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Assessment of Electric Farm Vehicle as Motive Power for Oil Palm Mechanisation Operation in Malaysia

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Abstract
A comparative study on suitability of electric farm vehicle deployment in oil palm mechanisation operations was carried out. Two research methodologies were pursued, the assessment of battery's state of charge and the load carrying test. The test was conducted in a 70-ha actual oil palm planted area with mild undulating topography and inland type soil. The first results of the test suggested that the farm electric vehicle is suitable to be deployed for the field maintenance activity as compared to the fresh fruit bunch and loose fruit evacuation activity. The second methodologies indicated that the electric vehicle could reduce up to 48% of energy as compared to a common sizeable internal combustion engine vehicle in oil palm plantation operation. In term of the environment, it was anticipated that a saving of almost 5.2 tonnes of $CO_{2\text{-}eq}$ per year could be realised from the electric vehicle deployment for farm maintenance activity in Malaysia. Besides environmental benefits, the electric vehicle also incurs lower purchase and maintaining cost compared to the common utility type diesel engine vehicle. The benefit obtained shows that the electric vehicle could reduce dependency on fossil fuel energy for a sustainable agriculture development in Malaysia.

Keywords: Electric Vehicle, Oil Palm Mechanisation, Energy, Sustainable Development

Introduction

Farm mechanization is important due to the scarcity of labours in the oil palm plantation industry (Azwan *et al.*, 2016). Besides that, various other factors militate in favour of the shift to mechanization as a way to increase labour productivity in oil palm plantation (Mohd Ramdhan and Abd Rahim, 2014) The quantity of produce harvested by unit area and all other related services can be increased by improving the timeliness of operations and the efficiency on tasks' execution, thus improving the overall productivity. Mechanization appears to be the most suitable alternative to the intensive use of manpower despite its cost and the need for equipment and machinery, with an attractive long-term return to investment, along with the additional values from the alternative cropping system or livestock integration.

Malaysian oil palm cultivation areas had reached 5.6 million hectares in 2014 of which only 60% of the total is suitable for mechanisation, mainly due to topographic limitations (Jelani *et al.*, 2008; Hashim *et al.*, 2014). Thus, more than 3 million hectares of cultivated areas with oil palm are suitable for mechanization and requires engineering of the most appropriate and efficient schemes and technologies. Furthermore, even with only 3 million hectares mechanised land, a reduction of 33% to 46% of manpower could still be achieved (Abd Rahim, Mohd Ramdhan and Mohd Solah, 2011).

Oil palm farm machinery is typically powered by diesel fuel since the powertrain could provide higher torque compared to a gasoline engine. Besides, the ease of storage within the field office and its high evaporative temperature make it more favourable for farm application since a nearby filling station will ensure steady operation. However, one of the disadvantages of relying on diesel fuel consumption is the GHG emissions.

Oil palm plantation industries in Malaysia consume approximately 200 million litres of diesel fuel annually mainly for the farm machinery consumption (Ludin *et al.*, 2014). This consumption will soon increase because of efforts to improve worker productivities. Oil palm plantation industries will require more diesel to fuel their machinery if the current scenario prolongs. An increase in petroleum fuel consumption definitely will lead to a rise in GHG emissions.

One of the technologies that have been extensively researched is the electric farm vehicle as a prime mover for the field operations. There are several benefits that could be obtained from economic and ecological perspectives. The electric motor drive is far more efficient compared to the combustion engines and emits less GHG to the atmosphere. This technology appears to be more suitable and efficient for sustainable development of agriculture. Furthermore, some other known advantages of the electric vehicle's utilisation are ascertained. Thus, there is no need for maintenance of the vehicle power plant such as replacing worn and torn parts of the systems or lubricating of components. The vehicle will not run idle or set in an unused condition, thus reducing energy requirement.

