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Analysis of Solar Energy Utilization on Electric Bicycles as an Energy Source for Automatic Fertilizer Spreading Systems for Agricultural Applications

Sheila Reinanda Putri[1], Yashinta Naila Evi Nastiti[1], Yurike Dwi Oktavia[1], Olivia Susanto[1,*], Singgih Dwi Prasetyo[1]

[1] Department of Engineering Technology, Power Plant Engineering Technology, Fakulti of Vocational, State University of Malang, 65145 Malang, Jawa Timur, Indonesia

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ABSTRACT

The agricultural sector requires technological innovations capable of improving operational efficiency while supporting the utilization of renewable energy. Fertilization is one of the essential activities in the cultivation process, which is generally still carried out manually, requiring considerable labor and potentially resulting in uneven fertilizer distribution. This study proposes an innovation of an automatic fertilizer spreading system integrated with an electric bicycle and powered by solar panels as a more efficient and sustainable technological alternative. The innovation utilizes photovoltaic panels as an energy source to supply the power requirements of the fertilizer spreading system, with a battery serving as an energy storage medium, allowing the generated energy to be used to operate the automatic fertilizer spreading mechanism. The system is integrated into an electric bicycle as a mobile platform, enabling the fertilization process to be carried out more practically across agricultural areas. The methodology employed is a Systematic Literature Review (SLR) to identify and synthesize previous studies related to the utilization of solar energy in electric vehicles, energy storage systems, automatic fertilizer spreading mechanisms, and agricultural automation technologies. The selected literature is analyzed to assess the potential of solar energy, the energy requirements of the fertilizer spreading system, and the feasibility of integrating solar panels, batteries, an electric bicycle, and an automatic fertilizer spreading mechanism. The expected outcome is a conceptual analysis of the performance and potential utilization of solar energy as an energy source for an automatic fertilizer spreading system integrated with an electric bicycle, including its suitability for supporting agricultural fertilization activities. This innovation is expected to improve the efficiency of the fertilization process, reduce dependence on manual labor and conventional energy sources, and promote the application of renewable energy in agricultural technology. Thus, the proposed system has the potential to serve as an automatic, mobile, energy-efficient, and sustainable agricultural technology solution.

* *Corresponding author.*
E-mail address: olivia.susanto.2409347@students.um.ac.id

1. Introduction

The agricultural sector plays an important role in maintaining food security and meeting the increasing demand for agricultural products. However, agricultural production continues to face challenges related to fertilizer utilization, resource efficiency, labor requirements, and environmental sustainability. Fertilization is an essential activity in crop production because nutrient availability directly affects plant growth and productivity. Conventional fertilization practices generally apply relatively uniform fertilizer rates without fully considering spatial variations in soil properties, crop conditions, and nutrient requirements, which can result in under-fertilization in some areas and over-fertilization in others [1, 2, 3]. Research on precision fertilization has therefore emphasized the importance of sensing, monitoring, decision-making, and controlled fertilizer application to improve nutrient-use efficiency [1, 2]. Variable-rate fertilization technology has also been developed to regulate fertilizer dosage according to field conditions and application requirements [4, 5]. Previous studies on fertilizer metering devices demonstrated that variable-rate mechanisms can control fertilizer dosage and application location, while automated applicators equipped with sensing and control systems have shown potential for improving application accuracy [5, 6, 7]. These developments indicate that the automation of fertilizer distribution can provide a technological approach to improve the consistency and efficiency of agricultural fertilization.

In addition to fertilizer utilization, agricultural activities require considerable energy for operating machinery and supporting various field operations. Conventional agricultural machinery has historically relied on internal combustion engines and fossil fuels, creating concerns regarding fuel consumption, pollutant emissions, and greenhouse gas emissions [8, 9]. The electrification of agricultural machinery has consequently attracted increasing research interest because electric drives can provide controllable operation, high drivetrain efficiency, and reduced dependence on fossil-fuel-based machinery [8, 9, 10]. Recent studies have examined the transition from conventional tractors toward battery-electric agricultural machinery and identified battery capacity, power requirements, charging infrastructure, and operating duration as important considerations in the implementation of electric agricultural equipment [10, 11]. Battery performance is particularly important because agricultural operating loads can vary according to working conditions, while higher operational loads can increase battery power consumption and reduce usable operating time [11]. The development of electrified agricultural machinery therefore requires not only an appropriate electric drive but also an energy supply and storage system capable of supporting the required operation. These conditions create an opportunity to combine electric agricultural mobility with renewable energy sources, particularly photovoltaic (PV) technology.

Solar photovoltaic technology has significant potential as a renewable energy source for agricultural applications because solar radiation can be converted directly into electrical energy for powering electric machinery or storing energy in batteries [8, 12]. Studies on solar-powered agricultural machinery have demonstrated the application of PV technology in electric tractors and agricultural robots, while highlighting battery storage, installation costs, environmental conditions, shading, dust accumulation, and solar intermittency as key technical challenges [8, 12]. The application of PV technology in electric vehicles has also developed through solar-powered electric vehicles and vehicle-integrated photovoltaics (VIPV), where the generated energy is affected by solar irradiance, temperature, shading, installation position, vehicle geometry, and available surface area [13, 14]. These limitations are particularly relevant to electric bicycles because their compact structure provides less space for PV installation, meaning that the generated solar energy cannot be assumed to continuously meet the electrical demand of the vehicle and its auxiliary equipment. Therefore, battery energy storage and energy management are essential for balancing solar energy

generation with operational demand, providing a foundation for developing mobile agricultural equipment with lower dependence on conventional energy sources [11, 13, 14].

