planting holes. The tractor also transported the seedlings from nursery to the planting areas. Weeding was undertaken by a combination of manual and chemical methods. In areas with immature trees, weeding was carried out using handheld tools to eliminate the weed from the ground. Meanwhile, chemicals with knapsack sprayer were utilized in areas of mature rubber. Fertilizing was carried out manually by workers. Type fertilizer applied was compound fertilizer or NPK fertilizer in granular form. Throughout the operation, the worker brings along the fertilizer inside a bucket and uses his hand to broadcast the fertilizer to ground nearby the trees. A tractor 37.3 kW was used to deliver the fertilizer bags from the fertilizer store to the assigned areas. Pruning was done manually using hand-sharp steel to cut dead leaves or unwanted part of trees with the purpose of achieving better circumference of the tree for higher rubber production. Tapping the trees was executed manually using a special tapping-knife to cut the trunk of trees to harvest the latex. Tapping begins when the trunk of the tree reached a circumference of 50 cm and a height of 125 cm from the bud union. A diagonal cut downward at approximately 30°of the slope was made to wound the bark of the tree to flow the latex. A small receiving cup was put below the wounded bark to receive the flow of latex and store it temporarily prior to collecting it throughout the areas. Collecting latex was performed manually. This activity was carried out after a week of tapping activity. The worker walks in the field and collect the rubber latex from the tree. The tractor was used to transport the collected latex to the main collecting point in the field.

2.3. Data Analysis

Energy use from both direct and indirect energy sources was analyzed based on the field operations involved in rubber cultivation. The number of energy inputs/output used for the operations was recorded in specified established units, such as human labor in hour and fuel in liter, while machinery, agrochemicals, seedlings, and latex yield were in kilogram units. Energy equivalent in mega Joule (MJ) per hectare was computed based on the amount energy inputs/output used, multiplied with the coefficient energy equivalent in agricultural operations published from the previous research literatures as shown in Table 1. The fuel consumption was measured by filling the tractor’s fuel tank before and after performing each operation as suggested by Alcock [19], Pribian and Yahya [20], Nazri and Pribian [13]. Amount of the fuel to be topped up once each operation completed was considered as fuel consumption of the operation. The energy utilized by machinery was computed by using f equation 1 by Moerschner and Gerowitt [21] and Nazri and Pribian [13].
\[ Em = \frac{(Wm \times Cm \times H \times N)}{Wo} \]  

Where \( Em \) indicates the energy of machinery in MJ/ha, \( Wm \) indicates weight of machine in kg, \( Cm \) indicates coefficient of energy for machine in MJ/kg, \( H \) indicates working hours in h/ha, \( N \) indicates number of application in unitless, and \( Wo \) indicates wear-outlife of machinery in hours.

The total inputs equivalent can be computed by summation of energy equivalences of all inputs in MJ units. Energy ratio (energy use efficiency) and energy productivity were calculated based on formulas by Nazri and Pebrian [13], Mandal et al. [22] and Singh et al. [23] in equation 2 and 3 by using the computed energy equivalents of the inputs and output.

\[ EE = \frac{Eo}{Ei} \]  
\[ EP = \frac{Lo}{Ei} \]

Where \( EE \) indicates energy use efficiency in unitless, \( Eo \) indicates energy output in MJ/ha, and \( Ei \) indicates Energy inputs in MJ/ha, \( EP \) indicates energy productivity in unitless, \( Lo \) indicates latex output in kg/ha.

