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Energy Consumption on Farm Automation: Case of Paddy Plantation

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ABSTRACT

Rice farming is one of the most energy-intensive production systems. Energy is becoming a critical factor that requires special attention to maintain efficiency. This study aimed to identify the introduction of automated systems and determine the energy consumption of automated systems in paddy plantations. The research covered Muda Agricultural Development Authority (MADA) areas, a major paddy planting area in Malaysia. Observations and interviews were conducted with selected farmers to obtain detailed data on energy consumption. The paddy planting process consists of nine steps: soil compatibility, condition of paddy fields, soil preparation, planting process, fertilisation, water management, pest control, harvest, and paddy handling. Nevertheless, as an automation system, drones were the only technology used in MADA areas (Region II). The harvesting process consumes the most energy during paddy planting, with an average value of 238.17 MJ, followed by the paddy handling process at 74.34 MJ. By using more powerful automation systems, farmers can reduce dependence on energy and increase yield efficiency. Greater engagement and impressive contributions are needed to enhance the yield and resilience of the agriculture sector.

1. Introduction

1.1 Paddy Plantation in Malaysia

Rice farming is one of the most important activities in Malaysia's agriculture sector, as the staple food of Malaysia is rice. Thailand and Vietnam are the world's largest rice exporters, while Indonesia, Malaysia, and the Philippines rely on imports to meet domestic demand [1]. About 510 million tonnes of milled rice were produced worldwide in 2022. Asian countries traditionally account for the largest share of the world's rice production. According to the latest official data, China became the world's top producer of rice in 2021, with over 212 million tonnes of production, followed by India and Bangladesh [2]. As part of the National Agriculture and Food Policy 2.0, the Malaysian government is committed to raising the income level of food producers and the National Rice Self-Sufficiency Ratio

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(SSL) from 63% to 75% by 2030 [3]. The agriculture sector suffers from uncertainty over farm ownership and tenure and labour shortages, leading to an increase in idle arable lands, low agricultural productivity and quality, low levels of automation and technology adoption, and high levels of suffering from agricultural instability. Until now, Malaysia lags behind major countries in food security measures [4]. Figure 1 shows the trend of Malaysia's paddy production from 1980 until 2019 [5] and the Malaysia-Japan-Thailand paddy yields [6]. The highest yield production was 4.255 t/ha. Nonetheless, the highest yield in Japan was up to 5.42 t/ha in 2008 [6]. Although the government implements various programmes and provides support and incentives every year, an analysis conducted by the ministry revealed that productivity is still satisfactory in both the granary and non-granary sectors [7].

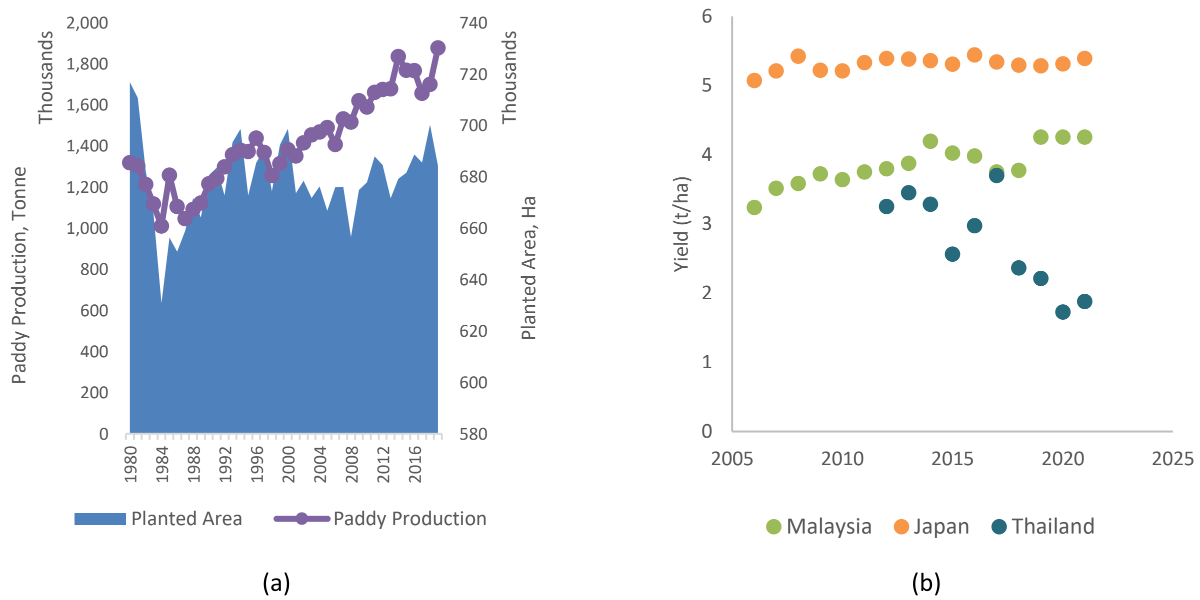


Fig. 1. (a) Malaysia's paddy production and planted areas, and (b) Malaysia-Japan-Thailand paddy yields

The Ministry of Agriculture (MOA), the Federal Land Consolidation and Rehabilitation Authority (FELCRA), the Department of Agriculture (DOA), the Malaysian Agricultural Research and Development Institute (MARDI) and the Farmers' Organisation Authority (FOA) of Malaysia to ensure implementation and compliance with the instructions of the farmers of rice production chains, with each authority playing a different role. Table 1 shows Malaysian stakeholders involved with paddy plantations. All parties concerned want to help develop paddy plantations in Malaysia and provide a stable income for farmers, in line with government policies, especially Malaysia's National Agriculture and Food Policy [8]. Academic institutions also play an important role in strengthening the paddy industry.