Based on these considerations, this study proposes a conceptual integration of a photovoltaic system, battery energy storage, an electric bicycle, and an automatic fertilizer spreading mechanism as a mobile agricultural fertilization system. The electric bicycle functions as the mobile platform for transporting the fertilizer spreading mechanism, while the photovoltaic system provides renewable energy that is stored in a battery and supplied to both the electric bicycle and fertilizer spreading mechanism. Previous studies have investigated precision fertilization and variable-rate fertilizer application [11–17], agricultural machinery electrification [8–11], solar-powered agricultural machinery [8, 12], and solar-powered electric vehicles and vehicle-integrated photovoltaics [13, 14], while recent research on solar-powered agricultural robots has demonstrated the potential for integrating solar energy, energy storage, control systems, and autonomous agricultural operations, despite challenges in energy storage, reliability, and field adaptability [15]. However, the integration of these technologies into an electric bicycle-based automatic fertilizer spreading system has not been sufficiently examined as a unified system, creating a research gap that this study addresses through a Systematic Literature Review (SLR). The proposed concept aims to establish a mobile, automated, and renewable-energy-powered fertilizer spreading system that can support more efficient and sustainable agricultural operations.

2. Methodology

2.1 Research Design and Research Questions

This study employs the Systematic Literature Review (SLR) method to identify, evaluate, and synthesize prior research related to the utilization of solar energy in electric vehicles, energy storage systems, automatic fertilizer-spreading mechanisms, and agricultural automation technologies. The Systematic Literature Review method was selected to obtain a systematic understanding of technological characteristics, energy requirements, operational methods, and the factors influencing the implementation of solar energy systems on electric bicycles as a platform for automatic fertilizer spreading. This study was conducted based on several Research Questions (RQ), which served as the basis for the process of searching, selecting, analyzing, and synthesizing the literature. These research questions were formulated to guide the review toward aspects related to the utilization of solar energy in electric bicycles and automatic fertilizer-spreading systems. The Research Questions used in this study are as follows:

RQ1: How is solar energy implemented in electric vehicles and electricity-based agricultural machinery?

RQ2: What technologies are used in automatic fertilizer spreading systems, and what are the characteristics of their performance?

RQ3: What is the potential for integrating solar panels, batteries, electric bicycles, and automatic fertilizer-spreading mechanisms as a mobile agricultural fertilization system?

These three Research Questions were formulated to guide the review toward the aspects of technology, performance, and system integration related to the utilization of solar energy in agriculture. RQ1 focuses on the implementation of solar energy as an energy source for electric vehicles and electricity-based agricultural machinery, including the use of solar panels and energy storage systems. RQ2 examines the various technologies used in automatic fertilizer-spreading systems and their performance characteristics based on prior research. Subsequently, RQ3 synthesizes the findings of the two preceding aspects to identify the potential integration of solar

panels, batteries, electric bicycles, and automatic fertilizer-spreading mechanisms as a mobile agricultural fertilization system.

2.2 Literature Search and Selection

The literature search was conducted across several scientific databases, namely ResearchGate, Scopus, ScienceDirect, IEEE Xplore, and Google Scholar. These five databases were selected due to their broad and relevant coverage of scientific publications in the fields of renewable energy, electric vehicles, electrical systems, automation, and agricultural technology, which constitute the focus of this study. The search was carried out using a combination of keywords tailored to the research focus. These keywords were subsequently combined using the Boolean operators AND and OR to obtain relevant literature. The keywords used in this study include:

- "Solar energy" OR "photovoltaic"
- "Solar-powered electric vehicle" OR "electric bicycle"
- "Electric agricultural machinery"
- "Automatic fertilizer spreading" OR "fertilizer spreader"
- "Precision fertilization" OR "agricultural automation"

2.3 Inclusion and Exclusion Criteria

The literature selection was carried out based on predetermined inclusion and exclusion criteria to ensure the suitability of the articles with the scope of the study. The inclusion criteria were used to determine articles that met the requirements for analysis, while the exclusion criteria were used to eliminate articles that did not align with the focus of the study or did not provide adequate information. These criteria were established based on language, year of publication, type of publication, topic relevance, availability of full text, and completeness of the information required for the analysis process. The inclusion and exclusion criteria used in this study are presented in Table 1.

Table 1
Inclusion and exclusion criteria of the study

Aspect	Inclusion Criteria	Exclusion Criteria
Year of publication	Articles published between 2017–2026	Articles published before 2017
Language	Articles written in Indonesian or English	Articles written in languages other than Indonesian or English
Type of publication	Scientific articles relevant to the field of study	Non-scientific publications or academically irrelevant sources
Topic relevance	Discusses solar energy, electric vehicles or machinery, energy storage systems, automatic fertilizer spreaders, and/or agricultural automation	Does not address aspects related to the focus of the study
Text availability	Full text of the article is available	Full text of the article is not available

Articles that satisfied the inclusion criteria and did not fall under the exclusion criteria as presented in Table 1 were subsequently determined as the literature analyzed in this study. The selection process was carried out in stages, beginning with a review of titles and abstracts. This initial review was then followed by a full-text examination to ensure that each article conformed to the

established criteria. The final results of this selection process served as the basis for the data analysis stage.

2.4 Data Analysis

Data from articles that satisfied the selection criteria were analyzed descriptively and comparatively based on the focus of the study. The information analyzed included the characteristics of solar energy technology, energy storage systems, electric vehicles or machinery, automatic fertilizer-spreading systems, as well as the performance parameters reported in each study. These data were then grouped according to the Research Questions, which encompassed the implementation of solar energy in vehicles and agricultural machinery, the technology and performance of automatic fertilizer-spreading systems, and the potential integration of system components. This grouping was employed to facilitate the comparison of findings across studies in accordance with the aspects examined.