Many farm duties would not require large amounts of power, and it could be undertaken by an electric vehicle, making the industry more self-sufficient. The electric vehicles have proven its efficacy in other industries such as the aircraft maintenance industry, and food and beverage handling industry. The system could easily deliver works such as pulling 1 to 5 tonnes of weight from one point to another point. Renewable source of energy such as photovoltaic system and wind turbine could provide power to charge the battery packs. The application could benefit sustainable development in any economic sectors for energy self-reliance in their operations.

An electric vehicle as motive power for oil palm mechanisation practice could reduce the diesel fuel utilisation in the oil palm field activity. However, capability analysis of the electric vehicle application in oil palm mechanisation and an energy density comparison with a comparable size of an internal combustion engine vehicle could further justify the benefit. Thus, this study is aim to provide scientific justification of an electric vehicle application in oil palm plantation operation and a comparative assessment of suitable farm duty for an electric vehicle deployment.

Materials and methods

The research was conducted in an oil palm plantation area with mild undulating topography and mineral type soil in Malaysia. About 70 ha of the plantation area was allocated for this study. The electric vehicle (EV) used for this study was a battery powered electric off-road buggy which is widely available and commonly used for the recreational activity.

There were two main research methods undertaken to measure the capability of an EV as a motive power for oil palm plantation operation. The two tests were the state of charge comparison and load carrying tests. A simple economic analysis is also incorporated for further justification.

State of Charge Comparison

The core question investigated within the state of the charge comparison methodology was the following: what are the suitable farm activities for deployment of an EV as one of the mechanisation fleets for oil palm plantation operation? Thus, a few real simulation tests were conducted in the field by measuring the state of charge (SoC) of the battery, which was one of the indicators that could be used for comparison purposes. The SoC is dimensionless, and this indicator mimics the function of fuel gauge indicator and always shows the percentage level of the battery. This voltage method is the fastest measurement technique to determine energy used from a battery (Nanaki and Koroneos, 2013). The aim of the state of charge comparison test was to analyse farm activities suitable for the EV based on the SoC comparison.

The SoC can be measured by five techniques such as chemical, voltage, current integration, Kalman filtering and pressure method (Doerffel and Sharkh, 2006). This study utilised battery voltage method to determine the SoC by installing the gauge to the EV's battery pack of 48 V in total. However, the battery temperature significantly affected the SoC reading. Thus, SoC reading was more accurate after a few minutes the EV had stopped.

The EV's operators recorded the SoC before the work started and after the work completed. The EV was required to be charged once a day after its usage. If the battery was depleted or the SoC indicated a low percentage, the EV was expected to stop working and put for charging event if the farm activity was not completed for a designated area. Thus, the SoC of the battery for each day of the test, machine daily coverage area and productivity of the farm work was recorded so that comparisons of each farm-work tested could be analysed and a statistical software was used in this study to evaluate the comparison.

Among the typical farm works in oil palm plantation are fresh fruit bunch (FFB) evacuation, loose fruit collection and herbicide spraying operation. These works were simulated in this test using the EV and conducted according to the test procedure elaborated below rather than the actual farm operation manner. The tests were replicated for a few days each at the selected area in the farm.

The first activity, FFB evacuation, required two workers. One worker was as a machine operator, and another was as FFB loader. Their task was to evacuate the FFB from the palm-based to the designated roadside platform in an area of 10 ha per day. It was an equivalent to almost 2 to 3 blocks of test area (about 3 ha in average per block). The machine must be fully charged before the daily activity conducted.

The collection of loose fruit was undertaken to gather the fruits scattered around the palm trunk. The loose fruits were detached from the main bunches during the harvesting process. The loose fruits had higher oil extraction rate than the main bunch and a proper care should be given to their collection to avoid opportunity lost. Normally, the loose fruits collection is carried out together with the FFB evacuation. However, in this test, they were conducted separately. During the test, the loose fruits were required to be filled into the EV's trailer bin before they were inserted into a few gunny bags to ease the external transportation to the mill and as productivity indicator in the test too. In this study, 10 ha of the area per day were assigned for the operators and replicated for five days.