Table 1
Malaysian stakeholders involved with paddy plantation

Name	Logo	Details
Agrobank		Improve agricultural standards and provide sustainable support that creates value for communities, the economy, the environment, and stakeholders.
Bioeconomy Corporation		Responsible for implementing National Biotechnology Policy (NBP) goals, identifying value propositions in both R&D and commercial operations, and playing a role in supporting these efforts through financial support and development services.
Department of Agriculture (DOA)		Through advanced technology and agricultural regulatory services, DOA will provide agricultural entrepreneurs with high-quality and efficient services, improve production capacity, and ensure the security of the country's agriculture sector.
Farmers' Organisation Authority (FOA)		Strengthen the involvement of farmers' organisations in the domestic agriculture and food sectors to produce highly productive farmers.
Federal Agricultural Marketing Authority (FAMA)		Developing and facilitating efficient and effective marketing services to promote growth, competitiveness, and innovation in the agrofood industry and increase value to customers.
Integrated Agricultural Development Area (IADA)		Transforming the agrofood sector into a modern, dynamic, and competitive sector.
Kemubu Agricultural Development Authority (KADA)		Aiming to become a leading agency in rice and agricultural products for high-income earners.
Malaysian Agricultural Research and Development Institute (MARDI)		Selected as a company that provides innovative technologies to realise a sustainable and competitive agriculture industry by 2030.
Ministry of Agriculture and Agro-based Industry (MOA)		Assess, define, monitor, and implement policies, strategies, and programmes for agricultural development in the country.
Muda Agricultural Development Authority (MADA)		A national leader in the socio-economic development of the rice industry and MADA farmers.

1.2 Farm Automation

Applying new technologies, such as artificial intelligence, big data analytics, automation, drones, and robotics, to sustainable modern agricultural practices, supply chain management, or grassroots farming innovations can help improve crop productivity [4]. Agricultural automation is still in its early stages. According to McKinsey & Company's 2022 Global Farmer Insights survey, less than 5% of farmers in Asia, Europe, and the United States of America used next-generation technology [9]. Agricultural automation or mechanization helps farmers cut costs, increase efficiency, reduce environmental impact, and address labour shortages [10].

Agricultural automation in rice plantations comprises the use of drones, autonomous tractors, robotic harvesters, seeders, automated irrigation, field monitoring, and intelligent analytics [11]. Currently, commercialised vertical farming systems only reach Levels 2 and 3 (Level 2: integrated monitoring and control; Level 3: including growing technologies). Teo and Yun [12] stated that technologies are developed to increase the effectiveness and automation of vertical farming systems. Among these technologies are unmanned aerial vehicles (UAVs), also known as drones. Many agricultural applications are using UAV technology, such as AeroVironment, X-Copter, VIPtero, Fieldcopter and senseFly eBee. UAV standards and operational guidelines in Malaysia are not yet well established; however, the DOA office has published minimum safety requirements. Unless duly approved by the DOA Secretariat, the weight of equipment shall not exceed 2 kg of the total weight. This regulation is rather for public safety and has no guidelines for agricultural practices [13]. Table 2 displays the industry players related to drone technology in Malaysia registered under DOA [14].

Table 2
List of industry players related to drone technology in Malaysia

No.	Company Name	Address
1	Sanyeong Agricultural Solutions Sdn. Bhd.	Lot 2973, Batu 8 3/4, Jalan Datuk Kumbar, Kampung Padang, Mukim Tajar, 06500 Langgar, Kedah.
2	FWF World Solutions Sdn. Bhd.	No. 28, Persiaran Bukit Setiawangsa, Taman Setiawangsa, 54200 Kuala Lumpur, Wilayah Persekutuan Kuala Lumpur
3	Spatial Synergy Consultant Sdn. Bhd.	No. 1-11, Suite 47, Sentral Business Suites@Kompleks Sentral Point, Jalan TKS 1, 43000 Kajang, Selangor.
4	Jurupro Sdn. Bhd.	B-09-11 Perdana Selatan, Taman Serdang Perdana, 43300 Seri Kembangan, Selangor.
5	Arinaa Kambyan Berhad	NuSentral, 201, Jalan Tun Sambanthan, Brickfields, 50470 Wilayah Persekutuan Kuala Lumpur.
6	MATA Aerotech Sdn. Bhd.	C-G-11 Coplace 1, 2270 Jalan Usahawan 2, 63000 Cyberjaya, Selangor.
7	Aerodyne Systems Sdn. Bhd.	Persiaran Cyber Point Selatan, Cyber 8, 63000 Cyberjaya, Selangor.