The analysis was conducted by comparing the technological characteristics, performance parameters, and research findings across articles to identify patterns, similarities, differences, and limitations of the technologies that have been developed. The results of this comparison were then used to identify the relationships among the utilization of solar energy, energy storage systems, electric vehicles, and automatic fertilizer-spreading mechanisms. Subsequently, the findings from each research group were synthesized to obtain an overview of the energy requirements and characteristics of each system component. The results of this synthesis were used to identify the potential integration of solar panels, batteries, electric bicycles, and automatic fertilizer-spreading mechanisms as a mobile agricultural fertilization system.

3. Results

3.1 Characteristics of the Reviewed Literature

Based on the results of the literature search and selection process, the studies relevant to this review can be grouped into three main themes: the utilization of solar energy in electric vehicles, automatic fertilizer-spreading systems, and the integration of agricultural automation technologies. The first group focuses on the use of solar panels as an energy source for charging electric-vehicle batteries, particularly electric bicycles. Studies in this group analyze solar-panel power output, charging efficiency, panel types, charging-control systems, and battery characteristics [16–19].

The second group focuses on automatic fertilization systems that utilize microcontrollers, sensors, actuators, electric motors, and pumps [17]. These systems are developed to reduce manual labor and improve the efficiency of the fertilization process [18].

The third group concerns the application of solar panels to vehicles or mobile platforms. Studies in this group indicate that solar panels can be used as an auxiliary energy source for charging electric-vehicle batteries. However, system performance is strongly influenced by solar-radiation intensity, temperature, testing time, and the available panel area [16, 19, 20].

The grouping results indicate that studies on solar energy and studies on automatic fertilization systems have largely been conducted separately. Research on solar energy has primarily focused on battery charging and panel efficiency, whereas research on automatic fertilization has mainly examined sensors, microcontrollers, actuators, and fertilizer-dispensing mechanisms. Therefore, the integration of these components into a single electric-bicycle-based mobile fertilization system remains a promising area for further development.

Table 2
Summary of the Reviewed Literature

No.	Authors and Year	Research Focus	Main Components	Main Findings
1	Nainggolan et al. (2017) [16]	Electric bicycle equipped with solar panels	Solar panel, battery, and electric motor	The solar panel was used as a charging source for the electric-bicycle battery.
2	Prasetyo et al. (2018) [21]	Solar-panel charging controller	Solar panel, Arduino Nano, and battery	The control system regulated the voltage supplied from the solar panel to the battery. A 100 Wp panel produced an average charging power of 39.03 W with an efficiency of 85.82%, whereas a 300 Wp panel produced an average power of 57.43 W with an efficiency of 88.48% [21].
3	Suhardi (2020) [20]	Automatic fertilization	Sensor ultrasonik, sensor cahaya, Arduino Uno, relay, dan pompa	The system was able to activate the fertilizer-spraying process automatically based on distance and lighting conditions.
4	Asrori et al. (2023) [18]	Comparison of flat and flexible solar panels on an electric bicycle	Flat panel, flexible panel, voltage sensor, current sensor, and battery	The flat panel produced 58.94 Wh of energy, whereas the flexible panel produced 44.87 Wh.
5	Pratama et al. (2024) [19]	Electric-bicycle battery charging using solar panels	Solar panel, solar charge controller, battery, and electric motor	The solar-panel charging system was able to charge the electric-bicycle battery in approximately three hours.
6	Anggraini et al. (2026) [23]	Automatic fertilizer applicator for water spinach	ESP32, ultrasonic sensor, servo motor, DC motor, and web server	The system successfully detected plant pots and operated the fertilization mechanism with an 80% success rate.

3.2 Application of Solar Energy in Electric Vehicles and Agricultural Machinery

The findings related to RQ1 indicate that solar energy can be utilized as an auxiliary energy source for electric vehicles. This utilization is generally achieved by installing solar panels on the vehicle or by using solar panels as a battery-charging source.

Nainggolan et al. [16] developed an electric bicycle equipped with solar panels for battery charging. The study demonstrated that solar energy can support the electrical system of an electric bicycle. The use of solar panels on electric bicycles has the potential to reduce dependence on conventional electricity sources.

Prasetyo et al. [21] developed a solar-panel charging controller using an Arduino Nano for a commercial electric bicycle. The system was designed to regulate the voltage supplied from the solar panel to the battery. Testing with a 100 Wp panel produced an average charging power of 39.03 W, a charging time of 160 minutes, and an average efficiency of 85.82%. Meanwhile, a 300 Wp panel produced an average charging power of 57.43 W, a charging time of 50 minutes, and an average efficiency of 88.48%.

These findings show that solar-panel capacity and the charging-control system affect battery-charging performance [21]. However, an increase in panel capacity does not necessarily produce a proportional increase in output power because the actual power is affected by light intensity, temperature, panel condition, and the ability of the controller and battery to receive energy.

Asrori et al. [18] compared flat and flexible solar panels for charging an electric-bicycle battery. At a maximum solar-radiation intensity of approximately 1008 W/m², the flat panel produced 58.94

Wh of energy, whereas the flexible panel produced 44.87 Wh. These results indicate that the flat panel provided higher charging performance under the tested conditions.

This difference may be caused by material characteristics, installation position, effective area, panel angle, and the panel's ability to receive solar radiation. Flexible panels offer advantages in terms of flexibility and ease of installation; however, under certain conditions, their power output may be lower than that of flat panels.