Weedicide operation was conducted to remove unwanted weeds especially within the circle palm base to ensure ease of FFB and loose fruits picking, conducted by applying the chemical herbicide mix to the targeted palm-based area using the spraying equipment attached to the EV, which was equipped with a 200 L water tank, a 12 V electric pump and its auxiliaries. A power sprayer is more effective than a manual knapsack sprayer in the particular area, especially in flat and undulated areas, thus reducing the number of workers required.

The circle spraying activity (herbicide sprayed around the palm-based) was conducted in this test at the designated area within the farm. There were two spraying nozzles connected to a low-pressure pump operated by two sprayer operators. In this test, a 12 V 'Shurflo" pump was powered by a portable generator set. However, the generator set could be replaced by a dedicated battery or from the EV's battery pack through a step-down transformer. However, the test was conducted to estimates the SoC level for the EV as a motive power for this activity and not included to power other application. The area covered for the daily test was made consistent throughout the 5-days replication process.

The Load Carrying Test

For the second methodology in this technical evaluation, a load carrying test was conducted to determine the energy and power consumption of the EV. To compare, the load test was also made with a commercial ten horsepower; three-wheeler diesel type utility machine that is commonly available and also known as mechanical buffalo (MB).

The weight carrying test was undertaken to simulate the energy consumed by the EV and MB based on weight carried at certain distance and area. Known loads of 250 kg, 300 kg and 350 kg had been placed in the trailer bin for both EV and MB as variables in the test, thus reflecting the energy requirement for the electric vehicle and the internal combustion engine (ICE) vehicle to undertake the similar task for comparison.

The voltage method aimed to determine the state of charge of the battery and to predict the remaining capacity of a battery. Meanwhile, techniques for predicting the remaining capacity of a battery discharged were based on Peukert's Law (Doerffel and Sharkh, 2006). The law expresses the capacity of a battery in terms of the rate of discharge. The Peukert's law is written as in Equation 1.

$$\mathbf{C_p = I^k t} \qquad \text{………………} \quad \textbf{(Eqn. 1)}$$

Where,

C_p is the capacity at a one-ampere discharge rate, which must be expressed in A·h.

I is the actual discharge current relative to 1 ampere, which is then dimensionless.

t is the actual time to discharge the battery, which must be expressed in h.

k is the Peukert constant

The law expresses the capacity of the battery remaining as it discharges at a certain rate of current over a certain period of time (Doerffel and Sharkh, 2006). However, it was hard to predict the remaining capacity of a battery pack while the EV was moving since the loads varied over the driving pattern and road conditions. Thus, the solution was made by measuring the energy required to charge the battery pack to its initial state for every time it was used at a constant current value.

This concept enabled the prediction or measurement of the energy consumption for an EV during the charging period. The energy for charging is equivalent to the energy consumption during its working time. a similar concept to determine the energy requirement based on the voltage method where a constant load of battery charging process could be measured.

Fuel consumption for the MB had been measured with a conventional method by gauging the fuel level in the fuel tank before and after each test. Diesel fuel was set at a certain height in the fuel tank before the trial started. Once each of the replication completed, the amount of diesel fuel to be refilled in a temporary reservoir were measured before it was poured into the tank. The amount of fuel that was refilled indicated the amount of fuel consumed (F_c) in the test for each replication. Even though the measurement error was high, but this technique had been suggested by Grisso (Grisso, Kocher and Vaughan, 2004) in predicting the fuel utilisation for their study. The energy density (E_a) was obtained by dividing the fuel usage (F_c) with the area (A) covered by the machine as depicted in Equation 2.

$$\mathbf{E_a = F_c / A} \qquad \text{………………} \quad \text{(Eqn. 2)}$$

Results and discussion

State of Charge Comparison

The results of this study are given in Figure 1 which indicates the depth of discharge (DoD) of the battery, obtained by subtracting initial SoC level with the final SoC level for each day the test was performed. An analysis of variant was performed by using the Minitab software to analyse the comparison between all of the data obtained. It was found that the probability value is greater than 5% (P>0.05), which rejected the initial hypothesis of all means are equals. Thus, the means of the data are significantly different except for the loose fruit collection and herbicide spraying, as they indicate low energy consumed in the allocated field especially for the loose fruit collection activity. It was a strong evidence, on average, the FFB evacuation was consuming higher energy as compared to other simulated activities.

