

Containerized Solar-Powered Irrigation Management System: A Sustainable and Portable Framework for Smart Agricultural Water Control

Dr. Nimal Jayawardena

Department of Agricultural and Biosystems Engineering,
Faculty of Engineering Technology,
South Eastern Institute of Science and Technology,
Ampara 32000, Sri Lanka

Dr. Tharushi Senanayake

Department of Biomedical Engineering and Smart Healthcare Systems,
Faculty of Applied Sciences,
Lanka Institute of Advanced Research and Innovation,
Kandy 20000, Sri Lanka

Received: 19 Mar 2025 | Received Revised Version: 15 Apr 2025 | Accepted: 30 May 2025 | Published: 01 June 2026

Volume 08 Issue 06 2026 |

Abstract

Agricultural water management is a critical determinant of food security, environmental sustainability, and rural economic development. Increasing water scarcity, rising energy costs, climate variability, and dependence on fossil-fuel-powered irrigation systems have intensified the need for innovative irrigation solutions. Solar-powered irrigation technologies have emerged as promising alternatives; however, challenges related to mobility, deployment flexibility, energy reliability, infrastructure requirements, and operational scalability continue to limit widespread adoption. This study presents a comprehensive research and review framework for a Containerized Solar-Powered Irrigation Management System (CSPIMS), designed as a portable, self-contained, and sustainable solution for smart agricultural water control. The proposed framework integrates photovoltaic energy generation, battery energy storage, intelligent irrigation scheduling, Internet of Things (IoT)-based monitoring, wireless sensor networks, and modular containerized architecture within a unified operational platform. Through critical synthesis of existing literature on renewable energy systems, smart irrigation technologies, photovoltaic-battery integration, agricultural energy optimization, and water resource management, the study develops a conceptual model for efficient agricultural water delivery. The analysis demonstrates that containerized solar-powered irrigation systems can significantly reduce fossil fuel dependence, enhance irrigation efficiency, improve deployment flexibility, and support climate-resilient farming practices. The study further identifies technological opportunities, implementation challenges, and future research directions related to system optimization, energy storage enhancement, artificial intelligence integration, and large-scale deployment. The findings contribute to sustainable agricultural engineering by establishing a practical framework capable of supporting smart farming initiatives in both developed and developing agricultural regions.

Keywords: Containerized irrigation system, solar-powered irrigation, smart agriculture, renewable energy, IoT irrigation management, sustainable water control, photovoltaic systems, agricultural automation, energy storage, precision irrigation.

© 2026 Jayawardena, D. N., & Senanayake, D. T. This work is licensed under a Creative Commons Attribution 4.0 International License (CC BY 4.0). The authors retain copyright and allow others to share, adapt, or redistribute the work with proper attribution.

Cite This Article: Jayawardena, D. N., & Senanayake, D. T. (2026). Containerized Solar-Powered Irrigation Management System: A Sustainable and Portable Framework for Smart Agricultural Water Control. The American Journal of Agriculture

and Biomedical Engineering, 8(06), 1–10. Retrieved from <https://theamericanjournals.com/index.php/tajabe/article/view/8044>

Introduction

1.1 Background

Agriculture remains one of the largest consumers of freshwater resources worldwide. Growing populations, increasing food demand, changing climatic conditions, and resource constraints have intensified pressure on agricultural water management systems. Traditional irrigation approaches often rely on diesel-powered pumps and manually controlled water distribution networks that contribute to inefficient water use, elevated operational costs, and environmental degradation. The continued dependence on fossil fuels further exacerbates greenhouse gas emissions and limits the sustainability of agricultural production systems (Beerge and Sachin, 2024).

Recent developments in renewable energy technologies have accelerated the transition toward cleaner agricultural energy solutions. Solar-powered irrigation systems have gained considerable attention because of their ability to utilize abundant solar resources for water pumping and irrigation operations. The integration of photovoltaic technologies with agricultural water systems offers opportunities for reducing energy costs while improving environmental performance (Al-Smairan et al., 2024). Simultaneously, advancements in smart irrigation technologies, wireless sensor networks, and IoT-based monitoring systems have enabled more efficient irrigation scheduling and water management practices (Obaideen et al., 2022; Ndunagu et al., 2022).

Despite these advancements, many existing solar irrigation installations remain fixed in location and require substantial infrastructure investments. Farmers operating in remote regions, temporary agricultural sites, leased lands, or climate-sensitive environments often require flexible irrigation systems that can be rapidly deployed and relocated. Containerized engineering solutions provide a promising alternative by integrating energy generation, storage, control systems, and irrigation equipment into portable modular units that can be transported and deployed with minimal infrastructure requirements.

The concept of containerization has demonstrated significant advantages in industrial logistics, energy systems, and infrastructure deployment due to its modularity, scalability, portability, and operational

efficiency. Applying containerized design principles to solar-powered irrigation management may provide a practical pathway toward sustainable and intelligent agricultural water control.