1.3 Energy Consumption

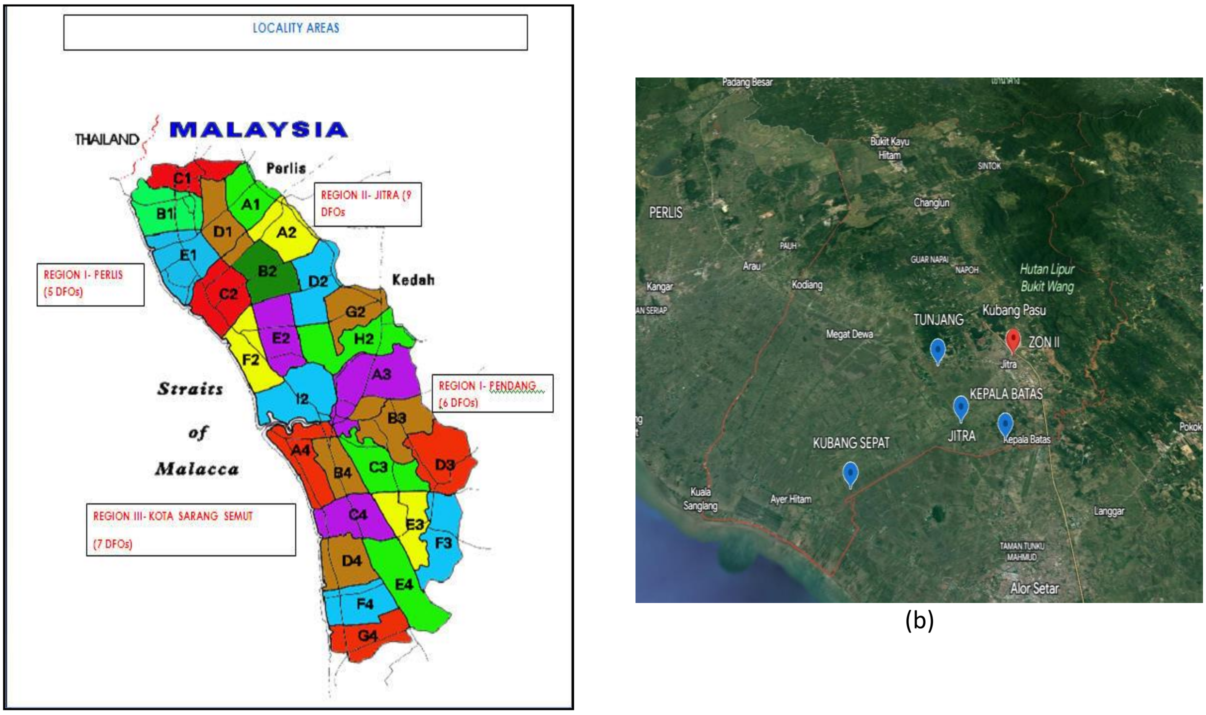
Energy use in agriculture has evolved in response to population growth, limited arable land supplies, and the desire for higher living standards [15]. Recently, population growth has increased energy consumption in agriculture, leading to the exhaustive usage of pesticides, fertilisers, electricity, agricultural machinery, and natural resources to secure the demand [16]. The total energy use ranges from 9,257 MJ/ha in India to 31,703 MJ/ha in China [17]. Meanwhile, a study conducted in Iran obtained an input energy consumption of up to 89,835.3 MJ ha^{-1} [18]. Due to different settings of system boundaries, the calculated amount of energy input varies from study to study.

Efficient usage of energy in agriculture is one of the key aspects of sustainable agriculture development [19]. Energy consumption is a key constraint for the agriculture sector to maximise its potential for increased yields, lower costs, and lower emissions. The aims of this study are to

i. identify the implementation of the automation system in paddy plantations
ii. determine the energy consumption of the automation system.

2. Methodology

This study was conducted to determine the energy consumption in paddy plantations, specifically in MADA areas. The primary data were collected through in-depth interviews with MADA officers, experienced farmers, and lorry drivers and from informal discussions. Figure 2 shows the map of MADA areas and a Google Map of the case study. The MADA areas cover up to 22682 ha and are divided into four regions. Region I covers Perlis, Region II at Jitra, Region III at Pendang, and Region IV at Kota Sarang Semut. In Region II, there are nine subzones, including Kodiang, Sanglang, Kerpan, Tunjang, Kubang Sepat, Jerlun, Jitra, Kepala Batas, and Kuala Sungai [20]. A field study on energy usage in paddy plantations was conducted in Region II – D-II (Tunjang), E-II (Kubang Sepat), G-II (Jitra), and H-II (Kepala Batas).



(a) (b)

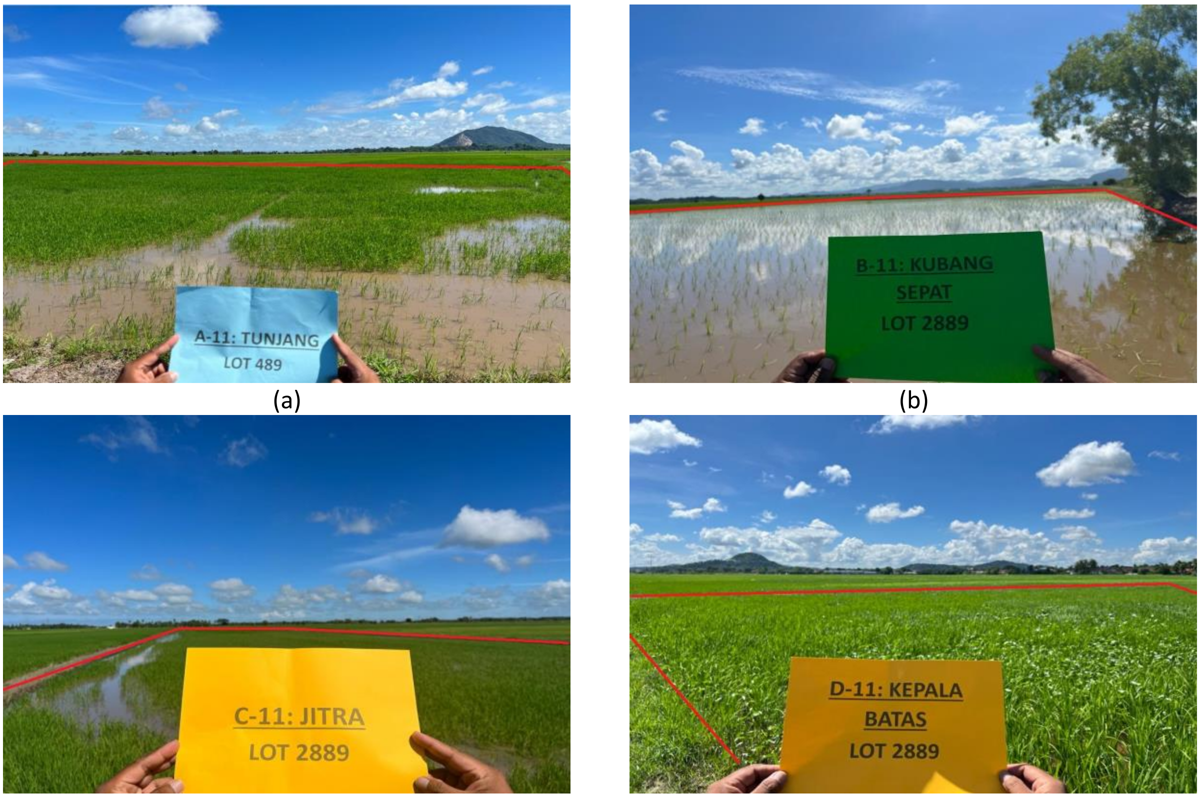
Fig. 2. (a) Map of MADA areas and (b) Google Map of the case study

