The 11th Asian-Australasian Conference on Precision Agriculture (ACPA 11)
October 14-16, 2025, Chiayi, Taiwan

Development of a Smart Low-Carbon Greenhouse Integrated Plasma-Activated Water and Second-Life EV Batteries

Chiao-Yin Tu[1], Yulian Fatkur Rohman[1], Muhammad Bilhaq Ashlah[1], Wu-Yang Sean[1*], Chia-Chiang Chang[2], Hong-Yi Wang[2], Jung-Tsan Lin[3], Chen-Yang Tai[3], Ya-Shih Chen[4]

[1] Department of Bio-Industrial Mechatronics Engineering, National Chung Hsing University, Taiwan. [2] AP Plasma Corporation, Taiwan. [3] Limited Liability Taichung Jin San Jiao Fruits and Vegetables Marketing Cooperative, Taiwan. [4] Industrial Technology Research Institute, Taiwan.

*Corresponding Author: wysean@nchu.edu.tw

Abstract

Global warming and the excessive use of nitrogen fertilizers pose significant challenges to sustainable agriculture. This study presents a smart low-carbon greenhouse system powered by a solar photovoltaic microgrid, integrated with second-life electric vehicle batteries and a real-time energy management system. Plasma-activated water (PAW) technology is employed to reduce dependence on chemical nitrogen fertilizers while enhancing crop productivity and reducing nitrous oxide emissions. The system incorporates wireless IoT sensors and a cloud platform to monitor energy production, consumption, battery storage, key battery health parameters, and PAW production. Field tests on tomatoes and sponge gourds in a subtropical environment demonstrated that the microgrid supplied an average of 74.7% of the greenhouse's energy demand, achieving up to 98% off-grid operation and reducing approximately 1,344 kg of CO_2e emissions. The second-life batteries, managed by the energy system, ensured stable power supply by addressing thermal resistance and impedance challenges. PAW application reduced nitrogen fertilizer use by 14.9%, improved fruit quality, and maintained nitrite levels within safety standards. This integrated solution shows strong potential for enhancing energy resilience, lowering carbon emissions, and advancing sustainable agriculture. Future research will focus on further optimizing automated controls and evaluating economic feasibility for broader deployment.

Keywords: smart agriculture , Internet of Things (IoT) , second-life batteries, plasma-activated water (PAW), low-carbon greenhouse

INTRODUCTION

Climate change, excessive fertilizer use, and rising energy demand necessitate sustainable agricultural solutions (IPCC, 2022). Conventional greenhouses consume high energy for lighting, irrigation, and climate control, while synthetic nitrogen fertilizers drive nitrous oxide (N_2O) emissions, a potent greenhouse gas (Butterbach-Bahl et al., 2013).

IoT technologies have improved agricultural resource efficiency by enabling real-time monitoring and optimizing irrigation (Channe et al., 2022). However, most applications remain function-specific, focusing on tasks such as sensing or irrigation control (Boursianis et al., 2022). Few studies integrate IoT with both energy management and sustainable nutrient supply, which are crucial for reducing greenhouse gas emissions and increasing resilience.

MATERIALS AND METHODS

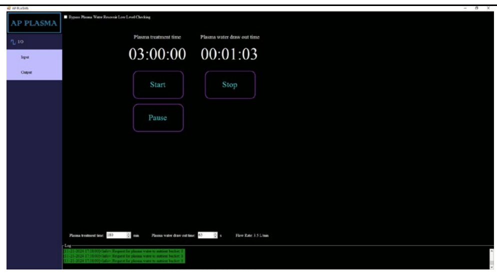

Fig.1 Facility control system connection system interface

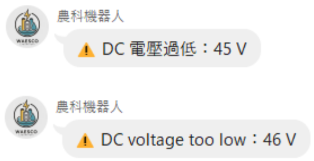

Fig.2 Battery low voltage alarm

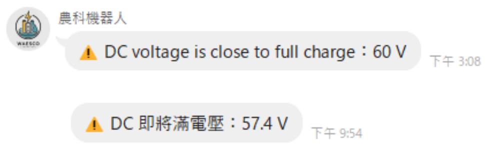

Fig.3 Battery full voltage alarm

The system integrates a photovoltaic (PV) microgrid, second-life EV batteries, and plasma-activated water (PAW) production into a unified IoT framework. The PV and battery subsystem provided renewable energy with real-time monitoring of voltage, current, impedance, and temperature, supported by adaptive algorithms for safety and lifetime prediction. The plasma unit produced PAW as a sustainable nitrogen source, with automated control of water intake, output power, and treatment duration based on storage levels and energy availability.