**Table 1. Energy equivalents for different inputs and outputs in agricultural production**

| Input    | Unit | Energy equivalent (MJ/unit) | Reference                      |
|----------|------|-----------------------------|--------------------------------|
| 1) Labor | h    | 1.96                        | Safa and Tabatabaeerfar [24]   |
| 2) Machinery |      |                              |                                 |
| Tractor 50 hp | kg  | 109.00                      | Pimentel [25]                  |
| Petrol engine, 5hp | kg  | 109.00                      | Pimentel [25]                  |
| High-pressure sprayer | kg  | 109.00                      | Pimentel [25]                  |
| 3) Fertilizer |      |                              |                                 |
| Nitrogen (N) | kg  | 61.53                       | Pimentel and Patzek [6]        |
| Phosphorus (P₂O₅) | kg  | 12.56                       | Pimentel and Patzek [6]        |
| Potassium (K₂O) | kg  | 6.70                        | Pimentel and Patzek [6]        |
| 4) Chemical |      |                              |                                 |
| Hydrated lime | kg  | 1.17                        | Pimentel and Patzek [6]        |
| Micronutrient* | kg  | 20.90                       | Anon [26]                      |
| Ethrel | kg  | 255.00                      | Anon [26]                      |
| Paraquat | kg  | 459.00                      | Anon [26]                      |
| Glyphosate | kg  | 453.00                      | Anon [26]                      |
| 5) Fuel |      |                              |                                 |
| Diesel | L   | 56.31                       | Safa and Tabatabaeerfar [24]   |
| Petrol | L   | 46.30                       | Safa and Tabatabaeerfar [24]   |
| 6) Suckers | kg  | 1.90                        | Ricaud [27]                    |
| Output |      |                              |                                 |
| Fruits | kg  | 1.90                        | Singh and Mittal [28]          |

Lastly, energy was classified into direct and indirect inputs, and renewable and non-renewable sources. In categorizing the direct and indirect energy inputs, therefore, agrochemicals, fertilizer, seeds and machinery was categorized as direct energy inputs, while human labor and fuel as indirect energy inputs. In grouping renewable and non-renewable energy sources, hence, fuel, fertilizer, agrochemicals and machinery were grouped into non-renewable energy, whereas human labor and seeds as renewable energy.
3. Results and Discussion

3.1. Energy consumption for field operations

Total energy consumption for field operations in rubber cultivation in the study areas was 16080.86 MJ/ha as shown in Table 2. Fertilizing consumed 10602.65 MJ/ha of energy, or billed for 65.93% of total energy was the largest portion of energy consumption in rubber cultivation. It followed by planting of 2559.34 MJ/ha (15.92%), weeding of 1552.84 MJ/ha (9.66%), harvesting of 647.38 MJ/ha (4.03%), land preparation of 632.37 MJ/ha (3.93%), spraying hormone of 70.67 MJ/ha (0.44%), tapping of 9.24 MJ/ha (0.06%), and pruning of 6.37 MJ/ha (0.04%). Energy expenditure in fertilizing operation came from the computation of energy of fertilizers, labor, tractor and fuel. Energy consumption in planting operation was originated from the sum of energy of planting material (seeds), labor, tractor and fuel. Energy spent for weeding operation was a summation of the energy of labor along with hand-held tools and equipment used. In the areas of immature rubber, weeding was performed manually using a hoe to pull the weeds. The operation was laborious and spent a lot of time to complete the operation because the distances in between rows are very narrow as the rubber cultivation in the study area implemented operation was carried out by a worker using knapsack sprayer to deliver herbicides for eradicating the weeds. Energy for collecting latex and land preparation came from the sum of energy of labor, tractor and fuel. Energy for spraying hormone was obtained from the total amount of energy of labor, chemical and equipment used, meanwhile energy for tapping and pruning operations were computed from the energy of labor only since the operation is done manually.

Table 2. Distribution of energy consumption on field operation basis

| Field operation       | Energy (MJ/ha) | Percentage (%) | Rank |
|-----------------------|----------------|----------------|------|
| Fertilizing           | 10602.65       | 65.93          | 1    |
| Planting              | 2559.34        | 15.92          | 2    |
| Weeding               | 1552.84        | 9.66           | 3    |
| Collecting latex      | 647.38         | 4.03           | 4    |
| Land preparation      | 632.37         | 3.93           | 5    |
| Spraying hormone      | 70.67          | 0.44           | 6    |
| Tapping               | 9.24           | 0.06           | 7    |
| Pruning               | 6.37           | 0.04           | 8    |
| Total                 | 16080.86       | 100            |      |

3.2 Distribution of Energy Inputs Based On Energy Resources

The distribution of energy inputs in rubber cultivation on energy resources basis is shown in Table 3. The highest share of energy inputs equivalent was fertilizer usage amounting to 9957.27 MJ/ha, or 61.92% of the total equivalent energy in rubber cultivation. Huge consumption of energy inputs for fertilizer was due to the cultivation requires various types of fertilizers. The fertilizer used in the cultivation comprised of 123 kg of nitrogen, 123 kg of phosphorus, 98 kg of potassium and 28 kg of magnesium. Among the fertilizer components themselves, nitrogen consumed 7568.19 MJ/ha of energy input as the largest energy consumption, while the lowest was magnesium with consumption of 187.60 MJ/ha.

