Smart hydroponic greenhouse with solar energy for urban agriculture

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Article Info

ABSTRACT

Increased industrial activity in South Cikarang has limited the availability of agricultural land, encouraging the adoption of controlled environment agriculture systems. This study describes the design and implementation of a smart hydroponic greenhouse that is fully supported by a 600 Wp solar photovoltaic (PV) system and controlled using an industrial-grade programmable logic controller (PLC). This system automatically regulates temperature and humidity through exhaust fans and sprayers based on real-time sensor feedback. Experimental results show that when the internal temperature exceeds 31 °C, the control system recovers to 29.7 °C within 15 minutes and maintains a temperature range of 24–30 °C. Relative humidity is maintained within the optimal range of 75–90%. The PV system produces an average daily energy output of approximately 2.0 kWh, resulting in an energy self-sufficiency ratio (ESR) of 138%, which indicates excess energy production compared to system demand. These results prove that the integration of industrial automation with renewable energy provides reliable environmental control, high energy efficiency, and operational stability for hydroponic greenhouse applications in urban industrial areas.

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1. INTRODUCTION

The rapid growth of urbanization and industrial development has intensified land-use competition and environmental degradation in developing countries [1]. In particular, the South Cikarang region in West Java, Indonesia, has transformed into a densely industrialized zone, leading to the conversion of agricultural land into factories and infrastructure [2]. This phenomenon has triggered two critical issues: the diminishing availability of fertile land for food production and the decline of soil quality due to industrial pollutants [3]–[5]. These factors, in turn, threaten local food security and increase the community's dependency on external food distribution networks, which are often vulnerable to logistical and economic disruptions [6]. To address these challenges, urban agriculture has gained momentum as a viable alternative to conventional farming, especially in land-constrained areas. One of the most promising approaches is hydroponics, a soilless cultivation system that allows plants to grow in nutrient-rich water solutions [7]–[9]. Hydroponic systems, when integrated into greenhouses, can provide a controlled microclimate environment that optimizes plant growth, conserves water, and maximizes land efficiency [10]–[12]. The application of automation and internet of things (IoT)-based monitoring has further enhanced the efficiency and productivity of hydroponic greenhouses [13]–[16].

Despite these advances, several limitations remain. Many existing smart farming solutions are based on microcontroller platforms such as Arduino and ESP32 [17]–[20]. While suitable for prototyping and

academic studies, these devices often lack the robustness, processing capability, and scalability required for long-term [21] deployment in industrial or semi-urban contexts. Furthermore, many of these systems implement only partial automation such as temperature control or irrigation timing rather than comprehensive, multi-variable environmental management. Additionally, the reliance on grid electricity makes them vulnerable to power interruptions, which can be frequent in semi-urban industrial zones. Many studies on greenhouses, smart farming, and hydroponics have not yet integrated programmable logic controller (PLC) control with assisted or partial energy sources from solar power plants [22]–[25].

Renewable energy, particularly solar photovoltaic (PV) technology, offers a compelling solution for enhancing the autonomy and resilience of smart agricultural systems [26], [27]. Solar energy can be harnessed to power critical greenhouse operations such as pumps, lighting, sensors, and control units, thereby reducing dependency on fossil fuels and central grid infrastructure [28]. However, the integration of solar PV systems with robust, industrial-grade automation in hydroponic greenhouses remains limited in existing studies. This research presents a smart hydroponic greenhouse that integrates renewable energy with PLC-based automation to control key environmental parameters, including temperature, humidity, potential of hydrogen (pH), and light intensity, within a modular structure. A small-scale solar PV system is utilized as backup power to ensure operational continuity during grid outages. Compared to microcontroller-based approaches, the use of PLCs provides superior signal stability, environmental robustness, programming flexibility, and compatibility with industrial sensors and actuators [29], [30].

The objectives of this study are fourfold: (i) to design a scalable hydroponic greenhouse system that is suitable for limited urban land, (ii) to integrate a solar-assisted backup power source, (iii) to implement precise automation of key climate parameters using PLCs, and (iv) to demonstrate the feasibility of the system as a replicable model for food production in industrial urban zones. A prototype unit will be built on a university campus in South Cikarang, serving both as a research model and a community empowerment center. The novelty of this research lies in three main aspects: (i) the integration of multi variable environmental control using PLC in a hydroponic system, (ii) the combination of renewable energy through a solar power plant system (*pembangkit listrik tenaga surya*, PLTS) with industrial grade automation in a low-cost, replicable model, and (iii) the real-world deployment of the system to empower communities in regions facing urban agricultural challenges.