The result of this study was consistent with previous findings that stated lighter EV consumed less energy and has a higher working range compared to the heavier EV (Abdelhamid, Singh and Haque, 2015). The study measured the range extension technology for a few types of EV with a different mass in the United States which indicates that a lighter type EV could be extended up to 50% of distance compared to heavier type EV, thus reflecting that a similar EV with a different load weight could consume a different level of energy.

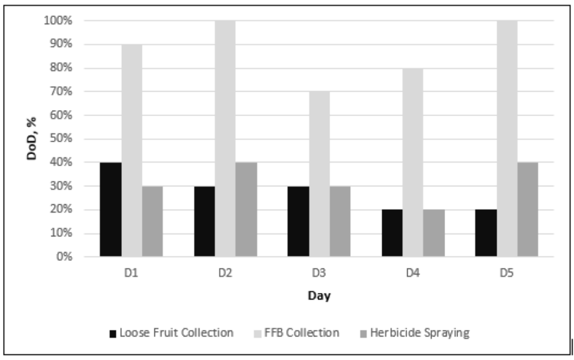

Figure 1: Comparison of depth of discharge for the EV's battery pack after each application or activities

The EV was also observed to have the similar capability with diesel machine in performing routine light duties. Besides that, the EV has excellent manoeuvrability and minimum daily maintenance requirements. These characteristics is beneficial to the user.

The EV is not practical for FFB evacuation since it needs to carry FFB from palm to palm at each palm rows until a designated roadside platform. In the test area, each row has at least 20 to 30 palms. If each palm bears 20 to30 kg of FFB, thus the EV needs to carry almost 300 to 400 kg of FFB in each trip, which is a high energy requirement. During the test, the EV could only work from morning to afternoon before the power depleted, and therefore could not complete its daily tasks efficiently. FFB that were not evacuated would cause a penalty to the workers since free fatty acid accumulation in the FFB would reduce its quality.

An electric vehicle (EV) is suitable to undertake load haul, and utility task since power requirement for those jobs are low and work even better in partial load condition (Cignini *et al.*, 2015). Distance covered by a 48V, 200 Ah EV usually in the range of 80 - 90 km. A mean agriculture road density in oil palm plantation is about 40 m per hectare, and for 1,000 ha of farming land, road length is about 40 km (Abd Rahim, Mohd Ramdhan and Mohd Solah, 2011). For herbicide spraying practice, coverage for a unit of typical machine used in plantation is about 10 hectare per day (Pebrian *et al.*, 2012) or less than 15 km a day of distance travels in the mechanisation paths if the planting distance is about 9 m (Soon, 2011). Thus, this total distance could be covered by an EV as a prime mover for the herbicide spraying activity.

The Load Carrying Test

An electric vehicle (EV) as a motive power for agriculture could reduce the diesel fuel consumption, and it had been investigated in term of its technical and economic point of views (Redpath *et al.*, 2011), which found that the EV utilised 80% of the energy obtained from any source of power to the wheel, meanwhile only 18% of the diesel fuel energy transmitted to the flywheel for tractors (Mousazadeh *et al.*, 2009).

The energy consumed by an EV varied based on certain conditions such as the weight of the load carried, topography, soil type, driving pattern and event climatic condition. Therefore, this study was carried out to investigate the energy consumed by the EV as a prime mover in the oil palm plantation. Energy to charge the battery pack for the EV was obtained from the national electricity grid and had been measured using a digital ammeter that was connected to the main charger.

Figure 2 shows the results of both trials, the EV and the Mechanical Buffalo (MB) for each replication and at the selected study site marked with area A, B, C, D and E. The energy consumption pattern of the MB or the internal combustion engine vehicle (ICEV) was almost consistent for all the test replications, with only slight differences, perhaps due to the ICEV carrying the load below its optimum carrying load of 500 kg. Thus, the energy was wasted for ICEV if it does not carry the optimal load. The previous study by Dyer & Desjardin (2003) had concluded that the fuel use per unit of work by ICEV rose significantly once the load was below about 60–70% of its maximum capacity. It was contradicted on the EV where the energy consumption reflected much on the weight carried.