Table 3 indicates the demographic details of the respondents involved in the study. All respondents were successful paddy farmers in Region II [20].

Table 3
Demographic details of respondents involved in the study

Respondent		Lot Number	Area (ha)	Age	Experience
A	Tunjang	489	0.1873	49	29
B	Kubang Sepat	2889	2.2542	39	9
C	Jitra	2143	0.1897	45	15
D	Kepala Batas	-	1.4389	70	50

Figure 3 presents the actual photo of each paddy field involved in this study. Interviews were held in December 2022, and observations were done from October 2022 to March 2023.



(a) (b) (c) (d)

Fig. 3. Photo for each paddy field involved in this study

2.1 Estimation Energy Consumption

The process of paddy plantation follows the rice check or guideline provided by MADA. Figure 4 indicates a summary of rice check from MADA.

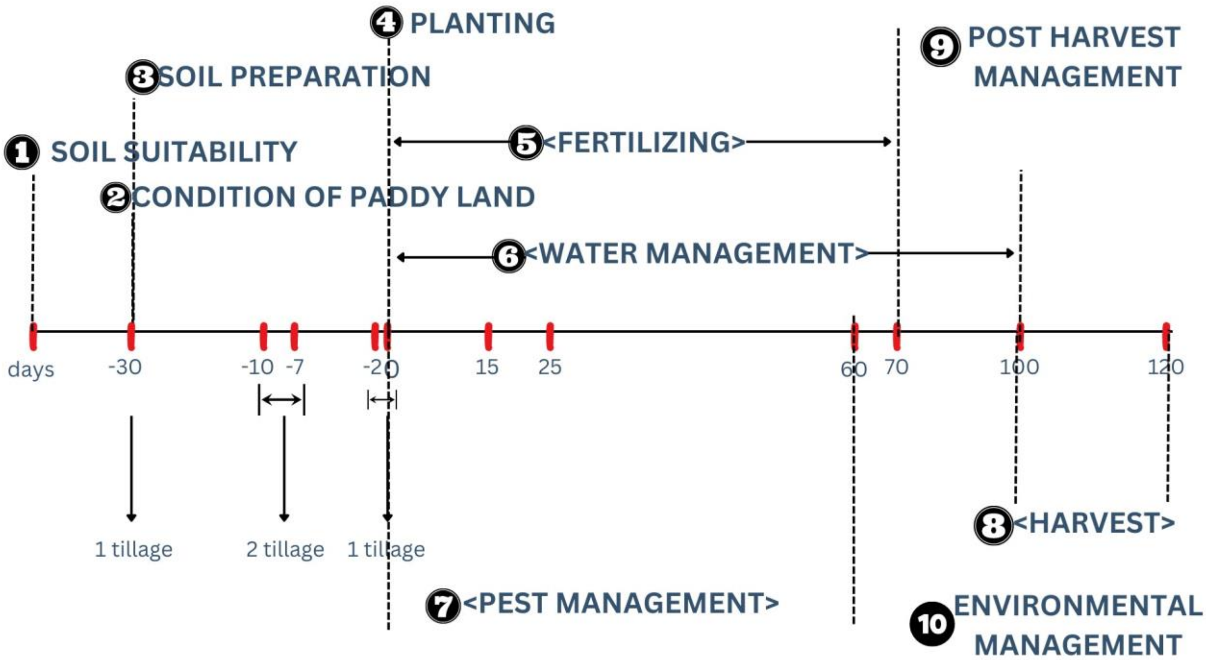


Fig. 4. Summary of rice check

2.1.1 Soil preparation

Soil preparation is performed by doing the tillage process. Tillage in paddy plantation refers to the preparation of land for rice seeds, destroying existing weeds, and stimulating the germination of weed seeds in the top soil layer. In this conventional era, farmers use tractors for the tillage process.

$$ME_T = C_{Ft} * W_t / F_C * L_t \tag{1}$$

Eq. (1) calculated the energy consumption in this operation. Where C_{Ft} is the conversion factor for the tractor, 93.61MJ/ha; W_t is the tractor weight, 2,510 kg; *Fc* is the fuel consumption (l); and *Lt* is the life of the tractor. In this study, farmers used rubber-wheeled and steel half-tracked tractors for tillage operation. Figure 5 shows the difference between the rubber-wheeled and steel half-tracked tractors.