2. METHOD

2.1. Site and system overview

This study was conducted in South Cikarang, West Java, an industrial area with limited agricultural land. A modular hydroponic greenhouse prototype was developed on a campus site, integrating an nutrient film technique (NFT) hydroponic system, a fully solar-powered energy supply, and PLC-based automation. The system consists of a modular greenhouse structure, PV unit with battery storage, environmental sensors, and automatically controlled actuators. The overall system configuration is shown in Figure 1.
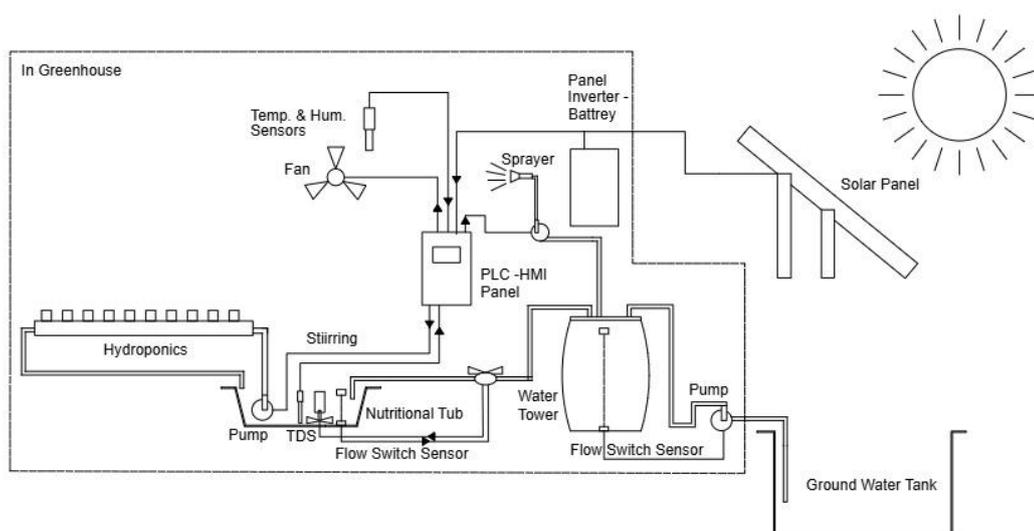

Figure 1. Integrated greenhouse system scheme

2.2. System design and implementation
2.2.1. Greenhouse hydroponic modular design

The greenhouse was designed as a compact modular structure for efficient space utilization in industrial urban areas. An NFT hydroponic system was implemented to optimize water and nutrient use, supported by integrated lighting, ventilation, sensors, and actuators for environmental control. The system consists of a modular greenhouse frame, hydroponic growing bed, nutrient tank, PLC control cabinet, and a PV power unit, as shown in Figures 2 and 3. Environmental parameters including temperature, humidity, light intensity, and pH are monitored in real time, while the PLC automatically controls pumps, exhaust fans, and lighting. All electrical loads are fully supplied by a solar PV system with battery storage, enabling autonomous and scalable greenhouse operation.
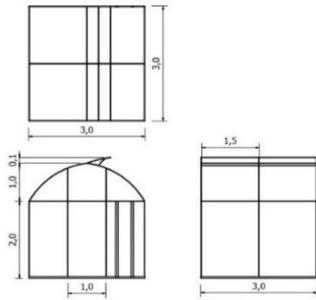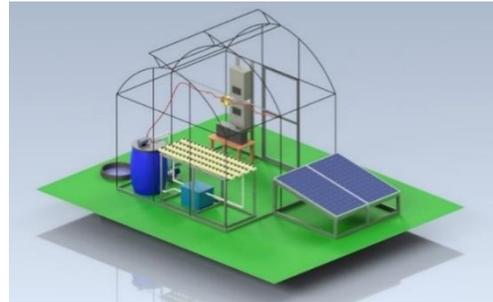

Figure 2. The dimensions of the greenhouse plan

Figure 3. Three-dimensional design of the proposed PLC-based smart greenhouse powered by PV solar energy