Pratama et al. [19] designed an electric-bicycle battery-charging system using solar panels, a solar charge controller, a battery, and an electric motor. The solar panels were configured to produce a voltage of 36 V, which was then stored in the battery. The test results showed that the battery could be charged in approximately three hours. These findings indicate that solar panels can serve as a renewable energy source to support electric-bicycle battery charging and reduce dependence on fossil-fuel-based energy sources.

Pambudi et al. [22] developed an electric-bicycle battery-charging system using solar panels, a charging controller, and a buck converter. The system maintained an average output voltage of 13.01 V even when the photovoltaic-panel input voltage varied from 10.09 V to 19.45 V. The reported system efficiency reached 97.31% under low-power conditions.

Based on these studies, solar energy can be used to support battery charging in electric vehicles. However, electric bicycles have limited surface area for solar-panel installation. Therefore, solar energy is more appropriately positioned as an auxiliary energy source, while the battery remains the primary energy-storage medium.

The performance of a solar-energy system in an electric vehicle is influenced by several factors, including solar-radiation intensity; the area and type of solar panel; the panel's installation position and angle; ambient and panel temperature; charging-controller efficiency; battery capacity and condition; electric-motor load; and vehicle and payload weight. All of these factors must be considered when designing an electric bicycle to be used as a platform for an automatic fertilizer-spreading system.

3.3 Technology and Performance of Automatic Fertilizer-Spreading Systems

The findings related to RQ2 indicate that automatic fertilizer-spreading or fertilization systems generally consist of a fertilizer container, a fertilizer-dispensing mechanism, sensors, a microcontroller, actuators, and an electrical power source [17].

Prayoga and Pawana developed an automatic watering and fertilization system based on an ESP32, an RTC, and the Blynk application. The system was designed for water spinach and used an RTC for scheduling, an ESP32 as the controller, the Blynk application as the user interface, and a pump for distributing water and fertilizer solution. The test results showed that the system could water plants at a rate of 220 mL per minute, perform watering twice a day, and apply urea fertilizer once a week according to the predetermined schedule [17].

Suhardi [20] developed an automatic fertilization system using an ultrasonic sensor, a light sensor, an Arduino Uno, a relay, and a water pump. In this system, the ultrasonic sensor detected the distance between the device and the plant. When the distance was within the specified range and the lighting conditions met the requirements, the microcontroller activated the pump to spray liquid fertilizer.

The system demonstrated that sensors and microcontrollers can be used to control the fertilization process automatically. However, the reviewed system still used liquid fertilizer and a spraying pump. This mechanism differs from a solid-fertilizer spreading system, which requires a container, a channel, and a metering mechanism.

Anggraini et al. [23] developed an automatic fertilizer applicator for water spinach using an ESP32, an ultrasonic sensor, a servo motor, a DC motor, and a local web server. The ultrasonic sensor was used to detect the position of the plant pot, while the servo motor opened the fertilizer outlet. The DC motor pushed the fertilizer out of the container.

Testing was conducted on five pots with two repetitions, and the system achieved an 80% success rate. These results indicate that the integration of an ESP32 with sensors, a servo motor, and a DC motor can be used to develop an automatic fertilization system. However, the study did not specifically regulate the fertilizer dosage; consequently, the amount of fertilizer delivered was not fully controlled according to plant requirements.

Based on the analyzed literature, the technologies used in automatic fertilizer-spreading systems can be grouped as presented in Table 3.

Table 3
Technologies Used in Automatic Fertilizer-Spreading Systems

Component	Technology Used	Function
Microcontroller	Arduino Uno, Arduino Nano, ESP32	Processes sensor data and controls the actuators.
Sensor	Ultrasonic sensor, light sensor, soil-moisture sensor	Detects operational conditions and supplies data to the controller.
Aktuator	DC motor, servo motor, pump, relay	Drives the fertilizer-dispensing mechanism.
Fertilizer container	Tank or storage container	Stores the fertilizer before it is distributed.
Dispensing mechanism	Pump, channel, valve, or pusher	Controls the fertilizer released from the container.
Control system	Arduino program or web server	Regulates the timing, position, and fertilization process.

In a fertilizer-spreading system installed on an electric bicycle, vehicle speed must be considered. If the vehicle moves too quickly while the fertilizer-discharge rate remains constant, the amount of fertilizer received per unit area may decrease. Conversely, if the vehicle moves too slowly, excessive fertilizer may be applied to a particular area.

Conceptually, the fertilizer-discharge rate can be formulated as follows:

$$Q = R \times v \times w \tag{1}$$

where (Q) is the fertilizer-discharge rate, (R) is the predetermined fertilizer dose per unit area, (v) is the electric-bicycle speed, and (w) is the working width of the fertilizer spreader.

Therefore, an automatic fertilizer-spreading system should be equipped with a speed sensor or a control system capable of adjusting the fertilizer-discharge rate in response to changes in vehicle speed.

3.4 Integration Potential of Solar Panels, Batteries, Electric Bicycles, and Fertilizer Spreaders

The findings related to RQ3 indicate that photovoltaic panels, batteries, electric bicycles, and automatic fertilizer-spreading systems can be conceptually integrated into a mobile agricultural fertilization system. This integration consists of photovoltaic panels for converting solar energy into electrical energy, a charging controller for regulating the energy supplied to the battery, a battery for storing and supplying power, and an electric bicycle and fertilizer spreader serving as the mobile platform and fertilizer-application system, respectively.

