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Characterising Off-Road EV Tractors for Agricultural Adoption: A Narative Review

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ABSTRACT

The current study investigates the technological changes in the automotive industry, especially electric vehicles (EVs) that have emerged as the latest trend since the environmental crisis, diminishing gasoline resources, and the requirement for higher work efficiency. The EV adoption remains novel in the Malaysian agricultural sector, although the adoption is beneficial, especially to oil palm plantations. Nonetheless, the adoption poses a significant challenge to farmers and government link companies (GLC) in uncertain economic conditions. Therefore, the present qualitative study aims to identify EV characteristics that contribute to the adoption of ideal EV tractors in the agricultural sector, which allows the tractors to be efficiently operated, managed, and repaired. Resultantly, four primary factors were identified and analysed after interviewing six stakeholders to obtain insights into the perspectives, certainty, and validity of the intended factors. The findings demonstrated significant advantages of EV towing and cargo capacity, off-road capability, and comfort and safety features. Comparatively, cost, maintenance, spare parts, and repairs were significant barriers to encouraging EV adoption. Hence, investments in maintenance infrastructure and technician training are crucial following the complexity of EV systems and operations to achieve long-term technological savings and environmental benefits.

Keywords: EV, harvest, agricultural, tractors, palm oil

INTRODUCTION

Overview of Electric Vehicles (EVs) Research

Academic attention has significantly increased for electric vehicle (EV) research as EV can potentially transform different sectors by increasing energy efficiency while decreasing negative environmental impacts. Santos et al. (2021), Sechel & Mariasiu (2021) and Ramanath (2024) emphasized that battery technological advancements, higher awareness of climate change, and supportive public policies also encourage the transition from internal combustion engines (ICE) to electric powertrains. Prior scholars examined several primary EV areas in terms of economic contributions, incorporation into existing infrastructures, environmental impacts, and technological advancements (Kumar et al., 2023; Gnanavendan et al., 2024). Previous research on EV has traditionally focused on several core areas. Specifically, previous academicians determined the cost-effectiveness of EV compared to ICE vehicles, such as maintenance expenses, upfront costs, and fuel savings (Roy et al., 2022; Abas & Tan, 2024). Moreover, Smith et al. (2021) and Waseem et al. (2023) asserted that battery technological development and improvement, including lithium-ion and solid-state batteries, was also appraised to elevate battery life and energy density at a lower price. Suravi (2021) also

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persisted that the reduction rate in greenhouse gas emissions and pollutants shifting from ICE to EV was recorded. Summarily, past research demonstrated several benefits of EV adoption.

The adoption of EV should account for practical economic viability (Kumar & Alok, 2020). The EV infrastructure, namely grid integration and charging stations, is a prerequisite for higher usage (Barman et al., 2023; Alrubaie et al., 2023). The EV were introduced in the early 20th century with limited adoption owing to technological constraints and higher usage of ICE vehicles. Nonetheless, an expansion in EV technologies, including battery technology, and higher environmental concerns in the late 20th and early 21st centuries led to a transition towards EV, with more energy-efficient and commercially viable EV models being launched. Accordingly, Aldhanhani et al. (2024) maintained that EV have emerged as the most popular trend in the automotive industry contributed by significant advancements in constant connectivity, autonomous driving, and smart grid integration. The current market focus is on increasing market penetration, enhancing performance, and promoting higher EV adoption in different industries and sectors (Cao et al., 2021).

Industrial EV Adoption

The benefits of higher energy efficiency and positive environmental impacts contribute to higher industrial EV adoption:

i. Electric tractors and different agricultural machinery are introduced to fulfil farming requirements, including higher efficacy with lower emissions (Malik & Kohli, 2020; Mocera et al., 2023).

ii. Electric forklifts and utility vehicles with lower emissions and operating expenses are increasingly common in industrial settings and warehouses (Haghi et al., 2020; Beltrami et al., 2021).

iii. Significant improvements are observed in personal and public transportation, such as buses, passenger cars, and delivery vehicles (Das & Bhat, 2022).

The higher efficiency owing to the instantaneous torque of EV aids in elevating operational performance and efficiency in agricultural off-road environments compared to ICE models. Simultaneously, greenhouse gas emissions and air pollution can be reduced. Beligoj et al. (2022) also established that lower fuel and maintenance expenditures could motivate higher off-road EV adoption in the agricultural sectors. Table 1 shows the common differences found between the EV and the ICE vehicles. The EV tractor could produce similar benefits considering its ideal and inventive design.