2.2.2. System block diagram description

All greenhouse energy demands including sensors, pumps, PLC, lighting, and ventilation are fully supplied by a standalone off-grid PLTS. The system uses 600 Wp monocrystalline PV modules, a 24 V / 100 Ah deep-cycle battery for 24-hour operation, and a hybrid inverter 2000 W and 30 A with MPPT charge controller for stable power conversion. The total daily energy consumption (E_{total}) was estimated based on the connected electrical loads.

$$E_{total} = \sum_{i=1}^{n} P_i \, x \, t_i \tag{1}$$

where,
P_i is the rated power of each load (pump, PLC, fan, light-emitting diode (LED))
t_i is the operational time (hours/day)

The overall configuration of the PV-powered smart greenhouse is shown in Figures 4. The system consists of two main subsystems: a renewable energy subsystem and a PLC-based automation and control subsystem. The PV subsystem supplies off-grid electrical power through PV modules, battery storage, and an inverter. The automation subsystem integrates a PLC, human–machine interface (HMI), sensors, and actuators to regulate temperature, humidity, and nutrient levels. Based on sensor feedback, the PLC automatically controls exhaust fans, sprayers, and pumps, while the HMI enables real-time monitoring and manual control. This integrated architecture ensures stable and autonomous greenhouse operation.
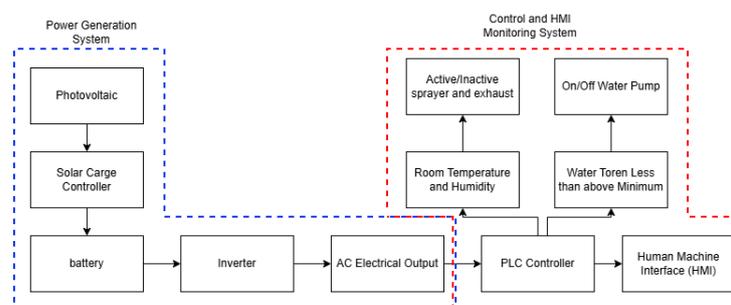

Figure 4. Block diagram of the integrated PLC-based smart greenhouse system powered entirely by PV solar energy

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2.2.3. Data acquisition, logging process and system integration

Data acquisition and logging are handled by the PLC as the central controller. Environmental parameters and actuator status are periodically collected, processed, and displayed in real time on the HMI. All data are logged as time-series records for performance evaluation and control optimization, supporting both real-time monitoring and offline analysis. The system integrates a PV power subsystem with a PLC-based control and monitoring interface for fully off-grid operation. The PLC processes sensor inputs and regulates actuators based on predefined temperature (<30 °C) and humidity (75–90%) setpoints. System components communicate through standard industrial interfaces, while the HMI provides real-time visualization and manual control. This architecture ensures reliable, energy-autonomous, and scalable greenhouse operation. The interface can be seen in Figure 5.

Figure 5. HMI system

2.2.4. Experimental setup and measurement procedure

The experimental setup was designed to evaluate a PLC-controlled smart greenhouse powered by a standalone PV system. The prototype was installed at Politeknik Takumi, South Cikarang, under semi-urban conditions with high solar exposure. The greenhouse features a modular polycarbonate structure and an NFT hydroponic system. Automation is handled by a Haiwell PLC interfaced with temperature humidity, pH, and total dissolved solids (TDS) sensors, and actuators including exhaust fans, sprayer pumps, and solenoid valves. A 600 Wp PV array with a 24 V/100 Ah battery, maximum power point tracking (MPPT) controller, and inverter supplies full off-grid power. System performance was tested for one week under varying weather conditions to evaluate control stability, energy self-sufficiency, and system reliability. Figure 6 is a real-world implementation.

Figure 6. The implemented smart greenhouse powered by PV system

3. RESULTS AND DISCUSSION
3.1. System performance overview

The implemented solar-powered PLC-based greenhouse automation system was tested continuously for one week under varying solar radiation and ambient temperature conditions. The results show that the system maintained stable environmental parameters within the predefined setpoints, with all electrical loads

fully supplied by the PV system. Average daily solar energy production ranged from 1.86 to 2.03 kWh/day, with an overall system efficiency of approximately 75%, including inverter and battery losses. The greenhouse's total daily energy consumption was about 1.45 kWh/day, as detailed in Table 1.