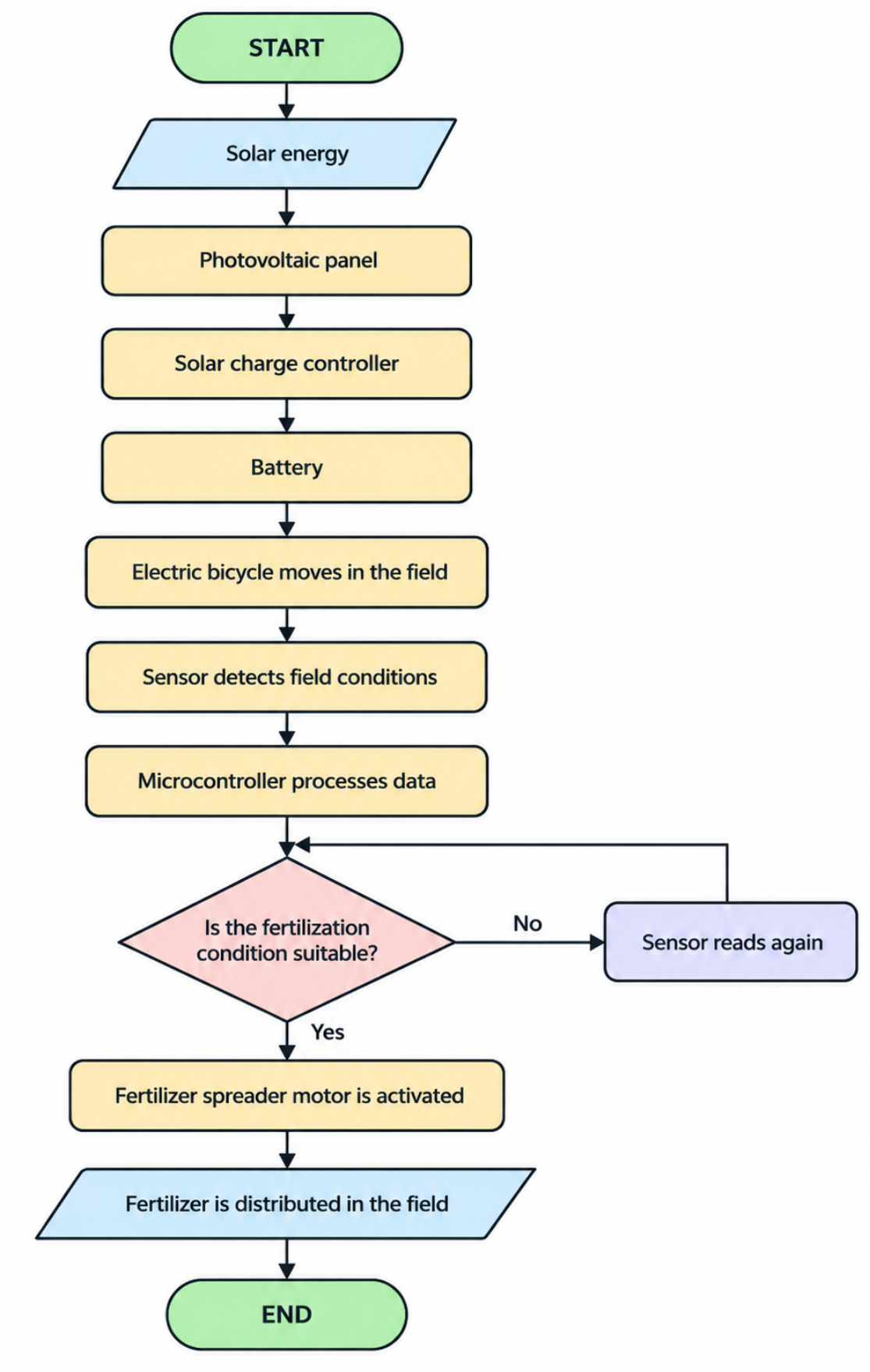

Fig. 1. Flow diagram of the automatic fertilization system based on an

Figure 1 presents the flow diagram of an automatic fertilization system based on an electric bicycle powered by photovoltaic energy. Solar energy is converted into electrical energy by the photovoltaic panel, regulated by the solar charge controller, and stored in the battery. The stored energy is used to power the electric bicycle, sensors, microcontroller, and fertilizer-spreading motor. The sensors monitor the operating conditions, while the microcontroller processes the data to determine when the fertilizer-spreading mechanism should be activated.

Based on the diagram, the photovoltaic panel generates electrical energy when exposed to solar radiation. The electrical energy is regulated by the solar charge controller and stored in the battery. The battery subsequently supplies energy to the electric-bicycle motor, fertilizer-spreading motor, sensors, and microcontroller. The total energy requirement of the system can be expressed as follows:

$$E_{total} = E_{bicycle} + E_{spereader} + E_{sensor} + E_{control} + E_{losses} \quad (2)$$

Where: E_{total} is the total energy requirement; $E_{bicycle}$ is the energy required to propel the electric bicycle; $E_{spreader}$ is the energy required to operate the fertilizer-spreading mechanism; E_{sensor} is the energy consumed by the sensors; $E_{control}$ is the energy consumed by the microcontroller and control devices; and E_{losses} is the energy lost in the battery, cables, converter, and other components.

Based on previous studies, solar panels can be used to charge electric-vehicle batteries, while microcontrollers and actuators can be used to operate automatic fertilization systems. Therefore, these two groups of technologies can conceptually be combined on a single platform.

Nevertheless, several aspects must be considered in such an integration. The electric-bicycle motor requires a relatively large amount of energy, particularly when carrying a fertilizer load and operating on uneven terrain. In addition, the fertilizer-spreading mechanism requires additional energy to operate its motor, pump, or actuator.

The weight of the photovoltaic panels, battery, fertilizer container, frame, motor, and other components affects the vehicle's energy consumption. The greater the total system weight, the greater the energy required to propel the electric bicycle. Therefore, the system design must consider the balance among battery capacity, photovoltaic-panel area, total vehicle weight, fertilizer capacity, motor power, operating time, and the area of land that can be serviced.