Table 1: EV and ICE comparisons

EV Tractor	ICE Tractor
Reduces noise pollution	High noise pollution
0% CO_2 emission	CO_2 emission
Electricity as energy input	Fossil fuel as energy input
Delivers higher torque and energy to the wheels	Greater torque and energy losses to the wheels
Reduce 50% operating cost	High operating cost
Able to control operation remotely and digitally	Manually controlled operation
Price (new) > RM50k (depend on specifications, various brands)	Price (new) > RM300k (locally made)

Source: Unanimous

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Off-Road EV Attributes for Oil Palm Plantation Usage

According to Gorjian et al. (2021), the strenuous circumstances of oil palm plantations when transporting heavy loads and travelling rough terrains can be effectively resolved by EV tractors for higher operational performance. Komatsu, John Deere, AGCO, and Kubota, are EV tractor models specifically developed for large-scale oil palm plantations to provide robust towing and cargo capacities and versatility in different usage scenarios. Other EV tractors could also assist in decreasing operating and maintenance expenses due to the absence of a fuel system and fewer mechanical parts (Scolaro et al., 2021), apart from reducing palm oil harvesting machinery emissions. Nonetheless, Asadi et al. (2022) opined that EV adoption in the Malaysia remains low. The GLC needs further inputs of reliable EV design characteristics. For agricultural sector, it may be required to effectively navigate the operational land terrain and surface (Gowtham Rajan & Prasad, 2020).

As shown in Figure 1, the Malaysian Palm Oil Green Conservation Foundation (MPOGCF) estimated that oil palm plantations in Malaysia cover an area of 5.9 million hectares, with Sarawak and Sabah having the largest oil palm plantations at 1.6 million hectares and 1.5 million hectares, respectively. This makes the country the second largest exporter of palm oil in the world by 30%. By 2023, Malaysia's oil palm plantation expansion has reached 6.5 million hectares through the exploration of new plantations and replanting activities. This initiative is encouraged by research into palm oil productivity and quality conducted through breeding, the use of fertilizers and the implementation of modern machinery (tractors).

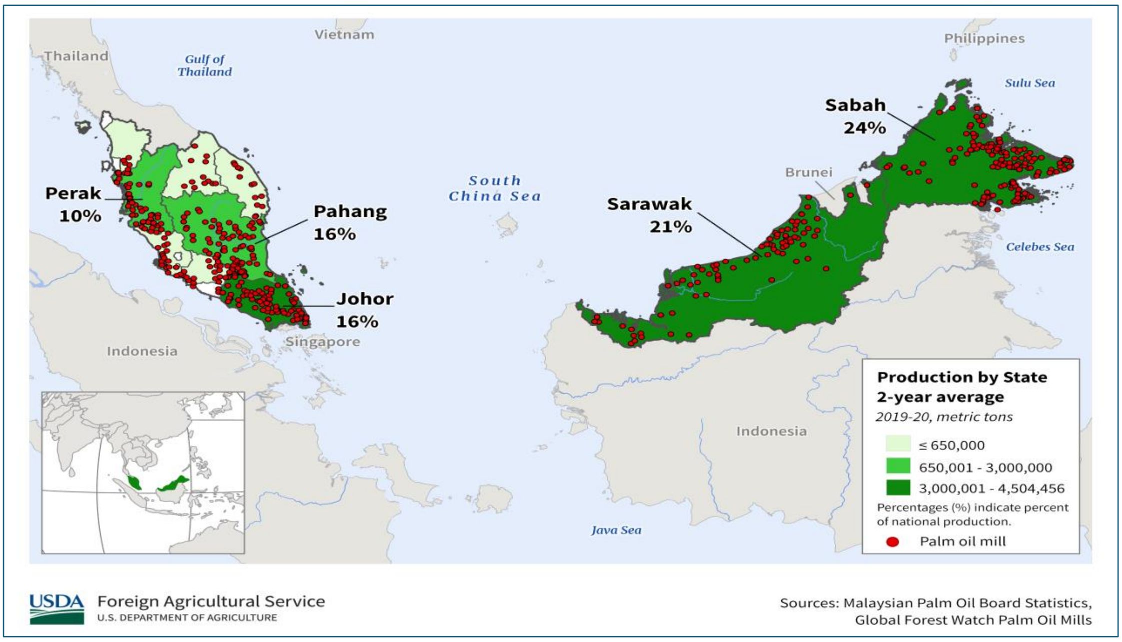

Figure 1: Malaysia palm oil plantation and production (Source: MPOGCF)

A few visits conducted at two biggest oil palm plantations in Malaysia situated in Johor Bahru (organization D), Jempol (organization E), and Jasin (Organization F) allowed the researchers to interview the management and observe the existing conditions of the terrain and conventional tractors at the oil palm plantations. The subsequent visit and guidance from a government agency on oil palm industry research (organization G) in Bangi and a system consultant (organization H) in Wangsa Maju also corroborated the demands and actions required to increase palm oil productivity.