$$E_{total} = \sum_{i=1}^{n} P_i \; x \; t_i \tag{2}$$

Table 1. Total load consumption

Load	Total	Watts	Time (hours)	Energy (Wh/day)
Water pump	1	18	24	432
Lamp	1	5	1	5
PLC device	1	15	24	360
Water pump Simizu	1	300	1	300
Motor spray	1	12	2	24
Exhaust	2	82	2	328
Load total		432 Watt		1449 Wh/day

3.2. Environmental control performance

The PLC control system maintained stable greenhouse conditions during testing. As shown in Figure 7, internal temperature remained below 30 °C despite ambient temperatures above 33 °C, while relative humidity was controlled within 75–90%. Control actions were automatically executed through exhaust fan and sprayer activation based on real-time sensor feedback. These results confirm that PLC-based automation ensures stable and reliable microclimate regulation suitable for industrial urban environments. Environmental control rules are summarized in Table 2.

The system can generally reduce the temperature from peak (~34 °C) to below 30 °C within 30-40 minutes with the system's blower. For humidity, improvement from ~70-75% to the target of ~82-85% was achieved more quickly about 15-25 minutes when the sprayer was turned on with the prototype design spray rate. The blower + sprayer combination (simultaneous action) gave the shortest stabilization time (~38 minutes), as both variables were controlled simultaneously and did not work against each other. For excessive humidity conditions (nighttime), the short blower pulse strategy (3 minutes every 30 minutes) was effective in holding RH ≤ 90% while saving battery energy. Furthermore, the time-series graph (temperature and RH vs time) can be seen in Figure 7.

The Figure 7 presents the temperature and humidity response of the PLC-controlled, solar-powered greenhouse under varying daily conditions. At 08:00, stable conditions were observed (25.8 °C, 75% RH). When temperature rose to 34.7 °C at 14:00, the PLC activated the exhaust fan, stabilizing temperature at approximately 26.5 °C. During nighttime (18:30–22:00), humidity exceeded 90%, triggering the sprayer system and restoring humidity to 88–89%. On average, the system returned environmental conditions to target ranges within 5–10 minutes after deviation, confirming effective microclimate regulation using PLC-based control powered entirely by solar energy.
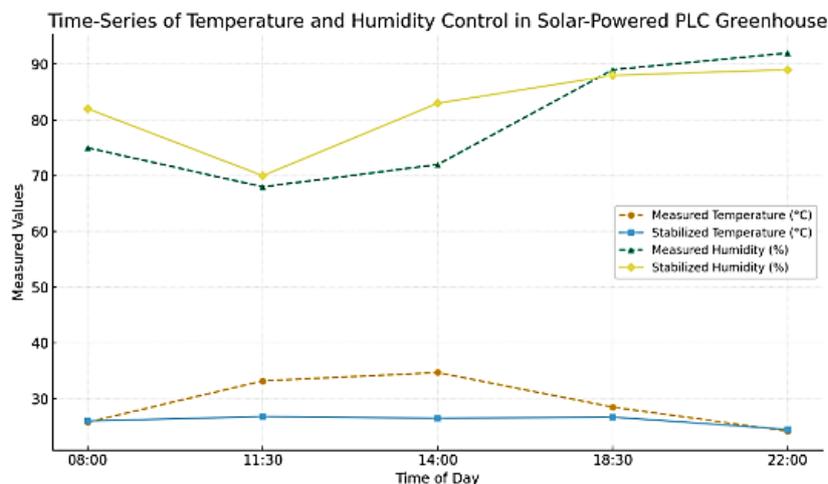

Figure 7. The time-series graph (temperature and RH vs time)

Table 2. Environmental control testing

Time (local)	Measured Temp (°C)	Measured relative humidity (RH, %)	Trigger condition	Actuator(s) activated	Activation duration (min)	Time to stabilize (min)	Stabilized values (temperature, °C / RH, %)	Remarks
08:00	25.8	75	RH < 80% (low humidity)	Sprayer pump (mist)	20	25	26.0/82	Sprayer cycle 20 min; RH reached 82% after 20 min, stabilized at 25 min due to residual evaporation
11:30	33.2	68	Temp > 27 °C (high temp)	Exhaust blower ON	35	40	26.8/70	Blower airflow reduced temperature; RH rises slightly after cooling but remains < 80%
14:00	34.7	72	Temp > 27 °C and RH < 80% (both require action)	Blower ON + sprayer ON (concurrent)	Blower 30 / sprayer 25	38	26.5/83	Blower reduces temp while sprayer restores RH; system stabilizes after 38 min
18:30	31	89	Temperature slightly >30 and RH > 90% (high humidity)	Blower ON (vent) — sprayer OFF	15	20	29.7/88	Blower reduces temp and lowers RH by improving exchange; sprayer kept off to avoid over-humidity
22:00	24.2	92	RH > 90% (excess humidity at night)	Blower intermittent (periodic flush)	3 min every 30 min (overnight)	N/A (managed)	24.5/89–90	Night strategy: short blower pulses to keep RH ≤ 90% without cooling below crop tolerance