(a) (b)

Fig. 5. (a) Rubber-wheeled and (b) Steel half-tracked tractors

2.1.2 Planting process

Rice planting can basically be carried out in two ways

i. No tillage – Directly dispersing pre-germinated rice seeds onto the field manually, using a low seeder, or by spraying with a drone
ii. Transplanting – Transplanting 25- to 35-day-old seedlings into the main field by hand or mechanical transplanters using seedlings sown in trays.

Machine rice planting takes less time and effort than manual rice planting and increases the daily applied area per person from 700 m^2 to 10,000 m^2 [21]. The machine is equipped with a 1.7 hp petrol engine. The weight is a little less than 60–70 kg. The distance between the rows is 30 cm, whereas the distance between plants is 13–18 cm. The mechanical efficiency is 0.6 ha per day at a speed of 2.0 km/h.

2.1.3 Fertilisation and pest management

The management of fertilisation aims to produce quality paddy plantations. Therefore, it needs to follow the schedule, quantity, and time. The fertilising process occurs four times per season. All respondents applied drones for fertilising and pest management control. According to [22], the energy consumption for paddy plantation is 0.05 MJ/km. Although MADA provides guidelines and checklists for farmers, each paddy field has its own characteristics and benefits. The respondents decided to carry out pest control according to the conditions of their paddy fields. Table 4 shows the number of fertilisers and pest control interventions for each respondent.

Table 4
Number of fertilisers and pest control management for each respondent

Parameter	Respondent A	Respondent B	Respondent C	Respondent D
Fertilisers	4	3	3	3
Weed Control	4	2	2	1
Pest Control	8	3	4	4

2.1.4 Harvesting

Harvesting operation was done using New Holland Clayson 1545 combine harvester. Table 5 indicates the detailed specification of the combine harvester used in the study area.

Table 5
Detailed specification of combine harvester

Parameter	Detailed specification
Brand	New Holland
Model	1545
Power	96 kW
Engine fuel tank	250 L
Width of cylinder threshing mechanism	127.5 m
Maximum speed	21.4 km/h

Meanwhile, Figure 6 shows the combine harvester machine during the harvesting operation.


(a)


(b)

Fig. 6. (a),(b) Harvester machine during harvesting operation

In the harvesting process, the Total Energy Input (TEI) is calculated using Eq. (2). *ME* refers to machinery energy (MJ), *FE* is fuel energy (MJ), and *HE* indicates human energy.

$$TEI = ME + FE + HE \tag{2}$$

Eq. (2) to Eq. (7) calculated the total energy input for the harvesting process, where C_F is the conversion factor, 62.7 MJ/kg [23]. *W* is the weight of the machinery (kg) and *L* is the useful life of the machinery (h). *Fc* is the effective field capacity (ha/h), *A* is the area of the paddy field, and *t* is the total operating time (h).

$$ME_H = C_{Fh} * W_h / F_{Ch} * L_h \quad (3)$$

$$F_C = A/t \quad (4)$$

Eq. (5) was used to compute fuel energy (FE).

$$FE = (A/t) \times (100/F_S * CW * 36) \quad (5)$$

$$F_s = D_R/t \quad (6)$$

where F_S is the average forward speed (ms^{-1}), *CW* is the cutting width (m), *A* is the total harvested area (ha), and *t* is the total working time (h). D_R refers to the distance in one row and *t* is the time taken. Human energy (HE) was calculated using Eq. (7).

$$HE = \tau * T * H_C/A \quad (7)$$

where τ is the number of workers, *T* is the duration of operation in hour, H_C refers to the energy conversion coefficient for human labour, and *A* indicates the total area harvested (ha). The detailed input data are listed in Table 6.

Table 6
Input data in this study

Parameter	Input Data
Number of workers, τ	2
Energy conversion coefficient for human labour, H_C	0.75 MJ/ha [24]
Weight of machinery, W	7,500 kg
Useful life of machinery, L	3,000 h [17]

2.1.5 Water management

The demand for rice is expected to reach approximately 533 million tonnes of milled rice in 2030. Rice is known as a crop that consumes a large amount of water. Paddy productivity has become a serious problem, and alternative irrigation water supplies are being sought [25]. (Hassan, Zawawi, & Jaeman). In Asia alone, irrigated rice uses up to 150 billion cubic metres of water. Therefore, producing more rice with less water is a major challenge, as water is the most important raw material for rice production [26]. The average water consumption over the last five years was 2,600 m^3/t [26], while the rice production recorded was 5,127 kg/ha.

2.1.6 Paddy handling

The transportation of paddy from the paddy fields to mills is by using lorries with 4–6 tonnes. Assume the energy intensity for short-distance road transport is equal to 1,362 KJ/t [27]. Table 7 indicates the summary of each paddy process with the data source.

Table 7
Summary of each paddy process with data source

Process	Subsystem	Data source
Soil preparation	Tillage operation	Interview selected farmers from Region II (D-II, E-II, G-II, and H-II) - MADA directory.
Planting process		Selected farmers from Region II (D-II, E-II, G-II, and H-II). Literature [28].
Fertilising	Drone operation	Selected farmers from Region II (D-II, EII, GII, and HII). Service providers: DJI Agriculture and Aonic (formerly Poladrone).
Pest management	Drone operation	
Harvesting		Selected farmers from Region II (D-II, E-II, G-II, and H-II) - MADA directory.
Paddy handling	Transportation	Selected farmers from Region II (D-II, E-II, G-II, and H-II). Data from questionnaire to selected paddy lorry drivers in Region II (MADA Paddy Purchase Centre).