In summarizing, a mixed collection of primary factors contributing to machinery suitability and requirements in the farming process were pinpointed. First, Un-Noor et al. (2022) and Chen et al. (2022) signified that substantial towing and cargo capacity must be achieved and involved a multifaceted approach encompassing vehicle construction (Renius, 2020; Bavendiek et al., 2020), battery technological advancements (Malik & Kohli, 2020; Gorjian et al., 2021), electric motor design (Baek et al., 2022; Rossi et al., 2021; Un-Noor et al., 2022), and charging infrastructure (Malik & Kohli, 2020; Gorjian et al., 2021). Next, reliable off-road capabilities of EV tractors demand high-capacity batteries (Rout et al., 2022; Goodenough et al., 2024),

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powerful electric motors (Beltrami et al., 2021; Husain, 2021), robust vehicle designs (Masrur, 2020; Un-Noor et al., 2022; Ghasemi et al., 2024), specialised tyres (Wong, 2022; Yin et al., 2023; Andersen, 2024), and efficient charging solutions (Mohamed et al., 2020; Smith et al., 2020; Un-Noor et al., 2022) to satisfy the requirements of various applications. Apart from that, safety and comfort features ought to fulfil ergonomic standards such as climate controls (Lajunen et al., 2020; Bubb, 2021), noise reduction (Beltrami et al., 2021; Bubb, 2021), automated safety controls (Taleb-Bendiab, 2020; Schockenhoffet al., 2020), enhanced visibility (Căseriu & Blaga, 2023), and collision avoidance (Ahangarnejad et at., 2021; Aledhari et al., 2023) can also reduce accidents while improving operating comfort (Breetz et al., 2018; Goodall, 2021; Thomas et al., 2019). Nevertheless, specialised repair and maintenance knowledge, training and tools are imperative to ensure long-term EV tractor usage (Smith et al., 2020). Notwithstanding, long-term fuel savings and decreased downtime can offset the high initial investment.

Research Objectives

This study seeks to ascertain the determinants and barriers to EV tractor adoption at Malaysian oil palm plantations by thoroughly assessing the key EV tractor characteristics.

LITERATURE REVIEW

To avoid inefficiencies, the quality of EV tractor should be durable enough to meet the towing and cargo capacity of the oil palm products. Existing literature suggests that its components system, functionality and features must have the capabilities to ensure the off-road operations can be smoothly conducted. Simultaneously, comfort and safety impact user satisfaction and operational performance, whereas repair and maintenance challenges will determine the perceived overall cost-effectiveness.

EV Towing and Cargo Capacity

Towing and cargo capabilities are essential to efficiently transport heavy loads and perform heavy duty tasks by agricultural tractors (Shamshiri, 2024; Un-Noor, 2022; Husain, 2021). This is because compared to ICE, the EV electric motor uses zero fuel but provides instant torque in addition to being supplied with battery storage technology which apparently increases the duration of its operation. However, the weight of the battery itself will somewhat reduce the load carrying capacity for the EV tractor. Scolaro et al. (2021) reaffirmed that the ability of an electric tractor to carry or tow heavy loads is critical and this ability is the main measure of its performance in agriculture. Past studies prove that the ability to tow loads for EV tractors is comparable to conventional tractors for certain work situations. Therefore, electric tractors can be safely used based on their design specifications to efficiently perform certain tasks not only in the agricultural sector, but also in the construction, transportation, and manufacturing sectors.

Heavy loads can be efficaciously transported by EV tractors with adequate structural support, technologically advanced materials, and optimised load distribution that provides high stability and durability (Beltrami et al., 2021). Enhanced aerodynamics and suspension systems also ensure more efficient load management. Concurrently, high-strength steel and lightweight composites protect structural integrity by decreasing the EV tractor weight.

Contemporary lithium-ion chemistries and solid-state batteries provide higher energy densities and more efficient thermal management, which are imperative for significant towing and cargo abilities. Solid-state batteries also increase EV tractor safety and longevity when transporting heavy loads. Fast charging systems and the wide availability of high-power charging stations support high-current levels while minimising downtime to ensure that EV tractors can be swiftly sent for services after performing heavy-duty tasks. Wireless charging technologies are also currently being experimented with to ensure convenient EV tractor usage commercially and agriculturally in the future.

Moreda et al. (2016) recognized that electric power and torque are pivotal to the towing and cargo capability as a high torque can efficiently transport heavy loads. Enhanced drivetrain systems with regenerative braking and torque management, such as high-efficiency permanent magnet synchronous motors (PMSMs), lead to higher overall efficiency and performance.

EV Off-Road Capabilities

EV tractors should be capable of travelling on uneven off-road road surfaces at rugged farmlands and construction sites to efficiently perform tasks (Johansson, 2022; Husain, 2021, Liu et al., 2020). Tyre and battery technologies, such as more efficient thermal management, can ensure EV tractors perform under demanding and diverse settings via improved higher power delivery, suspension systems, battery durability, and ground clearance, traction control. The instantaneous torque and regenerative braking features of EV tractors allow higher traction and stability on rough off-road surfaces. Moreover, Çolak & Irmak (2023) and McNulty et al. (2022) asserted that high-energy-density lithium-ion and solid-state batteries ensure longer travelled distances and operational hours with elevated reliability without frequent downtime under harsh environments.