Fuel with energy inputs equivalent of 2449.49 MJ/ha (15.23%) was in the second largest energy consumption in rubber cultivation. This sequence are significantly followed by energy inputs for planting material or seeds with energy input equivalent of 1900 MJ/ha (11.82%), and chemical application of 1558.85 MJ/ha (9.65%). Human labor and machinery with energy input equivalent of 160.05 MJ/ha (0.93%) and 65.4 MJ/ha (0.40%), respectively, was considered as the lowest energy inputs.

Fuel energy input was considered as the second highest energy consumption due to the high mobility of the tractor that was used to assist transportation of other inputs for land preparation, planting, weeding, fertilizing operation, spraying hormone, tapping and collecting latex. Planting material or seed
also consumed huge energy input due to a large amount of seeds planted for supplying the planting material for the areas. A total of 4000 kg of seeds were planted in a hectare of rubber plantation in the study area. Such amount of seeds can be considered as a large amount of energy input among the largest inputs in rubber cultivation. For the chemical, glyphosate and ethrel contributed to equivalent energy of 1558.65 MJ/ha. Labor and machinery instigate were in the lowest energy inputs in the study as operations were done manually. Lack involvement of machinery along with the low energy equivalent for labor (1.09 MJ/ha) are believed become factors that contributed the lowest energy to these inputs.

3.3. Energy Use Efficiency
Concerning yield per hectare, the total energy output of latex from rubber cultivation was 7108.6 kg/ha. Such yield was produced by energy inputs equivalent to 16080.85 MJ (Table 3). Thus, the energy productivity shows that the amount of product from the return of energy inputs use was 0.44 MJ/kg, which means for production 0.44 kg of the yield of latex consumed energy 1 MJ. As shown in Table 3, the energy use efficiency in rubber cultivation was 0.83. The energy use efficiency was computed based on the ratio of energy output to energy inputs. The computed value was then referred to a definition energy use efficiency by the International Agency (2016), who mentions that something or activity that can be considered having more efficient energy use if it delivers more services for the same energy input, or gives same services for less energy input. With that reference, conclusively, the energy use efficiency of 0.83 in rubber cultivation in the study area was less efficient since the ratio is lesser than 1. The energy use efficiency in rubber cultivation was much lower than the energy efficiency use of other crops cultivations in Malaysia such as pineapple of 3.6 by Nazri and Pebrian [13] and rice of 8.86, excluding inputs for irrigation by Gevao et al. [17]. The energy use efficiency in rubber cultivation in Malaysia was also lower than that of the other similar tree crops production in Turkey such as apple (1.10), apricot (1.24 to 3.37), citrus orange (1.25), lemon(1.06) and mandarin fruits (1.17) reported by Nuray [29], Gezer et al. [30], Esengun et al. [31], and Ozkan [32]. Generally, these findings are inline with the statement by Schäfer [33], who said that the energy input for crop cultivation varies in a wide range depending on habitat, crop species and variety, the intensity of production, and employed tools and machinery.

3.4 Energy Use based on Direct, Indirect and Renewable, Non Renewable
Energy use was grouped based on direct and indirect and also renewable and non-renewable forms. Grouping energy forms by Nazri and Pebrian [13] was used to divide inputs. The direct energy was defined as the energy that produced physically in farms such as labor and fuel, meanwhile the indirect energy referred to energy that was developed outside of farm such like fertilizers, chemical and machinery. These inputs were obtained from manufacturers. Renewable energy includes labor and seeds, while fuel, chemical and machinery are non-renewable energy. The results of the computation of energy use based on direct, indirect and renewable, non-renewable energy are presented in Table 4. Indirect and non-renewable energy forms were dominantly used in rubber cultivation with portions of 84% and 87%, respectively. The results reflected that the rubber cultivation in Malaysian is still highly depending on off-farm energy and low-returns energy from the farm. The percentage of the direct energy of 16% in rubber cultivation was lower than the similar energy in pineapple cultivation, which accounted for 23.56% [13]. The share of 84% indirect energy of in rubber cultivation was bigger than that of 76.44% in pineapple cultivation by Nazri and Pebrian [13]. In relation to renewable energy, its portion in rubber cultivation was 13% or lower than that of the pineapple cultivation of 20.68%. In the context of non-renewable energy, the portion of 87% in rubber cultivation was also bigger than that of 79.32% in pineapple cultivation. The results reflected that the rubber cultivation in Malaysian is still highly depending on off-farm energy and low in returns energy from the farm.
Table 3. The distribution of energy inputs used in rubber cultivation