3.3. Energy flow and autonomy analysis

Figure 7 shows the energy flow profile between the PV array, battery, and load throughout a typical testing day. During peak solar hours (10:00–14:00), the PV array generated surplus energy that simultaneously powered all greenhouse loads and recharged the battery bank. At night or during low-irradiance periods, the stored energy supplied the automation system through the inverter. The battery discharge depth remained below 35%, ensuring long-term sustainability and minimizing degradation. The energy self-sufficiency ratio (ESR) was calculated as (3) and (4).

$$ESR = \frac{E_{PV}}{E_{Load}} x100\% \tag{3}$$

$$ESR = \frac{2.0}{1.45} x100\% = 138\% \tag{4}$$

This result indicates that the system can operate autonomously without any external grid support while maintaining energy reserve capacity.

3.4. Reliability and system response analysis

The PLC executed sensor scanning and actuator response cycles with a scan time of approximately 50 ms, ensuring a near real-time response. No communication delay or actuation failure was observed during testing. Table 3 shows a series of performance parameters for the system. The high stability index (>95%) indicates that the PLC control system and the solar power source worked in synchrony to maintain optimal operational parameters throughout the observation period.

Table 3 summarizes the overall system performance indicators obtained during the experiments

Parameter	Target	Measured average	Stability index (%)
Temperature (°C)	≤ 30	26.4	98.2
Humidity (%)	75–90	84.6	96.5
ESR (%)	100	155.6	100
PLC response time (ms)	≤100	50	100
Uptime (%)	100	99.8	99.8

3.5. Comparative discussion and summary discussion

Compared to previous studies [31], [32] that implemented Arduino or ESP32-based greenhouse automation systems powered by power grid. Previous research used PLC system control [33]–[35] but still not integrated with renewable energy, namely solar energy using solar panels with a solar power generation system. this study introduces a fully autonomous industrial-grade control system powered entirely by solar energy. The PLC-based approach offers higher reliability for continuous operation, faster and deterministic control responses, and improved scalability for multi-greenhouse deployment. Its compliance with industrial automation standards makes it suitable for large-scale applications. Combined with PLTS as a renewable energy source, the system provides a practical and sustainable solution for smart agriculture in industrial and semi-urban areas with limited land and grid power availability.

The experimental results confirm the feasibility and reliability of the proposed solar-powered PLC-based greenhouse system. All operational processes were fully supported by the PV system, enabling complete off-grid operation with stable energy supply under typical weather conditions. The PLC control algorithm effectively maintained the greenhouse microclimate, keeping temperature below 30 °C and humidity within 75–90%, with stabilization achieved within 7–10 minutes after deviations occurred. Real-time monitoring and manual override through the HMI enhanced operational flexibility, while the use of an industrial PLC ensured reliable, deterministic, and scalable control compared to microcontroller-based systems. Battery-supported energy management also provided resilience under variable solar irradiance. Overall, the integration of PV energy and PLC automation offers a robust and sustainable solution for greenhouse operation in energy-constrained and industrial urban environments, with future potential for cloud-based monitoring and predictive control enhancements.

4. CONCLUSION

Based on experimental evaluation, the PV-powered PLC-based greenhouse system successfully maintained optimal microclimate conditions in an autonomous and energy-independent manner. The integrated control system effectively regulated temperature below 30 °C and relative humidity within 75–90%, restoring stable conditions within 5–10 minutes after deviations through automatic activation of exhaust fans and sprayers. These results confirm that the research objectives outlined in the Introduction have been achieved. The full utilization of solar energy ensures sustainable operation, while the integration of PLC and HMI enables reliable automation, real-time monitoring, and manual override when required. The proposed system demonstrates a scalable and robust solution for smart greenhouse applications in urban and industrial areas with limited land and energy access. Future development will focus on integrating IoT connectivity for remote monitoring and cloud-based data analytics, as well as implementing adaptive control strategies to further enhance system efficiency and intelligence. Overall, the proposed system contributes to the advancement of sustainable and resilient agricultural technology suitable for industrial regions such as South Cikarang.