All operational data—including PV generation, battery health, and PAW concentration—were collected by IoT sensors and transmitted to a cloud platform for centralized monitoring and automated control. This integration allowed coordinated management of energy supply and nutrient delivery, ensuring stable greenhouse operation.

RESULTS & DISCUSSION

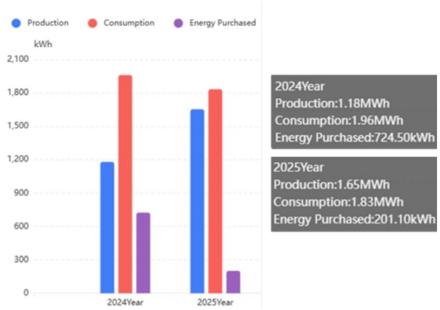

Figure 4. Statistical Summary of PV System Performance During the Testing Period

$$Total\ PV\ Production\ (MWh) \times 1{,}000 \times Carbon\ Emission\ Factor\ (kg\ CO^2e/kWh) = Reduce\ Carbon\ Emissions \quad (1)$$

$$2.83 \times 1{,}000 \times 0.475 = 1{,}344.25\ kg\ CO_2e \quad (2)$$

Field trials in a subtropical greenhouse with tomato (Solanum lycopersicum) and sponge gourd

(Luffa cylindrica) demonstrated the effectiveness of the integrated system. Based on the global average grid carbon emission factor of 0.475 kg CO_2e/kWh reported by the International Energy Agency Photovoltaics supplied an average of 74.7% of energy demand and enabled up to 98% off-grid operation, reducing approximately 1,344 kg CO_2e emissions. Continuous monitoring of impedance and thermal resistance allowed predictive battery lifetime modeling, extending the estimated service life of second-life EV batteries by 9.3 years while ensuring safe operation.
Plasma-activated water reduced synthetic nitrogen fertilizer use by 14.9% without compromising crop yield or fruit quality, and nitrite concentrations remained below safety thresholds. These results highlight the potential of combining renewable microgrids, circular energy storage, and sustainable fertilization within an IoT-based framework. Compared with conventional greenhouses, the system achieved lower carbon emissions, higher energy resilience, and improved input efficiency, demonstrating a scalable pathway toward low-carbon smart agriculture.

CONCLUSIONS

This study demonstrates the potential of IoT technologies to advance sustainable agriculture through intelligent energy management and precision nutrient application. By integrating a solar photovoltaic microgrid, second-life electric vehicle batteries, and PAW production within a unified IoT framework, the greenhouse achieved high energy resilience, reduced carbon emissions, and improved crop yield and quality. The results highlight how IoT-driven integration of renewable energy, circular battery use, and sustainable fertilization can transform greenhouses into low-carbon, data-driven, and autonomous agricultural systems.
Although the proposed system has shown promising results under subtropical greenhouse conditions, future research should expand its validation across diverse climatic zones and crop species to assess scalability and adaptability. Further integration of predictive analytics and machine learning could enhance decision-making for energy dispatch, battery lifetime management, and crop growth optimization. In addition, evaluating the system's techno-economic feasibility at larger scales, including commercial farming operations, will be critical for translating this model into practical applications. Ultimately, the combination of IoT, renewable energy, and sustainable nutrient management provides a blueprint for next-generation smart farming systems capable of addressing global food security and climate challenges.

REFERENCES

Shukla, P. R., Skea, J., Slade, R., Al Khourdajie, A., van Diemen, R., McCollum, D., ... & Malley, J. (2022). Climate change 2022: Mitigation of climate change. Contribution of working group III to the sixth assessment report of the Intergovernmental Panel on Climate Change, 10, 9781009157926.

Butterbach-Bahl, K., Baggs, E. M., Dannenmann, M., Kiese, R., & Zechmeister-Boltenstern, S. (2013). Nitrous oxide emissions from soils: how well do we understand the processes and their controls?. Philosophical Transactions of the Royal Society B: Biological Sciences, 368(1621), 20130122.

Boursianis, A. D., Papadopoulou, M. S., Diamantoulakis, P., Liopa-Tsakalidi, A., Barouchas, P., Salahas, G., ... & Goudos, S. K. (2022). Internet of things (IoT) and agricultural unmanned aerial vehicles (UAVs) in smart farming: A comprehensive review. Internet of Things, 18, 100187.

International Energy Agency (IEA). *Emission Factors 2023 Database Documentation*; IEA: Paris, France, 2023.