The potential benefits of the integrated system include reduced fossil fuel consumption, emissions, and noise; decreased dependence on manual labor; improved consistency in fertilizer distribution; greater utilization of renewable energy; support for fertilization activities on small- and medium-sized farms; and the potential for automated process monitoring and control.

Nevertheless, the findings of this review remain conceptual. It has not yet been established whether the power generated by the photovoltaic panel can meet the entire energy demand of the system without additional charging. Therefore, experimental testing is required to determine the appropriate photovoltaic panel and battery capacities and to evaluate operating time, energy consumption, and fertilizer-spreading performance.

3.5 Challenges and Development Opportunities

The literature synthesis identifies several challenges associated with the development of a solar-powered, electric bicycle-based automatic fertilizer-spreading system.

3.5.1 Limited Solar Panel Power

An electric bicycle has a limited surface area available for solar panel installation. Consequently, the electrical power generated by the photovoltaic panel may not always be sufficient to charge the battery and operate the motor simultaneously.

3.5.2 Dependence on Weather Conditions

Solar energy generation depends on the intensity of solar radiation. Cloudy weather, rainfall, shading, dust accumulation, and changes in the vehicle's position can reduce the power output of the photovoltaic panel.

3.5.3 Battery Capacity and Weight

A battery with a larger capacity can extend the operating duration of the system but also increases the overall vehicle weight. This additional weight may increase energy consumption and affect bicycle performance when transporting fertilizer across agricultural land.

3.5.4 Additional Load of the Fertilizer-Spreading Mechanism

The fertilizer spreader motor, pump, sensors, and microcontroller introduce additional electrical loads beyond the bicycle's propulsion motor. Therefore, the combined energy requirements of all system components must be considered when determining the total power demand.

3.5.5 Agricultural Land Conditions

Muddy, sloping, rocky, or uneven agricultural terrain can increase the load on the electric motor. Such conditions may also generate vibrations that affect the stability of the fertilizer container and spreading mechanism.

3.5.6 Fertilizer Characteristics

Fertilizer particle size, moisture content, shape, and density can influence the discharge rate. Moist or agglomerated fertilizer may obstruct the dispensing outlet, resulting in nonuniform fertilizer distribution.

3.5.7 Limitations of Previous Studies

Previous studies investigating solar panels installed on electric bicycles have primarily focused on battery-charging performance. Meanwhile, research on automatic fertilization has generally been conducted using potted plants, specific crops, or liquid fertilizer spraying systems. Few studies have evaluated an integrated system under actual agricultural field conditions.

3.5.8 Development Opportunities

Based on the reviewed findings, future development may focus on designing an electric bicycle with a lightweight structure, optimizing the solar panel area and battery capacity, incorporating a

high-efficiency solar charge controller, and developing an appropriate battery management system. Furthermore, a speed sensor could be integrated to regulate the fertilizer discharge rate, while a weight sensor or fertilizer flow sensor could be employed to measure the quantity of fertilizer released more accurately.

Additional development opportunities include designing a spreading mechanism suitable for solid fertilizers and protecting electronic components against water, dust, vibration, and corrosion. The system should also be evaluated under different agricultural field conditions to determine the effects of surface characteristics, slope, and soil moisture on vehicle performance. Assessments of energy consumption, operating duration, fertilizer dosage accuracy, and operational capacity are also necessary to establish the overall feasibility of the proposed system.

Overall, the review indicates that integrating solar energy, batteries, electric bicycles, and automatic fertilizer-spreading systems has the potential to support more efficient and sustainable agricultural operations. Photovoltaic panels can function as an auxiliary energy source, batteries can serve as energy storage devices, the electric bicycle can provide the mobile platform, and the automatic control system can regulate the fertilizer-spreading process.

However, the proposed system requires further validation through prototype development and field testing. Such evaluations should include photovoltaic panel power output, battery energy consumption, operating duration, vehicle speed, fertilizer-spreading capacity, distribution uniformity, and the effects of different field conditions.

Table 4
Summary of Findings Based on the Research Questions

Research Questions	Summary of Findings
RQ1	Solar energy can be utilized as an auxiliary energy source for charging electric vehicle batteries. System performance is influenced by photovoltaic panel capacity, solar radiation intensity, panel type, charging control system, installation position, and battery condition.
RQ2	Automatic fertilizer-spreading systems can incorporate Arduino or ESP32 microcontrollers, ultrasonic sensors, light sensors, DC motors, servo motors, pumps, relays, and web servers. Their performance is influenced by sensor accuracy, fertilizer characteristics, metering mechanisms, vehicle speed, and system calibration.
RQ3	Solar panels, batteries, electric bicycles, and fertilizer spreaders can be conceptually integrated into a mobile agricultural fertilization system. However, energy capacity, overall system weight, terrain conditions, available panel area, and electrical power requirements must be evaluated through prototype development and testing.

4. Conclusions

The findings of this systematic literature review indicate that solar energy can serve as an additional energy source to support the operation of electric vehicles, including electric bicycles, through photovoltaic panels and battery energy storage systems. The review demonstrates that the performance of solar energy systems is influenced by photovoltaic panel capacity and type, solar radiation intensity, installation orientation, battery condition, and vehicle load. Integrating solar energy into electric vehicles can reduce dependence on conventional energy sources for operational requirements. However, because electric bicycles have limited surface areas available for photovoltaic panel installation, solar panels are more suitable as supplementary energy sources, while batteries remain the primary energy storage medium. Therefore, solar-assisted electric bicycles offer potential for the development of renewable-energy-powered mobile agricultural systems.