Higher ground clearance, high-strength steel, advanced composite materials, reinforced suspensions, durable undercarriages, improved drivetrains, enhanced cooling systems, and larger battery storage are necessary for off-road conditions. High-efficiency permanent magnet synchronous motors (PMSM) ensure stable and manoeuvrable navigation on steep slopes and the transportation of heavy loads via optimised power delivery to all wheels. All EV tractors are increasingly equipped with specialised tyres with improved tread materials and patterns for optimal grip, stability, durability, and traction control on uneven terrains, which prevents slippage when navigating through gravel, mud, and rocky surfaces (Gogoi, 2022).

In addition, Prasetya (2024) and Pathrose (2022) established that the Autonomous Driving and Advanced Driver Assistance Systems (ADAS) and autonomous driving can improve EV off-road capabilities via terrain mapping, automated obstacle detection, and adaptive cruise control for efficient and safe operations in challenging conditions environments, which provides additional support for operators by automating certain tasks and increasing overall control.

Safety and Comfort Features

Safety and comfort are vital to operational safety and user experience as robust safety features decrease risks associated with operating heavy machinery while a safe and comfortable working environment improves productivity with decreased fatigue.

Safety Features

Prasetya (2024), Husain (2021), and Liu et al. (2020) perceived that EV tractor performance and conditions are constantly monitored to identify potential mechanical issues or low battery levels, which assists in reducing breakdowns by ensuring adequate maintenance. Technicians could also remotely check and resolve potential faults. Lane-keep assist, proximity sensors, collision avoidance, automated braking, and adaptive cruise control are several ADAS features that ensure safe operations (Mehta et al., 2023). Rollover protection structures (ROPS) protect operators from a rollover or collision and enclosed cabins with reinforced structures and safety harnesses reduce injury. Emergency shut-off and fire suppression systems assist in mitigating the negative impacts of accidents. The Advanced Traction Control and Electronic Stability Control (ESC) Systems features provide high stability on uneven or slippery off-road surfaces by efficiently distributing power to all wheels via corrective measures, which reduces the skidding risk and subsequently losing control of the vehicle (Kumar, 2021; Shetty, 2018).

Comfort Features

Customisation also allows tractor operators to adjust performance parameters, such as power delivery and speed, based on personal preferences or specific tasks (Jensen et al., 2024). Intuitive controls, climate control, vibration reduction, adjustable seating, and noise insulation features ensure quieter, smoother, and more comfortable operations. Enhanced visibility via advanced camera systems and larger windows also allows efficacious monitoring of the surrounding environment. Voice-command systems and touchscreen interfaces minimise physical strains. Advanced ventilation and air conditioning systems and adjustable steering wheels and pedals provide a comfortable operating setting under prolonged periods to account for different weather in climate control systems.

EV Tractor Repair and Maintenance

Repair and maintenance are the fundamentals of lifecycle management due to the impact on reliability, performance, and total ownership cost. All EV tractors comprise distinct components and systems, including high-voltage batteries and electric drivetrains, compared to diesel tractors, which require specialised repair and maintenance knowledge and methods. Therefore, El Hadraoui et al. (2024) insisted that technicians should undergo advanced training and be equipped with diagnostic tools to effectively manage and troubleshoot the systems, as electric drivetrain maintenance, battery management, and component replacement present specific challenges. All repair and maintenance processes ensure EV tractors serve as efficient and feasible alternatives for agricultural and industrial applications.

Electric drivetrains, such as inverters and motors, necessitate specific maintenance techniques on the bearing wear and cooling system despite less frequent maintenance compared to ICEs. Regular checks are also required for the electrical and thermal performance of inverters, which convert DC to AC, for efficient operation. Including advanced materials and cooling systems can improve electric drivetrain reliability and durability. The EV battery maintenance is one of the most complicated and vital components (Reza et al., 2024). Cell balancing, monitoring battery health, and managing thermal conditions are crucial to prevent battery degradation. The latest battery management systems (BMSs) allow real-time data on battery performance for predictive maintenance, which also requires technicians to be well-versed in interpreting BMS data to resolve thermal anomalies and voltage imbalances.

Replacing and repairing EV tractor components is a significant task compared to ICE vehicles as high-voltage electrical components and battery packs necessitate careful handling and specialised removal and installation equipment. The latest modular component designs allow more efficient and effortless replacements and repairs, although safety and precision are the top priorities. Technicians should be adequately equipped with specialised EV tractor knowledge and skills in electric drivetrains and high-voltage systems, such as diagnosing battery issues, managing high-voltage electrical systems, and understanding electric motor components, to resolve unique EV challenges.