3. Results and Discussion

In Malaysia, the paddy plantation process involves nine steps. Figure 7 illustrates the paddy plantation process employed in this study. Nonetheless, MARDI also provided a similar rice check standard as a guideline for farmers to follow to achieve 10 t/ha [29]. Until 2021, the average paddy yield in Malaysia was 4,255 t/ha [5]. Based on the feedback from the interviews, the first and second stages of the rice fields are currently evaluated by visual characteristics and their experience without the involvement of any technology. No technology component is used to access and fulfil the best condition for both processes. Even though there is abundant research regarding this precision technology in paddy plantations, farmers still face constraints due to the high cost of a large-scale implementation. This finding is similar to the result from a previous survey [30], whereby MADA, KADA, and Project Barat Laut Selangor (PBLS) rice farmers did not actively adopt precision farming techniques in their farming practices due to cost constraints. Nonetheless, there are concerns about the expected rising costs of any technology application [31].

Fig. 7. Paddy plantation process

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Figure 8 shows the checklist suggestion for the paddy plantation process. The paddy checklist is adapted from MADA. The process considered in this study directly followed this process. Figure 8 indicates the mapping paddy plantation process with farm automation. All processes should be connected to the farm automation system for full application of the system. Nevertheless, in 2013, as part of a large-scale agricultural research project in Japan, research into the introduction of fully robotic farming, from tillage to harvest, had already been carried out [32]. In 2020, MARDI opened new opportunities in rice farming by developing the MyPadiManager mobile app. Unfortunately, this only helped 200 farmers to manage their rice crops more efficiently and systematically [33]**.** This number only contributed about 0.1% of the total paddy farmers in Malaysia with the data in 2018 [34].

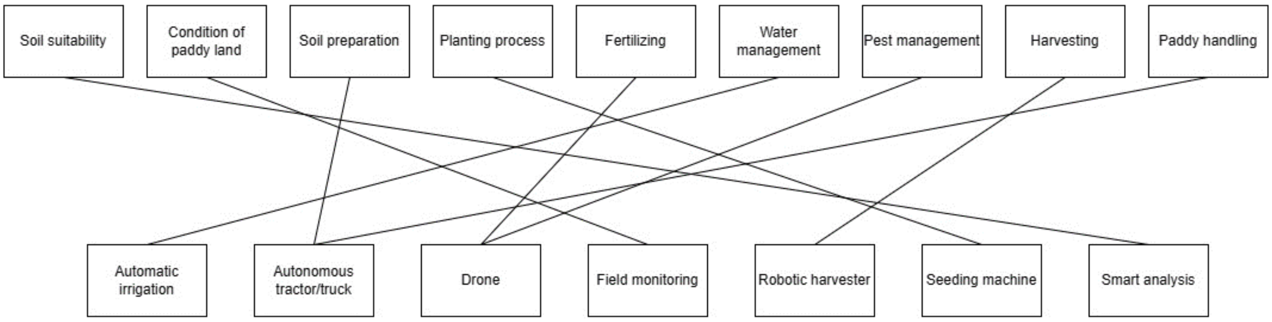

Fig. 8. Mapping paddy plantation process with farm automation

Based on the interviews and observations in the MADA areas, the current farm automation system is illustrated as below (Figure 9). Only drones were applied in the MADA area of Region II (D-II, E-II, G-II, and H-II). Even though the fertilising and pest management processes were linked with drone technology, only 66.7% of the respondents in the MADA area of Region II consumed drones for these processes. The outcome of this study was based on the feedback from the interview sessions with the respondents. In penetrating the automation system for the entire paddy plantation process in MADA areas, full commitment among stakeholders, the government, and farmers should be included. Figure 9 presents the mapping of the paddy plantation process with the current farm automation practice.

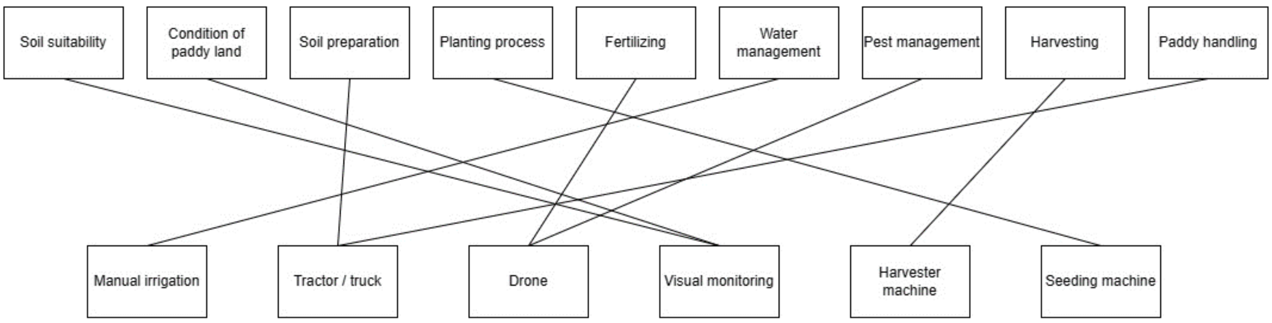

Fig. 9. Mapping paddy plantation process with the current farm automation practice

3.1 Machinery Inventory and Energy Consumption Performance Analysis

Farmers in the study area used two-wheel drive (2WD) tractors of different models with power ratings between 55–70 kW in performing the tillage operation. The tillage operation aims to prepare the seedbed for rice seeds, destroy previous seeds, and stimulate the soil condition. Tillage work is recommended by MADA to be carried out three times: 30 days, 7 days, and 1–2 days before planting. Unfortunately, in this study, one of the respondents had to plough up to four times because flooding had affected the fields. Figure 10 below shows the soil condition before and after the tillage operation.