1.2 Problem Statement

Agricultural irrigation systems face several interconnected challenges. First, conventional irrigation infrastructures often require significant capital investments and fixed installations that reduce operational flexibility. Second, diesel-powered pumping systems contribute to rising fuel expenditures and environmental impacts. Third, inefficient irrigation scheduling leads to substantial water losses and reduced resource productivity. Fourth, remote farming locations frequently lack reliable electrical grid access, limiting the deployment of advanced irrigation technologies.

Although renewable-energy-based irrigation systems offer potential solutions, existing systems frequently operate as isolated technologies without comprehensive integration of mobility, automation, energy management, and decision-support capabilities. Consequently, there is a need for a unified framework capable of addressing energy sustainability, irrigation efficiency, and operational flexibility simultaneously.

1.3 Research Objectives

The primary objectives of this study are:

1. To analyze the role of renewable energy technologies in sustainable irrigation management.
2. To develop a conceptual framework for a containerized solar-powered irrigation management system.
3. To examine the integration of photovoltaic generation, energy storage, IoT monitoring, and irrigation automation.
4. To evaluate the potential benefits, limitations, and implementation challenges associated with containerized irrigation platforms.
5. To identify future research opportunities for improving smart agricultural water control systems.

1.4 Scope and Significance

This study focuses on the intersection of renewable energy systems, irrigation engineering, smart agriculture, and modular infrastructure design. The research contributes to both theoretical and practical understanding by proposing an integrated framework capable of addressing multiple sustainability challenges simultaneously. The findings are particularly relevant for rural agricultural communities, off-grid farming operations, climate-vulnerable regions, and emerging smart agriculture initiatives.

2. Literature Review

2.1 Renewable Energy and Agricultural Sustainability

Renewable energy has become increasingly important in agricultural sustainability strategies due to its ability to reduce carbon emissions, lower operational costs, and enhance resource independence. Pacesila et al. (2016) emphasized that renewable energy technologies play a crucial role in sustainable development by reducing dependence on conventional energy resources. Similarly, Aziz et al. (2024) highlighted the interconnected relationship among renewable energy adoption, agricultural productivity, environmental protection, and economic growth.

Agricultural operations increasingly require reliable energy for irrigation, storage, processing, monitoring, and automation activities. Traditional diesel-powered systems remain prevalent in many developing regions but contribute significantly to greenhouse gas emissions and operational expenses. Renewable alternatives therefore provide both environmental and economic advantages.

Augustyn et al. (2021) demonstrated how hybrid off-grid renewable energy systems can achieve energy self-sufficiency in agricultural operations. Their findings indicate that integrated renewable energy infrastructures can support agricultural productivity while reducing external energy dependence. Likewise, Emezirinwune et al. (2024) showed that hybrid photovoltaic, biomass, diesel generator, and battery systems can effectively supply energy requirements in farm environments.

The literature collectively suggests that renewable energy integration represents a foundational element of future agricultural sustainability frameworks. However, successful implementation requires appropriate energy storage systems, intelligent control mechanisms, and operational flexibility.

2.2 Solar-Powered Irrigation Systems

Solar-powered irrigation technologies have emerged as one of the most promising applications of renewable energy in agriculture. Al-Smairan et al. (2024) conducted a techno-environmental-economic assessment of photovoltaic water pumping systems and demonstrated their viability for farmland applications. Their study revealed that solar-powered pumping systems can substantially reduce operating costs while improving environmental performance.

Solar irrigation systems convert solar radiation into electrical energy that powers water pumps, enabling irrigation without reliance on conventional fuel sources. The advantages include lower maintenance requirements, reduced emissions, energy independence, and long-term economic benefits. However, system performance remains dependent on solar availability and storage capabilities.

Obalalu et al. (2025) further investigated optimization approaches for solar water pumping technologies and found that enhanced thermal management can significantly improve operational efficiency. Their findings indicate that technological innovations continue to improve the performance potential of solar irrigation systems.

Although these studies establish the effectiveness of solar-powered irrigation, they primarily focus on stationary installations. Limited research has examined containerized configurations capable of combining mobility with renewable energy-driven irrigation operations.

2.3 Smart Irrigation Technologies and IoT Integration

The transition from conventional irrigation toward smart irrigation systems represents a significant advancement in agricultural water management. Smart irrigation technologies utilize sensors, communication networks, environmental monitoring systems, and automated control mechanisms to optimize water delivery according to crop requirements.

El Mezouari et al. (2022) described smart irrigation systems as intelligent infrastructures capable of enhancing water-use efficiency through automated decision-making processes. Similarly, Obaideen et al. (2022) emphasized the importance of IoT technologies in enabling real-time monitoring and adaptive irrigation control.

Wireless sensor networks constitute a critical component of smart irrigation architectures. Ghareeb et al. (2023) identified both opportunities and challenges associated with artificial intelligence-enabled irrigation networks. Their analysis highlighted the importance of sensor reliability, communication efficiency, and data management capabilities.

Ndunagu et al. (2022) developed an IoT-based smart irrigation framework that demonstrated improved irrigation precision through real-time environmental monitoring. Such systems facilitate data-driven irrigation scheduling by continuously collecting information related to soil moisture, temperature, humidity, and crop conditions.