The review of automatic fertilizer dispensing systems indicates that these technologies can incorporate microcontrollers, such as Arduino or ESP32, integrated with sensors, actuators, and fertilizer dispensing mechanisms. Sensors and microcontrollers enable automated control of fertilization activities, while DC motors, servo motors, pumps, and relays operate the fertilizer dispensing mechanisms. System performance is influenced by sensor accuracy, fertilizer characteristics, metering mechanisms, vehicle speed, and calibration procedures. Vehicle speed is particularly important because variations in speed can affect the quantity of fertilizer applied per unit area. Consequently, an automatic fertilizer-spreading system should be designed to adjust the fertilizer discharge rate according to operating conditions and vehicle speed to maintain consistent fertilizer distribution.

Based on the synthesis of the reviewed studies, photovoltaic panels, batteries, electric bicycles, and automatic fertilizer-spreading systems can be conceptually integrated into a mobile agricultural fertilization platform. The photovoltaic panels generate electrical energy, the solar charge controller regulates energy supplied to the battery, the battery stores and delivers electrical power, and the electric bicycle and fertilizer-spreading mechanism function as the mobile platform and fertilizer application system, respectively. This integration has the potential to reduce dependence on conventional energy sources and manual labor while improving the consistency of fertilizer application. Nevertheless, limitations related to photovoltaic panel area, weather dependence, battery capacity and weight, additional electrical loads, agricultural terrain conditions, and fertilizer characteristics may affect overall system performance. Therefore, further investigation through prototype development and field testing is required to evaluate photovoltaic power generation, battery energy consumption, operating duration, fertilizer-spreading capacity, and the accuracy and uniformity of fertilizer distribution under different operating conditions.

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Conflict of Interest Statement
The authors declare that they have no conflicts of interest regarding the publication of this paper. The research was conducted independently, without any commercial or financial relationships that could have influenced the study findings or their interpretation.

Author Contributions Statement
Sheila Reinanda: Writing – original draft, Results analysis, Data interpretation, Investigation, Visualization.
Yashinta Naila Evi: Methodology, Literature search, Data curation, Investigation, Writing – original draft.
Yurike Dwi: Conceptualization, Writing – original draft, Investigation, Formal analysis.
Olivia: Writing – original draft, Conclusion, Data curation, Reference management, Citation analysis.
Singgih Dwi: Supervision, Methodology, Validation, Writing – review and editing.
All authors contributed to the revision and approval of the final manuscript.

Data Availability Statement

The data analyzed in this study were obtained from scientific publications retrieved through ResearchGate, Scopus, ScienceDirect, IEEE Xplore, and Google Scholar. All sources used in the study are cited in the reference list. The data analyzed are available from the corresponding author upon reasonable request.

Ethics Statement

This study was based exclusively on published literature and did not involve human participants, animals, or the collection of personal data. Therefore, ethical approval and informed consent were not required.

References

[1] Mocera, Francesco, Aurelio Somà, Salvatore Martelli, and Valerio Martini. "Trends and Future Perspective of Electrification in Agricultural Tractor-Implement Applications." Energies 16, no. 18 (2023): 6601. https://doi.org/10.3390/en16186601.

[2] Pambudi, Wahyu Setyo, Candra Fahreza Ardhani, Yuliyanto Agung Prabowo, Misbahul Munir, Novian Patria Uman Putra, and Titiek Suheta. "Desain Pengisian Baterai Sepeda Listrik dengan Solar Cell." Jurnal Informatika dan Teknik Elektro Terapan 14, no. 2 (2026). https://doi.org/10.23960/jitet.v14i2.9240.

[3] Asrori, Asrori, Faizul Ahmad Jatmiko, Mohammad Noor Hidayat, and Dony Perdana. "Pengaruh Panel Surya Bentuk Flat dan Flexy terhadap Daya Pengisian Baterai Sepeda Listrik." Jurnal Rekayasa Hijau 7, no. 1 (2023): 90–100. https://doi.org/10.26760/jrh.v7i1.90-100.

[4] Nainggolan, Benhur, Fadhilla Inaswara, Gilang Pratiwi, and Hirzan Ramadhan. "Rancang Bangun Sepeda Listrik Menggunakan Panel Surya sebagai Pengisi Baterai." Jurnal Poli-Teknologi 15, no. 3 (2017). https://doi.org/10.32722/pt.v15i3.861.

[5] Xue, Xiuyun, Xufeng Xu, Zelong Zhang, Bin Zhang, et al. "Variable Rate Liquid Fertilizer Applicator for Deep-Fertilization in Precision Farming Based on ZigBee Technology." IFAC-PapersOnLine 52, no. 30 (2019): 43–50. https://doi.org/10.1016/j.ifacol.2019.12.487.

[6] Commault, Benjamin, Tatiana Duigou, Victor Maneval, Julien Gaume, Fabien Chabuel, and Eszter Voroshazi. "Overview and Perspectives for Vehicle-Integrated Photovoltaics." Applied Sciences 11, no. 24 (2021): 11598. https://doi.org/10.3390/app112411598.

[7] Mogavi, Reza Hadi, Bingcan Guo, Yuanhao Zhang, Ehsan Ul Haq, Pan Hui, and Xiaojuan Ma. "When Gamification Spoils Your Learning: A Qualitative Case Study of Gamification Misuse in a Language-Learning App." In Proceedings of the Ninth ACM Conference on Learning @ Scale. Association for Computing Machinery, 2022. https://doi.org/10.1145/3491140.3528274.