| Input            | Unit | Amount of input used per hectare | Energy equivalent (MJ/unit) | Energy equivalent (MJ/ha) | Percentage (%) |
|------------------|------|----------------------------------|----------------------------|---------------------------|----------------|
| Labor            | H    | 76.55                            | 150.05                     | 0.93                      |                |
| Land Preparation | h    | 1.86                             | 1.96                       | 3.65                      |                |
| Planting         | h    | 15.62                            | 30.62                      |                            |                |
| Pruning          | h    | 3.25                             | 6.37                       |                            |                |
| Weeding          | h    | 14.5/15.06                       | 57.94                      |                            |                |
| Fertilizing      | h    | 8.5                              | 16.66                      |                            |                |
| Spraying         | h    | 3.53                             | 6.92                       |                            |                |
| Hormone          | h    | 4.71                             | 9.23                       |                            |                |
| Tapping          | h    | 9.52                             | 18.66                      |                            |                |

Machinery
- Tractor 37.3 kW kg: 1792.8 kg, 109.00, 65.40%
- Knapsack sprayer 16 L kg: 7.2 kg, 255.00, 65.13%

Fertilizer
- Nitrogen(N) kg: 123 kg, 61.53, 7568.19
- Phosphorus kg: 123 kg, 6.70, 544.88
- (P2O5) kg: 98 kg, 6.70, 656.60
- Potassium(K2O) kg: 28 kg, 6.70, 187.60
- Magnesium kg: 3.55 kg, 1558.65, 61.92

Chemical
- Ethrel kg: 0.25 kg, 255.00, 63.75
- Glyphosate kg: 3.30 kg, 453.00, 1494.90

Fuel
- Diesel L: 43.50, 2449.49, 15.23

Seeds
- kg: 1000 kg, 1900, 11.82

Total energy inputs MJ/ha: 16080.86, 100

Output
- Yield of latex kg/ha: 7018.6 kg, 1.90, 13335.34

Energy use efficiency (energy output/inputs ratio): 0.83

Energy productivity MJ/kg: 0.44

Table 4. Energy use based on direct, indirect and renewable, non-renewable.

| Type of energy        | Energy equivalent (MJ/ha) | Percent (%) |
|-----------------------|---------------------------|-------------|
| Direct energy         | 2599.54                   | 16          |
| Indirect energy       | 13481.32                  | 84          |
| Renewable energy      | 2050.05                   | 13          |
| Non-renewable energy  | 14030.81                  | 87          |

4. Conclusion
This paper has successfully presented and analyzed the energy consumption in rubber cultivation in Malaysia through a case study. The computed energy use in rubber cultivation in the study area was 16080.86 MJ/ha. On the basis of operation, the findings of the study indicated that fertilizing consumed
the highest share of energy use in rubber cultivation, which account for 65.93% of total energy use. While the lowest consumption was in the pruning operation. This study found that the ratio of energy output/inputs the rubber cultivation was 0.83. Conclusively, the energy inputs used in the rubber plantations were less effective since the ratio is lower than 1. This ratio also showed that the rubber cultivation in Malaysian is still highly depending on off-farm energy and low in returns energy from the farm. Thus, technological improvements, which are able to save the energy use and produce energy on farm should be introduced in Malaysian rubber cultivations. Anyhow, it is certain that the study contributed to enrich the database of energy consumption for major crops in Malaysian agricultural sector.

Acknowledgment
The authors are very grateful to the Rubber Research Institute of Malaysia Mini Station in Jasin, Melaka and Lakai, Negeri Sembilan, Malaysia for providing the study area for this research project.

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