Land preparation before tillage operation

Soil condition after tillage operation

Fig. 10. Soil condition before and after tillage operation

All respondents in this survey used drones for fertilisation and pest control. The frequency of pest control varied accordingly [35]. Due to an illness outbreak at that point in time, they were unable to follow the checklist provided by MADA. However, the fertilising process was performed as recommended.

The energy consumption for the current practice is indicated in Figure 11. The harvesting process consumed the most energy during paddy planting, with an average value of 238.17 MJ, followed by the paddy handling process, with 74.34 MJ. Harvesting was the most critical process contributing to postharvest losses [36]. Compared to other studies, this study focused solely on automation and machinery when calculating energy consumption, resulting in lower energy consumption results.

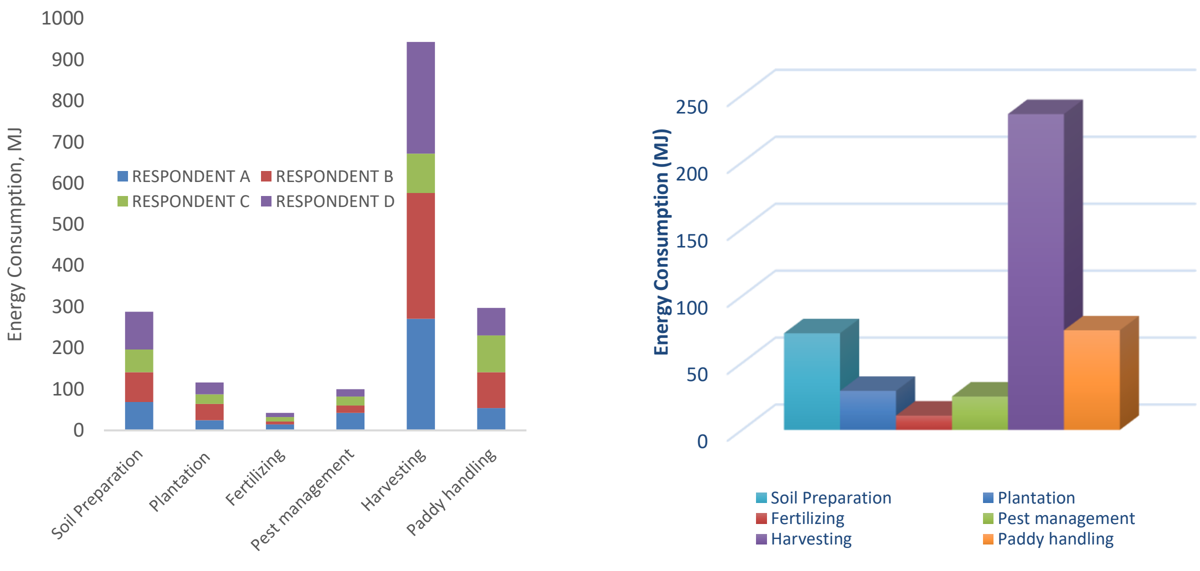

Fig. 11. Energy consumption for (a) each respondent and (b) the average value of the paddy plantation process

Figure 12 shows the percentage of energy consumption for each respondent. Respondent C had the highest rice handling work due to the long distance from the paddy field to the rice mill. This respondent sold paddy to a factory that was 12.4 km from the paddy field. It was approximately 1.5 km from the paddy field to the nearest rice mill. The lack of best practices in the paddy handling process when choosing the rice mills led to increased energy consumption. The interviewees relied entirely on the lorry drivers to select the right factory. Respondent B used a mechanical transplanter for the planting process, which consumed 39.01 MJ of energy. Others employed paddy sprayers that consumed about 23.9 MJ to 28.68 MJ energy.

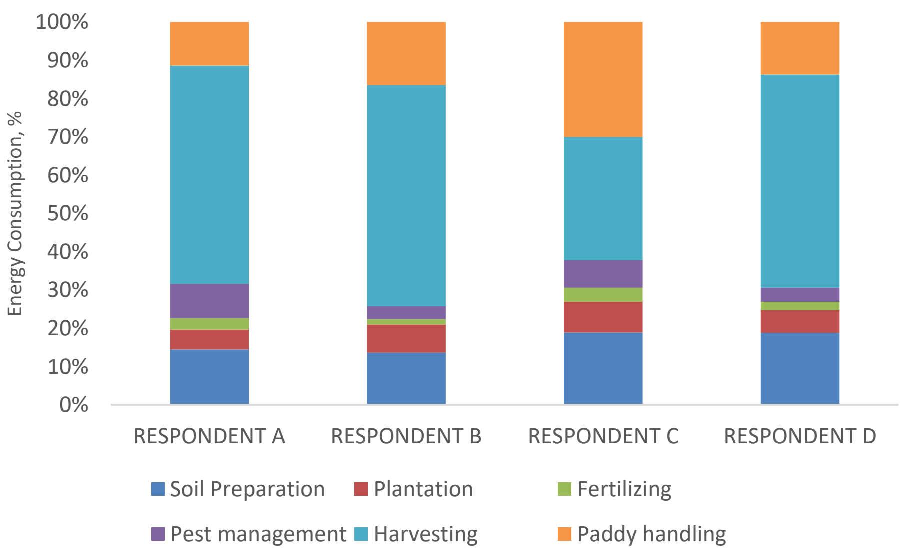

Fig. 12. The percentage of energy consumption for each respondent

Figure 13 indicates the relationships between the total energy consumption (TEC), the paddy output, and the area. Respondent C performed the best at 0.018 t/MJ due to less energy consumption in the harvesting process. The minimum value was 0.014 t/MJ. Mechanical harvesters accounted for the largest share, about 54.32% of the total paddy planting process, while drones only consumed 8.2%. Machinery energy was the highest contribution element in the harvesting process, whereby the parameters contributing to this increment were the physical size of the machine and the driver's performance. The best performance for speed, as suggested by [36], was 3.87km/h. Respondent A had the best performance in terms of rice yield area ratio with 6.95 t/ha.