Modules of EV tractor diagnostic tools, safety protocols, and repair techniques are integral to sufficiently preparing technicians (Etezadi & Eshkabilov, 2024; Vogt et al., 2021). Advanced diagnostic tools and systems can aid technicians in monitoring the performance of key components, including motors, batteries, and inverters, to determine potential issues and faults. Higher accuracy and efficiency are possible via suitable equipment for self-initiated maintenance. Specialised repair services can be exorbitant despite fewer moving parts in EV tractors than in ICE models due to high-voltage components.

RESEARCH METHODOLOGY

Research Design

Several perspectives of stakeholders are analysed to get the big picture of the tractor attributes for agricultural purpose. Qualitative research is useful for exploring in depth the main characteristics of EV studies before establishing key variables for the research framework. This method is found suitable in studying complex situations to understand the views, experiences and ideas of experts in the field (Fossey et al., 2002). Accordingly, the focus on the observation process can provide real-time information related to the terrain that will be covered by the electric tractor in the process of harvesting oil palm products. In this sense, Butina (2015) regarded the narrative interview method conducted is suitable for the researcher to collect and analyse data, prior to validating the interpretation of the desired information.

Thematic Analysis

According to Jovchelovitch & Bauer (2000) and Schütze (1977), narrative interviews are helpful in investigating new project situations, for instance the EV project. In this situation, social groups can have opinions whose narrative perspective can construct a configuration of events that reflects the data for project under study.

The consensus within the literature on data analysis seems to be that coding should not be exhaustive and is in fact a process for reducing the data (Elliott, 2018). It is important to manage qualitative data in a structured manner through thematic analysis to capture the right patterns in the narrative interview process (Braun & Clarke, 2006). This is based on the following procedure.

- Reread the transcripts that have been recorded for each participant.
- Systematically code the keywords found in the data, which are certain characteristics.
- Combine codes that have potential relevance to the data into common themes.
- Review the themes if necessary to refine them based on the function of the entire data set in parallel.
- Confirm the themes and give them labels that are different from the meanings of other themes.
- Report the results of the analysis so that the findings from the narrative interview data clearly represent each theme shared by the participants.

Narrative Interview

Narrative interviews encouraged respondents to share personal insights, experiences and thoughts, which offered richer descriptive data to reveal contributing factors to the adoption of off-road EV tractors that could effectively meet existing operational needs and solve oil palm plantation challenges (Moser & Korstjens, 2018; Butina, 2015). A total of six oil palm plantation sector management representatives including an EV consultant were selected because of their direct involvement in equipment procurement and operational decision making. They are also familiar with practical and commercial strategies in implementing modern or innovative agricultural practices. All respondents were contacted in advance via email or telephone regarding the time of their appointment. It is important that they understand the purpose and importance of their participation and cooperation in this study as the findings are expected to be useful to them. Finally, the researcher managed to meet the respondents individually and discuss in-person at their oil palm plantation and firm.

Semi-Interview Question Structure

Semi-structured interviews allow flexibility of expression to encourage the sharing of relevant information (Adeoye-Olatunde & Olenik, 2021; Adams, 2015). Off-road electric vehicles (EVs) can be practiced in oil palm plantations where their uniqueness is able to open opportunities for sustainable technology applications in the agricultural sector. In this interview, respondents ought to understand that their answers reflect the importance of palm oil products as a major commodity that generates one of the country's main incomes. Compared to ICE tractors, respondents may also describe expectations, performance on difficult terrain, weather challenges and other factors needed to meet commercial requirements.

The interview questions that are posed need to be more focused to get an accurate narrative about the components of this study.

1. Towing and Cargo Capacity: revolved around the extent to which this EV tractor can meet the towing and cargo capacity compared to conventional tractors. It is important to know the work requirements of diverse oil palm plantations to produce comparable efficiency and productivity.

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2. Off-Road Capability: related to the smooth off-road movement of this EV tractor in oil palm plantations either for normal or challenging terrain conditions, especially when the weather changes become erratic.

3. Comfort and Safety: defined features that are important for comfortable and safe operation of EV tractors that include the driver's well-being in performing various tasks and farm needs.

4. Maintenance and Repair: identified aspects and needs in the maintenance and repair of EV tractors to ensure that they can always operate in the best and perfect conditions and avoid problems that hinder the productivity of oil palm plantations.

Data Collection

Physical interviews were conducted based on respondents' availability and time preferences, with each lasting between one hour and 90 minutes. Respondents were informed about the right to withdraw at any time without consequences. Informed consent was also obtained from all respondents before the interviews to ensure data anonymity and confidentiality. All the interviews were audio-recorded with respondents' consent, and detailed notetaking was also performed to complement the findings. Ethical guidelines were fully adhered to, which protected respondents' rights and confidentiality.