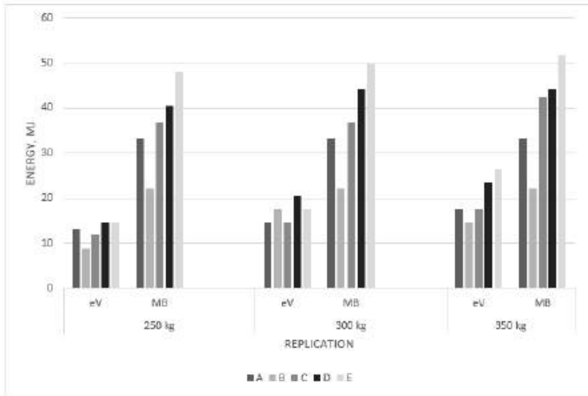

Figure 2: Energy consumption for the EV and internal combustion engine vehicle for the load carrying test.

Figure 3 summarises the cumulative energy for the EV and the ICEV to complete the task. Weights of 250 kg, 300 kg and 350 kg were the load or replication of the test that the machines carried into the paths at the test site area of A, B, C, D and E. Analysis of varians was conducted for the data obtained. It was assumed that all the data means for both sets of trial, EV and MB were different and with equal variances. The P-Value obtained for both sets of data were less than 5% significat levels. Thus, the alternative hypothesis indicated that at least one mean of difference is acceptable. Thus, it is strongly agreed that the two set of means are differed for EV and MB.

It was also found that the EV utilized lower energy if it hauled the load weight lower than 200 kg compared to carrying the load more than 300 kg. It was reflected that the EV was more efficient under partial load conditions. As a contrast, the ICEV had utilized almost equivalent energy for all the test replications. This analysis was in agreement with the previous finding (Dyer and Desjardins, 2003) on the ICEV, which concluded that energy was not utilized efficiently in ICEV for the weight of the load lower than its optimal requirement of power.

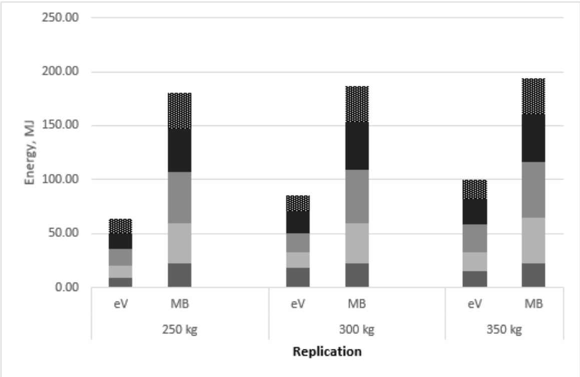

Figure 3: Cumulative energy consumption on the load carrying test.

Table 1 shows a simple analysis of energy density in terms of energy per distance travel of the EV and ICEV calculated based on Equations 2. The average distance per area was used to obtain the energy density. The distance was logged based on the distance meter attached to one of the machines. The result obtained shows that the energy density requirement for the EV was between 0.50 to 0.80 Wh/m. Meanwhile, the energy density for the ICEV was between 1.44 to 1.54 Wh/m. The result also indicated that difference in energy density requirement for both the EV and the ICEV was between 32% to 48% where the higher the load carried, the difference was reduced.

The result obtained in Table 1 was also consistent with Abdelhamid (2016) on the energy density for the EV and ICEV, that reported the energy consumed by a few US mid-sized EV was between 0.05 Wh/m and 0.22 Wh/m. A study conducted in the UK for their Brighton to London Future Car Challenge (BLFCC) estimated that the energy density for the EV was 0.17 Wh/m and that for ICEV was 0.47 Wh/ (Howey *et al.*, 2011). However, both studies by Abdelhamid (2016) and Howey (2011) measured the energy density for the EV and ICEV that drove on the asphalt road conditions.