[8] Mirzakhaninafchi, Hasan, Manjeet Singh, Vishal Bector, O. P. Gupta, and Rajvir Singh. "Design and Development of a Variable Rate Applicator for Real-Time Application of Fertilizer." Sustainability 13, no. 16 (2021): 8694. https://doi.org/10.3390/su13168694.

[9] Anggraini, Safira Nur, I Putu Surya Wirawan, and I Gusti Ketut Arya Arthawan. "Rancang Bangun Alat Pemupuk Otomatis pada Tanaman Kangkung." Jurnal BETA (Biosistem dan Teknik Pertanian) 14, no. 1 (2026): 10–23. https://doi.org/10.24843/jbeta.2026.v14.i01.p02.

[10] Park, Chanwook, Haneul Park, Hwanhee Jeon, Kyoik Choi, and Jangwon Suh. "Evaluation and Validation of Photovoltaic Potential Based on Time and Pathway of Solar-Powered Electric Vehicle." Applied Sciences 13, no. 2 (2023): 1025. https://doi.org/10.3390/app13021025.

[11] Prasetyo, Kurnifan Adhi. "Pengembangan Alat Control Charging Panel Surya Menggunakan Aduino Nano untuk Sepeda Listrik Niaga." Jurnal Edukasi Elektro 2, no. 1 (2018): 50–58. https://doi.org/10.21831/jee.v2i1.19947.

[12] Pratama, Mochamad Rendi, Jamaaluddin Jamaaluddin, and Indah Sulistiyowati. "Electric Bicycle Battery Charging System Design Using Solar Panel." JEEE-U (Journal of Electrical and Electronic Engineering-UMSIDA) 8, no. 2 (2024): 71–81. https://doi.org/10.21070/jeeeu.v8i2.1698.

[13] Prayoga, Kadek Agus Mahabojana Dwi, and I Gusti Ngurah Agung Pawana P. "Pengembangan Sistem Penyiraman dan Pemupukan Otomatis Berbasis ESP32 dengan RTC dan Blynk." Jurnal Ilmiah Telsinas Elektro, Sipil dan Teknik Informasi 8, no. 1 (2025): 1–10. https://doi.org/10.38043/telsinas.v8i1.6020.

[14] Reddy, Chandrasekhar, Razia Sultana W., and V. Sunitha. "Towards Sustainable Farming: A State of Art Review on Electrification of a Farm Tractor." Results in Engineering 25 (2025): 104403. https://doi.org/10.1016/j.rineng.2025.104403.

[15] Samadi, Hamid, Guido Ala, Pietro Romano, and Fabio Viola. "Investigation of Effective Factors on Vehicles Integrated Photovoltaic (VIPV) Performance: A Review." World Electric Vehicle Journal 14, no. 6 (2023): 154. https://doi.org/10.3390/wevj14060154.

[16] Azis, A., R. P. A. Setiawan, W. Hermawan, and T. Mandang. "Dynamic Performance Test of Auger-Type Metering Device for Variable Rate Fertilizer Applicator (VRFA)." IOP Conference Series: Earth and Environmental Science 486, no. 1 (2020): 012064. https://doi.org/10.1088/1755-1315/486/1/012064.

[17] Scolaro, Elia, Matteo Beligoj, Manuel Perez Estevez, Luigi Alberti, Massimiliano Renzi, and Michele Mattetti. "Electrification of Agricultural Machinery: A Review." IEEE Access 9 (2021): 164520–41. https://doi.org/10.1109/ACCESS.2021.3135037.

[18] Siddique, Md Abu Ayub, Cheol-Woo Yang, Nyunki Chung, Seung-Min Baek, Seung-Yun Baek, Hyeon-Ho Jeon, Yeon-Soo Kim, Wan-Soo Kim, and Yong-Joo Kim. "Usable Time Estimation and Suitable Battery Selection for Electric Tractor Considering Agricultural Operational Load." Scientific Reports 15, no. 1 (2025): 36606. https://doi.org/10.1038/s41598-025-20517-5.

[19] Suh, Jangwon. "Estimation of Photovoltaic Potential of Solar-Powered Electric Vehicle: Case Study of Commuters on Donghae Expressway, Korea." Applied Sciences 14, no. 15 (2024): 6574. https://doi.org/10.3390/app14156574.

[20] Suhardi. "Pemupukan Tanaman Otomatis Menggunakan Sensor Ultrasonik dan Cahaya Berbasis Arduino Uno R3." JISTech (Journal of Islamic Science and Technology) 5, no. 1 (2020): 49–61. https://doi.org/10.30829/jistech.v5i1.7662.

[21] Tanaka, Takashi S. T., Gerard B. M. Heuvelink, Taro Mieno, and David S. Bullock. "Can Machine Learning Models Provide Accurate Fertilizer Recommendations?" Precision Agriculture 25, no. 4 (2024): 1839–56. https://doi.org/10.1007/s11119-024-10136-x.

[22] Chauhan, Suhani, and Lalit Mittal. "Solar-Powered Agricultural Vehicles: Advancing Sustainable Farming in India." The Indian Journal of Agricultural Sciences 95, no. 2 (2025): 233–36. https://doi.org/10.56093/ijas.v95i2.157126.

[23] Vullaganti, Niharika, Billy G. Ram, and Xin Sun. "Precision Agriculture Technologies for Soil Site-Specific Nutrient Management: A Comprehensive Review." Artificial Intelligence in Agriculture 15, no. 2 (2025): 147–61. https://doi.org/10.1016/j.aiia.2025.02.001.

[24] Wang, Luxi, Jianmin Gao, and Waqar Ahmed Qureshi. "Evolution and Application of Precision Fertilizer: A Review." Agronomy 15, no. 8 (2025): 1939. https://doi.org/10.3390/agronomy15081939.