FINDINGS

Interviews

As mentioned above, the transcripts need to be re-read to understand the context of the data that will be extracted in this qualitative analysis. The context of the interviews in this study is based on the following general statements:

"The use of ICE tractors in agriculture, especially oil palm, needs to be converted to EV transport to increase productivity and reduce pollution. This also helps save on petrol, maintenance and increased in labour costs. An understanding of the plantation work concept needs to be appropriate for the proposed EV tractor. This should also consider the plantation manager's work experience against the users' expectations of the tractor functions that are useful and effective. As users of technology and AI, companies have a key role in helping researchers to identify the ideal features of EV tractors to be designed to meet the challenges of oil palm plantation work."

Next, the researcher began to organize the data obtained to be more systematic with a clear meaning. Codes were used after selecting specific data for the study so that the interpretation burden was smaller. In this case too, the interview questions and data analysis were conducted through theoretical thematic analysis where only relevant data (not text) according to the segments were coded as related to our research questions (Elliott, 2018). Therefore, the researcher chose preset codes by categorizing the interview responses according to the determination of a certain set of answers that had been determined in advance so that the analysis and interpretation of the data became easier, in which the codes did not need to be developed or modified throughout this process. The transcription coding for each segmentation was ensured to be relevant in addressing the research questions. This process was followed by evaluating, discussing and either maintaining or generating new codes that were more appropriate for each transcript.

Hence, a total of six interviews were conducted with the management personnel from the five organizations as follows:

Narrative Interview 1: Mr P, Operation Manager, located at Jempol.

Mr P was highly confident in off-road EV tractor towing and cargo performance equivalent to or beyond those of diesel tractors. Specifically, the instantaneous torque of EV tractors significantly improved the capability to transport heavy loads on challenging oil palm plantation terrains, which led to higher harvesting efficiency and productivity. Furthermore, the efficiency of EV battery technologies with regenerative braking and advanced

Battery Management Systems (BMSs) allowed optimal operational efficiency and performance in harsh environments. Higher comfort and safety levels were also provided by ergonomic cabins with adjustable seating, climate control, and noise insulation features to decrease operators' exhaustion. Simultaneously, stability control and automated collision avoidance could aid in minimising risks for a safer working environment. Meanwhile, specialised maintenance equipment and technician training were significant barriers to higher EV tractor adoption.

Narrative Interview 2: Mr Q, Regional Assistant Director, located at Jempol.

Mr. Q has expressed the plantation needs regarding the possible use of off-road EV tractors in oil palm harvesting. He agrees that the aspects of towing and cargo capacity, capability, comfort and safety features, as well as maintenance and repair must be considered. Regarding the towing and cargo capacity of the off-road EV tractor, Mr. Q has set his priorities. The instant torque of the electric motor is critical to increase the capacity of the EV tractor in lifting heavy loads and traversing rough terrain. The off-road capability will indeed determine the productivity of oil palm harvesting operations. In this sense, the assistant director is determined to try out the advanced technology based on electric drives and battery systems adapted to the plantation works and hope the high torque motor and efficient power delivered could at least maintain operational performance in challenging conditions. Mr. Q was impressed with regenerative braking and advanced battery management systems that should result in more efficient operations. The comfort and safety of the off-road EV tractor operator have to be guaranteed by its cabin ergonomically design with climate control and noise reduction. The addition of automatic braking and collision detection make an EV tractor safety feature standard to reduce the risk of accidents. Specialized training needs to be provided to technicians which may relatively incur high initial investment, but this ensure the vehicle's ability to function optimally if the maintenance and repair factors are systematically overseeing. Finally, Mr. Q pointed out that the long-term savings on fuel and maintenance costs will improve the overall usability of the EV tractor.

Narrative Interview 3: Mr R, Assistant Operation Manager, located at Jasin.

Mr R positively perceived off-road EV tractor adoption in oil palm plantation should be welcome but not without its limitation. He also stressed the importance of meeting towing and cargo capacity, capability, comfort, and safety features, as well as maintenance and repair. According to him, off-road EV tractors can certainly be designed with towing and cargo capacity suitable for oil palm harvesting. He stressed that high electric motor torque would enable these vehicles to carry heavy loads, and traverse uneven plantation surfaces due to efficient power transmission. Mr. R felt optimistic about the possibility of increasing harvesting productivity due to the breakthrough in electric motor technology and battery management systems. Regenerative braking and advanced power management technology can confirm the efficiency and performance required for plantation activities. Off-road EV tractors should significantly improve operator comfort and safety due to ergonomic cabin design features, climate control systems and visibility which are considered important in risk management and meeting the set standards. In addition, Mr. R opined that other critical challenges include training, readiness, and skills to maintain and repair the tractors which might require initial investment. Long-term costs benefits would be savings on fuel and maintenance, which necessitate infrastructure and qualified technicians to ensure the effectiveness of EV tractors.