AUTHOR CONTRIBUTIONS STATEMENT

This journal uses the Contributor Roles Taxonomy (CRediT) to recognize individual author contributions, reduce authorship disputes, and facilitate collaboration.

Name of Author	C	M	So	Va	Fo	I	R	D	O	E	Vi	Su	P	Fu
Zeluyvenca Avista	✓	✓	✓	✓	✓	✓		✓	✓	✓		✓	✓	
Muhammad Asep Rizkiawan		✓	✓	✓		✓		✓	✓	✓	✓		✓	
Yudha Witanto	✓		✓	✓			✓			✓	✓		✓	

C : **C**onceptualization	I : **I**nvestigation	Vi : **Vi**sualization
M : **M**ethodology	R : **R**esources	Su : **Su**pervision
So : **So**ftware	D : **D**ata Curation	P : **P**roject administration
Va : **Va**lidation	O : Writing - **O**riginal Draft	Fu : **Fu**nding acquisition
Fo : **Fo**rmal analysis	E : Writing - Review & **E**diting	

CONFLICT OF INTEREST STATEMENT

The authors declare that there is no conflict of interest regarding the publication of this paper.

DATA AVAILABILITY

The data supporting the findings of this study will be available at researchgate https://www.researchgate.net/publication/401156746_Human_Machine_Interface_data after a waiting period of 6 months from the date of publication to allow for the commercialization of research findings.

REFERENCES

[1]   A. Etter, A. Andrade, C. R. Nelson, J. Cortés, and K. Saavedra, "Assessing restoration priorities for high-risk ecosystems: An application of the IUCN Red List of Ecosystems," *Land Use Policy*, vol. 99, Dec. 2020, doi: 10.1016/j.landusepol.2020.104874.

[2]   L. Gandharum, D. M. Hartono, A. Karsidi, and M. Ahmad, "Monitoring urban expansion and loss of agriculture on the north coast of west Java Province, Indonesia, using google earth engine and intensity analysis," *The Scientific World Journal*, vol. 2022, pp. 1–16, Jan. 2022, doi: 10.1155/2022/3123788.

[3]   B. Yang and D. Lee, "Urban green space arrangement for an optimal landscape planning strategy for tunoff reduction," *Land*, vol. 10, no. 9, Aug. 2021, doi: 10.3390/land10090897.

[4]   A. Wiszniewska, E. Hanus-Fajerska, E. MuszyŃska, and K. Ciarkowska, "Natural organic amendments for improved phytoremediation of polluted soils: A review of recent progress," *Pedosphere*, vol. 26, no. 1, pp. 1–12, Feb. 2016, doi: 10.1016/S1002-0160(15)60017-0.

[5]   D. Parthiban *et al.*, "Role of industrial based precursors in the stabilization of weak soils with geopolymer – A review," *Case Studies in Construction Materials*, vol. 16, Jun. 2022, doi: 10.1016/j.cscm.2022.e00886.

[6]   S. Sriyoto, I. Irnad, B. Sumantri, and B. S. Priyono, "Food security and performance of rice agribusiness institutional in coastal areas of seluma regency," *Journal of Agri Socio-Economics and Business*, vol. 2, no. 2, pp. 69–84, Dec. 2020, doi: 10.31186/jaseb.2.2.69-84.

[7]   S. Ranganathapura Sathyanarayana, W. Vishal Gangadhar, M. G. Badrinath, R. M. Ravindra, and A. U. Shriramrao, "Hydroponics: An intensified agriculture practice to improve food production," *Reviews in Agricultural Science*, vol. 10, pp. 101–114, 2022, doi: 10.7831/ras.10.0_101.

[8]   S. Jan *et al.*, "Hydroponics – A review," *International Journal of Current Microbiology and Applied Sciences*, vol. 9, no. 8, pp. 1779–1787, Aug. 2020, doi: 10.20546/ijcmas.2020.908.206.

[9]   D. I. Pomoni, M. K. Koukou, M. G. Vrachopoulos, and L. Vasiliadis, "A review of hydroponics and conventional agriculture based on energy and water consumption, environmental impact, and land use," *Energies*, vol. 16, no. 4, Feb. 2023, doi: 10.3390/en16041690.