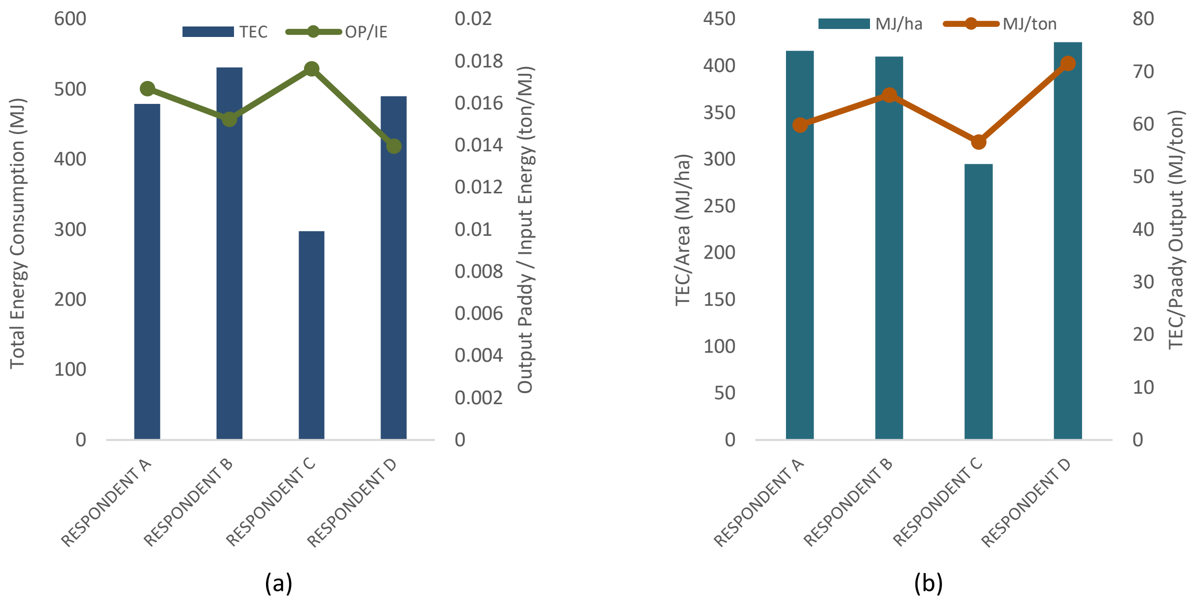

Fig. 13. The relationship between the (a) total energy consumption and paddy output and (b) TEC and the area

Figure 14 illustrates the blocks of each energy consumption element. The average amount for TEC was 449.43 MJ. In this study, pump equipment was only applied once for the paddy plantation process.

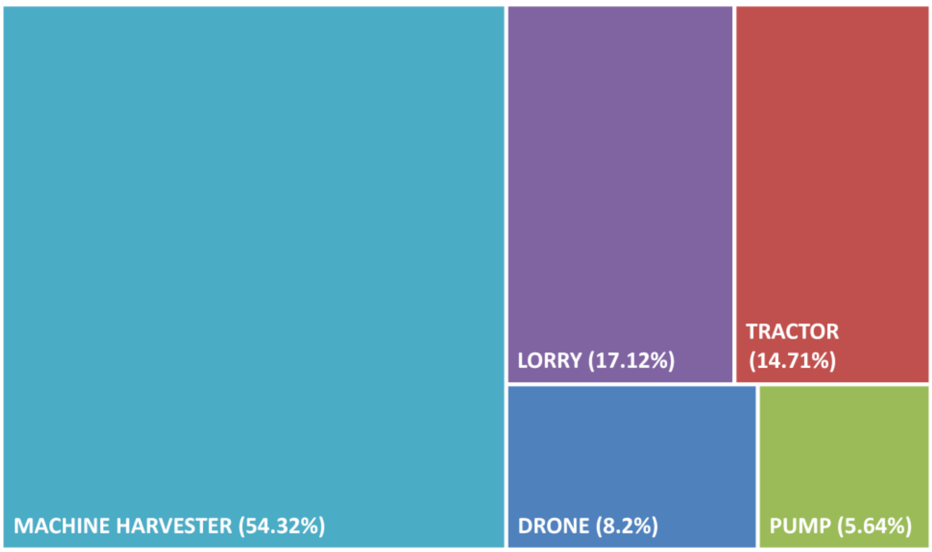

Fig. 14. Block for each energy consumption components

4. Conclusions

In Malaysia, the paddy plantation process involves nine steps: soil suitability, condition of paddy land, soil preparation, planting process, fertilisation, water management, pest management, harvesting, and paddy handling. Nevertheless, drones were the only automation system technology applied in the MADA area of Region II. The harvesting process consumed the most energy during paddy planting, with an average value of 238.17 MJ, followed by the paddy handling process, with 74.34 MJ. The overall drone energy consumption contributed about 13%.

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