Narrative Interview 4: Mr S, Assistant Operation Manager, located at Johor Bahru.

Mr. S highlighted similar benefits and limitations of EV tractor adoption as the three previous respondents. He believes that it is not wrong to try out off-road EV tractors in oil palm harvesting as this will be the trend of the future. He agrees with the requirements of towing and cargo capacity, off-road capability, comfort and safety features, as well as maintenance and repair. Mr. S has no doubt that off-road EV tractors have the ability to tow cargo of oil palm products. The torque of the electric motor must be capable of handling heavy loads according to rough terrain and this is particularly important to ensure efficiency and productivity can be achievable by electric drives and battery systems. Regenerative braking and advanced power management technology are also beneficial in improving overall traction. Mr. S emphasized that the operator comfort and safety need to be prioritized through ergonomic cabin design, climate control and vision systems, in addition to automatic features and stability control to avoid the possibility of accidents. All of this requires an initial investment including training and maintenance infrastructure for technicians. Fuel savings and low maintenance costs are vital as EV technology provides long-term benefits.

Narrative Interview 5: Mr T, Operation Manager, located at Bangi.

Mr T was confident in the higher towing and cargo abilities of EV tractors compared to ICE models owing to the instantaneous torque of electric motors, battery technological advancements, and regenerative braking for more efficient and efficacious operations. Ergonomic cabins, such as climate control and enhanced visibility, and safety features, including automated braking and collision avoidance, enhanced comfort, and safety by decreasing operational risks. While initial investment and specialised maintenance training were required, long-term fuel and maintenance savings with constant maintenance infrastructure and technician training could compensate for the initial costs and ensure effective EV tractor operations.

Narrative Interview 6: Mr U, Manager, located at Wangsa Maju.

Mr. U anticipated off-road EV tractors with adequate towing and cargo capacities for oil palm harvesting through the instant torque and efficient power delivery of electric motors to transport heavy loads and navigate uneven terrains, which was comparable to or beyond the performance of diesel tractors. Regenerative braking and advanced BMSs also enhanced the overall power efficiency and traction control. In addition, ergonomic cabins with noise reduction, climate control, stability control, and automated collision avoidance improved comfort and safety levels. Investing in technician training and maintaining relevant infrastructure could also efficaciously ensure long-term adoption and maximise the advantages of off-road EV tractors despite the initial investment and the requirement for specialised maintenance training.

Summary of Narrative Interview

As describe by Table 2, the narrative interviews suggest that off-road capabilities, comfort and safety features, and towing and cargo capacities, were the key advantages of employing EV tractors in the agricultural sector, especially palm oil harvesting. Nonetheless, specialised repair and maintenance might pose significant barriers to higher adoption. The findings were also in line with previous scholars literatures on the four themes.

Table 2: Narrative interviews themes summaries

Themes address	Research questions	Emergent codes
1. Towing and cargo capacity	• the extent to which this EV tractor meets this function • the work requirements of diverse oil palm plantations • comparable efficiency and productivity	• torque • harvesting • rough terrain • future trend
2. Off-road capability	• smooth off-road EV movement in oil palm plantations • terrain conditions in weather challenge	• heavy load • terrain • battery technology system • regenerative braking • electric drive
3. Comfort and safety	• features of user comfort	• cabin ergonomic

	• features for safe operation • driver's well-being in performing work	• climate control • collision avoidance • noise reduction • visibility
4. Maintenance and repair	• aspects of the maintenance and repair • operation best conditions	• maintenance infrastructure • qualified technicians • specialize training • initial investment

Source: Authors

Interview Finding Validation

The current study demonstrated a positive outlook on off-road EV tractor adoption due to higher towing and cargo abilities. The findings were consistent with Lombardi et al. (2023) and Johnston & Sobey (2022) revealing electric drivetrain and battery technological advancements significantly increased the towing and cargo capacities of EV tractors, especially on uneven off-road surfaces, powered by the instantaneous torque. The current respondents also highlighted enhanced comfort and safety. It was discovered that higher operator comfort in EV tractors through reduced vibration and noise than ICE models after incorporating advanced comfort and safety features (Krishna et al., 2023). Meanwhile, a higher upfront cost was required to enjoy the benefits. Smith et al. (2020) elucidated that specialised knowledge and EV tractor parts might result in higher repair costs and longer downtime, although lesser maintenance was required compared to ICE tractors. Konstantinou et al. (2022), Patyal et al. (2021), and Christensen & Salmon (2021) also delineated exorbitant upfront costs and the requirement for specialised training during the transition to EVs despite the long-term advantages. The findings posited more training and infrastructure investments required for higher EV tractor adoption.