[10]   S. T. Magwaza, L. S. Magwaza, A. O. Odindo, and A. Mditshwa, "Hydroponic technology as decentralised system for domestic wastewater treatment and vegetable production in urban agriculture: A review," *Science of The Total Environment*, vol. 698, Jan. 2020, doi: 10.1016/j.scitotenv.2019.134154.

[11]   D. Cherif, R. Ayed, S. Skouri, S. Bouadila, M. Lazaar, and A. Guizani, "Enhancing crop yield in hydroponic greenhouses: Integrating latent heat storage and forced ventilation systems for improved thermal stratification," *Thermal Science and Engineering Progress*, vol. 45, Oct. 2023, doi: 10.1016/j.tsep.2023.102163.

[12]   M. Rufí-Salís, M. J. Calvo, A. Petit-Boix, G. Villalba, and X. Gabarrell, "Exploring nutrient recovery from hydroponics in urban agriculture: An environmental assessment," *Resources, Conservation and Recycling*, vol. 155, Apr. 2020, doi: 10.1016/j.resconrec.2020.104683.

[13]   T. Akter, T. Mahmud, R. Chakma, N. Datta, M. S. Hossain, and K. Andersson, "Smart monitoring and control of hydroponic systems using IoT solutions," in *2024 Second International Conference on Inventive Computing and Informatics (ICICI)*, Jun. 2024, vol. 4, no. 1, pp. 761–767, doi: 10.1109/ICICI62254.2024.00128.

[14]   M. C. Moreno, L. D. Quintero, and N. A. Torres, "Automated monitoring and control system for greenhouses using modern speech processing through mathematical-based methods," in *2023 Argentine Conference on Electronics (CAE)*, Mar. 2023, pp. 35–40, doi: 10.1109/CAE56623.2023.10086980.

[15] I. Ardiansah, R. G. Calibra, N. Bafdal, A. Bono, E. Suryadi, and S. Nurhasanah, "An IoT-enabled design for real-time water quality monitoring and control of greenhouse irrigation systems," *INMATEH Agricultural Engineering*, pp. 417–426, Apr. 2023, doi: 10.35633/inmateh-69-39.

[16] R. Siskandar, S. H. Santosa, W. Wiyoto, B. R. Kusumah, and A. P. Hidayat, "Control and automation: Insmoaf (integrated smart modern agriculture and fisheries) on the greenhouse model," *Jurnal Ilmu Pertanian Indonesia*, vol. 27, no. 1, Jan. 2022, doi: 10.18343/jipi.27.1.141.

[17] T. Malini, D. L. Aswath, R. Abhishek, R. Kirubhakaran, and S. Anandhamurugan, "IoT based smart poultry farm monitoring," in *2023 9th International Conference on Advanced Computing and Communication Systems (ICACCS)*, Mar. 2023, pp. 13–18, doi: 10.1109/ICACCS57279.2023.10112870.

[18] L. S. Ezema, E. C. Ifediora, A. A. Olukunle, and N. C. Onuekwusi, "Design and implementation of an Esp32-based smart embedded industrial poultry farm," *European Journal of Engineering and Technology Research*, vol. 6, no. 3, pp. 38–43, Apr. 2021, doi: 10.24018/ejers.2021.6.3.2397.

[19] S. M. Abubakar and S. Ahmed, "A smart and secure agricultural system using IoT," in *2022 OPJU International Technology Conference on Emerging Technologies for Sustainable Development (OTCON)*, Feb. 2023, pp. 1–6, doi: 10.1109/OTCON56053.2023.10113901.

[20] M. A. Rizkiawan, H. Ramza, N. Nuroji, and A. Sofwan, "Data center room monitoring based on temperature and humidity with Internet of Things," *Jambura Journal of Electrical and Electronics Engineering*, vol. 6, no. 2, pp. 115–123, Jul. 2024, doi: 10.37905/jjeee.v6i2.23344.

[21] E. E. K. Senoo, E. Akansah, I. Mendonça, and M. Aritsugi, "Monitoring and control framework for IoT, implemented for smart agriculture," *Sensors*, vol. 23, no. 5, Mar. 2023, doi: 10.3390/s23052714.