This study indicates that the EV could reduce diesel consumption up to 0.3 L/ha (from the ICEV consumption) based on energy reduction between 30% and 50% which has been found throughout the test, in which ICEV consumed about 0.8 to 1 L/ha. The saving in terms of diesel fuel consumption reduction based on the total area covered by oil palm plantation area in Malaysia of 5.6 million ha is almost 1.68 million L, which makes up to a saving of almost 5.2 tonnes of $CO_{2\text{-eq}}$ based on GHG emission factor of 3.1 kg $CO_{2\text{-eq}}$ per L of diesel (Nikander, 2008).

Based on the experience of utilising the EV for oil palm plantation activities, maintenance was only carried out on the batteries for a cost estimated to less than RM 50 per year (Azwan *et al.*, 2017). It was also anticipated that the total cost of purchasing and operating the EV for five years including its maintenance is approximately RM 28,000. The comparison of owning and maintaining cost with the three-wheel utility type vehicles is shown in Table 2. It was found that the owning and maintenance cost is almost similar in between the EV and the commonly used three-wheeled type utility farm vehicle but the EV could provide the lowest operational cost for herbicide spraying activity in oil palm plantation. It was anticipated that the operational cost of the EV for the operation was in between RM 3 and RM 7 cheaper compared to the manual knapsack practice and a dedicated 20 horsepower herbicide spraying vehicle (Azwan *et al.*, 2017).

Table 1: Analysis of the energy density based on the load carrying test.

Loads	250 kg		300 kg		350 kg	
AREA - SIZE (ha)	**EV (Wh / ha)**	**MB (Wh / ha)**	**EV (Wh / ha)**	**MB (Wh / ha)**	**EV (Wh / ha)**	**MB (Wh / ha)**
A - 17 ha	222.19	558.12	246.88	558.12	296.25	558.12
B - 9 ha	285.04	716.01	570.09	716.01	475.07	716.01
C - 11 ha	293.32	921.01	366.66	921.01	439.99	1059.16
D - 16 ha	248.83	687.56	348.37	750.06	398.13	750.06
E - 14 ha	292.96	956.65	351.55	993.44	527.32	1030.23
Average (Wh/ha)	268.47	767.87	376.71	787.73	427.35	822.72
Average (Wh/m)	0.50	1.44	0.71	1.48	0.80	1.54
Difference (%)	**48%**		**35%**		**32%**	

Table 2: Comparison of owning and maintaining cost

	Electric Vehicle	**Three-Wheel ICEV**
Capital cost	RM 28,000	RM 22,000
5 years maintenance cost	Negligible	RM 8,000*
Total	RM 28,000	RM 30,000

*Input provided by a local supplier.

Conclusions

The electric vehicle for a motive power in the oil palm plantation operation could provide numerous benefits in terms of economic and environment. The study established that a few low power requirement operations could be undertaken by the electric vehicle to replace a diesel combustion vehicle such as a three-wheeled 10 horsepower utility vehicle, commonly used in oil palm plantations. The benefit is that a reduction of the energy density of up to 48% could be achieved in utilising the EV.

The study also found that inefficient energy utilisation occurred for the under-utilised diesel engine vehicle with a specific horsepower for certain low power requirement activities in oil palm plantation operations. A minimum load should be recommended for a diesel engine vehicle to avoid inefficient fuel utilisation. Thus, more energy efficient utilisation could be promoted in the sector.

In terms of economic, it was established that the EV ensures low cost of maintenance which is a very important aspect in operating a vehicle especially for agriculture operations. The study compared the preventive maintenance cost between a small utility vehicle and the EV. If bigger utility vehicle or a medium size tractor were to be compared, then more saving in terms of preventive maintenance could be realised from the EV utilisation. Therefore, based on the economic and environmental gained in utilisation the EV in oil palm plantation operations, more energy efficient practices should be emphasised to promote a sustainable development goal for the industry.

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