Policies & Incentives

In contrast to the National Automotive Policy (NAP) 2020, the Malaysian Automotive, Robotics and IoT Institute (MARii) urged the government to provide fixed incentives and special incentives that benefit EV manufacturers, consumers and interested industries. The main challenges to EV ownership are consumer trust and the lack of availability of battery charging stations. In this context, people are used to driving ICE vehicles which are more cost-effective than EVs. Non-pollution factors are not the main factor if the perception of high maintenance costs is questionable.

For 2025, the Malaysian government continues to provide incentives for the development of critical electric vehicle (EV) charging infrastructure. The Ministry of Investment, Trade and Industry (MITI) through the Green Investment Tax Allowance (GITA) programme, has facilitated the importation of EVs for the domestic market to create at least 10,000 charging stations for use in Malaysia. Furthermore, it is encouraging global EV manufacturers to develop assembly or production plants in Malaysia which will boost local automotive small and medium enterprises (SMEs) to participate in the global EV production supply chain for parts, components and factory automation systems. Since 2023, the MITI Minister was optimistic that local brands could produce EVs and as a result, prototypes were successfully realized by both automotive companies PROTON and PERODUA by the end of 2024.

MITI has confirmed tax exemptions in the form of 100 percent Investment Tax Allowance for a period of five years to charging point operators (MPOs), if they meet the set criteria. In addition, full income tax exemption incentives are also offered to companies that manufacture EV charging equipment until the tax assessment year

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2032. In supporting the development of EV charging bays (EVCBs), Petronas and Tenaga Nasional Bhd. have committed to investing approximately RM76 million until June 2024. The construction of EVCBs throughout Malaysia, including by other parties, is essential to provide EV charging services to the public.

Although EVs are very new to commercialization in the country, the Ministry of Transport is actively studying methods to manage EVs after they have been in use for more than 8 years. This development, which catalyses the development of EVs and their infrastructure, has prompted local public university researchers through smart partnerships with local companies to finally produce EV tractor prototypes successfully for commercial agricultural purposes by the early 2025.

Future Strategies

EVs are believed to be cleaner as they can operate efficiently and are connected to the electric grid by generating clean, renewable energy, primarily from natural sources such as solar, wind, hydroelectricity and bioenergy (organic matter). Unfortunately, consumers are sceptical about the sustainability of lithium-ion as the primary generator of global EV batteries.

These concerns extend beyond lithium-ion-based EV batteries. Problems arising from the use of lithium-ion include: 1) the environmental side effects of its mining; 2) the dwindling raw material; 3) the carbon-producing manufacturing process; and 5) the toxic effects of battery disposal. Therefore, innovation in EV battery components needs to continue to be improved and diversified.

The development of solid-state battery technology with improved performance and sustainability could be the answer to the challenges faced by lithium-ion batteries. Despite the large investment, the first solid-state battery is expected to make appearance in the market by 2027. The hope is to see new EV battery sources continue to be researched to allay concerns from potential users.

CONCLUSION

Valuable insights were contributed to the aspects of off-road performance, comfort, and safety, towing and cargo abilities, and repair and maintenance.

The Advantages of EV Tractors

The six respondents similarly expressed the potential of EV tractors in performing on-par or beyond the towing and cargo abilities of ICE models via the instantaneous torque of electric motors to transport heavy loads and travel through uneven off-road surfaces for higher operational efficiency. Electric motors and battery technological advancements also provided more efficient regenerative braking and power delivery under harsh conditions. Additionally, ergonomic cabins with noise reduction, climate control, automated collision avoidance, enhanced visibility, and stability control could aid in increasing operator comfort while preventing accidents.

Practical Challenges in Adopting EV Tractors

The high initial investment cost with associated maintenance infrastructure was perceived as a significant adoption barrier, which required deliberate financial planning. High-voltage systems and the requirement for specialised maintenance training were also significant challenges for long-term benefits. Insufficient skilled personnel and specialised diagnostic tools might prevent successful or higher EV tractor adoption.

Future Opportunities of EV Tractors

Long-term fuel and maintenance savings could compensate for the high initial investment, which potentially allows oil palm plantations or enterprises to be environmentally responsible without compromising operational efficiency.

Potential Threats of Adopting EV Tractors

The reliability of EV technologies and performance across various conditions remained ambiguous. A perceived risk could emerge from certain operational scenarios. Inadequate skilled maintenance personnel might also pose a significant threat to successful EV tractor adoption.

The Preparedness Level for EV Tractor Adoption

The significant advantages of EV tractors could serve as a driving factor, although practical challenges must be resolved to ensure higher adoption. Investments in maintenance infrastructure and technician training are integral to managing the complexities of high-voltage systems and ensuring the effective operation of EV tractors. Highlighting potential long-term savings and environmental benefits could drive higher EV tractor adoption.

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