[22] S. Bardi and C. E. Palazzi, "Smart hydroponic greenhouse: Internet of Things and soilless farming," in *Proceedings of the 2022 ACM Conference on Information Technology for Social Good*, Sep. 2022, pp. 212–217, doi: 10.1145/3524458.3547221.

[23] I. Hermala, A. Ismail, N. Hendrasto, A. Maulida Darda, and S. Daulay, "The application of IoT-based hydroponic system and solar power to increase agricultural production and horticultural crop productivity," *International Journal of Engineering and Technology*, vol. 11, no. 1, pp. 20–26, Feb. 2022, doi: 10.14419/ijet.v11i1.31943.

[24] A. C. Austria, J. S. Fabros, K. R. Sumilang, J. Bernardino, and A. Doctor, "Development of IoT smart greenhouse system for hydroponic gardens," *International Journal of Computing Sciences Research*, vol. 7, pp. 2111–2136, Jan. 2023, doi: 10.25147/ijcsr.2017.001.1.149.

[25] Z. Avista, Ubaidillah, D. D. D. P. Tjahjana, E. P. Budiana, M. Nizam, and I. Yaningsih, "Design and analysis of battery thermal management system employing air cooling method," in *AIP Conference Proceedings*, 2023, doi: 10.1063/5.0135783.

[26] R. Alfanz, A. H. Affan, and W. Martinsih, "Smart farm agriculture design by applying a solar power plant," *Jurnal Nasional Teknik Elektro*, Jul. 2023, doi: 10.25077/jnte.v12n2.1085.2023.

[27] G.-F. Sargentis, P. Siamparina, G.-K. Sakki, A. Efstratiadis, M. Chiotinis, and D. Koutsoyiannis, "Agricultural land or photovoltaic parks? The water—energy— food nexus and land development perspectives in the thessaly plain, Greece," *Sustainability*, vol. 13, no. 16, Aug. 2021, doi: 10.3390/su13168935.

[28] S. Suresh, R. Zahira, K. S. Ahmed, D. Lakshmi, S. Palanisamy, and S. Chenniappan, "Solar PV integration into bulk power systems," in *Power Systems Operation with 100% Renewable Energy Sources*, Elsevier, 2024, pp. 23–33, doi: 10.1016/B978-0-443-15578-9.00012-1.

[29] T. Zindove, T. Van Niekerk, T. Wilm, and P. Mercorelli, "Development of a temperature controlled weathering test box to evaluate the life cycle behaviour of interior automotive components," *IFAC-PapersOnLine*, vol. 48, no. 4, pp. 117–122, 2015, doi: 10.1016/j.ifacol.2015.07.018.

[30] J.-R. Aira, S. Gallardo-Saavedra, M. Eugenio-Gozalbo, V. Alonso-Gómez, M.-Á. Muñoz-García, and L. Hernández-Callejo, "Analysis of the viability of a photovoltaic greenhouse with semi-transparent amorphous silicon (A-si) glass," *Agronomy*, vol. 11, no. 6, May 2021, doi: 10.3390/agronomy11061097.

[31] S. Hassan, A. Jadallah, and G. Bilal, "Design and implementation of a smart greenhouse automated and conditioned by solar power system," *Engineering and Technology Journal*, vol. 41, no. 1, pp. 37–44, Sep. 2022, doi: 10.30684/etj.2021.131279.1024.

[32] M. L. Q. Galon, M. V. R. Tumaliwan, and M. M. Sejera, "Automated monitoring and control system of solar greenhouse using ESP32 and Blynk application," in *2024 IEEE 6th Eurasia Conference on IoT, Communication and Engineering*, May 2025, doi: 10.3390/engproc2025092057.

[33] T. B. Dwinugroho, Y. T. Hapsari, and Kurniawanti, "Greenhouse automation: smart watering system for plants in greenhouse using programmable logic control (PLC)," *Journal of Physics: Conference Series*, vol. 1823, no. 1, Mar. 2021, doi: 10.1088/1742-6596/1823/1/012014.

[34] M. Huang, "Design of intelligent greenhouse control system based on MCGS and PLC," *Journal of Physics: Conference Series*, vol. 2510, no. 1, Jun. 2023, doi: 10.1088/1742-6596/2510/1/012022.

[35] A. Zhang *et al.*, "Equipment and experiment of greenhouse high-pressure atomization spraying based on PLC," *INMATEH Agricultural Engineering*, pp. 147–155, Dec. 2022, doi: 10.35633/inmateh-68-15.

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