The literature consistently indicates that intelligent irrigation technologies can significantly improve water conservation while maintaining agricultural productivity. Nevertheless, effective implementation requires reliable energy supplies and robust infrastructure support, particularly in remote agricultural regions.

2.4 Irrigation Scheduling and Water Resource Optimization

Efficient irrigation scheduling remains one of the most important determinants of agricultural water productivity. Traditional scheduling approaches frequently rely on fixed irrigation intervals rather than actual crop water requirements, leading to resource inefficiencies.

Fernández García et al. (2020) identified numerous challenges associated with irrigation scheduling in semi-arid agricultural regions, emphasizing the need for adaptive management approaches. Their work demonstrated that optimized irrigation scheduling can significantly improve water-use efficiency under resource-constrained conditions.

Mainuddin et al. (2015) examined climate-related impacts on irrigation requirements and revealed substantial temporal and spatial variations in water demand. These findings underscore the importance of dynamic irrigation management systems capable of responding to changing environmental conditions.

Poddar et al. (2020), Poddar et al. (2021a), Poddar et al. (2021b), and Poddar et al. (2022) collectively contributed important insights regarding crop water requirements, irrigation scheduling methodologies, root water uptake modeling, and predictive irrigation management. Their

research demonstrates that advanced modeling techniques can substantially improve irrigation efficiency and water resource allocation.

The literature review indicates that combining intelligent scheduling algorithms with renewable-energy-powered irrigation infrastructures may provide substantial improvements in agricultural water management performance.

3. Methodology

3.1 Research Design

This study adopts a conceptual research and review methodology based exclusively on the provided literature. The research integrates findings from renewable energy systems, irrigation engineering, smart agriculture, photovoltaic technologies, energy storage systems, and IoT-enabled monitoring platforms to develop a comprehensive framework for a Containerized Solar-Powered Irrigation Management System (CSPIMS).

The methodological approach consists of four interconnected stages. The first stage involves literature synthesis to identify technological components associated with solar-powered irrigation and smart water management. The second stage examines existing renewable energy and irrigation optimization models. The third stage develops a conceptual containerized architecture capable of integrating energy generation, storage, monitoring, and irrigation control subsystems. The final stage evaluates expected operational outcomes, sustainability benefits, and implementation challenges.

This methodology is appropriate because containerized solar-powered irrigation remains an emerging concept with limited empirical deployment studies. Consequently, framework development through interdisciplinary synthesis provides an effective foundation for future experimental validation.

3.2 Theoretical Foundation

The proposed framework is grounded in three complementary theoretical perspectives:

Renewable Energy Sustainability Theory

Renewable energy sustainability theory emphasizes reducing dependence on finite fossil-fuel resources while maintaining economic viability and environmental protection. Studies by Pacesila et al. (2016), Aziz et al.

(2024), and Augustyn et al. (2021) demonstrate that renewable energy integration contributes directly to agricultural sustainability through energy independence and emission reduction.

Precision Agriculture Theory

Precision agriculture promotes resource optimization through data-driven decision-making. Smart irrigation systems apply precision agriculture principles by supplying water according to actual crop requirements rather than predetermined schedules. Research conducted by Fernández García et al. (2020), Poddar et al. (2021a), and Poddar et al. (2022) supports the importance of adaptive irrigation management for maximizing water-use efficiency.

Cyber-Physical Systems Theory

The integration of physical irrigation infrastructure with digital monitoring and control technologies reflects cyber-physical systems theory. IoT devices, wireless sensor networks, and automated control mechanisms create interconnected agricultural systems capable of real-time decision-making (Obaideen et al., 2022; Ndunagu et al., 2022).

3.3 Proposed Containerized Solar-Powered Irrigation Management Framework

The proposed CSPIMS framework consists of six major subsystems integrated within a standardized transportable container.

Photovoltaic Energy Generation Unit

The primary energy source consists of photovoltaic panels mounted either directly on the container roof or through deployable external support structures. Solar energy is converted into electrical power and supplied to irrigation operations through charge controllers and energy management systems.

The photovoltaic subsystem is designed according to principles identified by Al-Smairan et al. (2024), who demonstrated the effectiveness of solar-powered water pumping systems under agricultural conditions.

Battery Energy Storage Unit

Energy storage is essential for maintaining irrigation operations during low solar radiation periods, cloudy conditions, and nighttime irrigation requirements. Battery systems stabilize energy supply while enhancing operational reliability.

Research by Rana et al. (2022), Inada et al. (2022), and Rekioua (2023) highlights the strategic importance of advanced storage technologies in renewable-energy-based systems. Within CSPIMS, battery banks are integrated into dedicated container compartments equipped with thermal management and safety systems.

Intelligent Water Pumping Unit

The pumping subsystem includes high-efficiency electric pumps controlled through intelligent variable-speed drives. Water extraction may occur from wells, reservoirs, rivers, storage tanks, or other available water sources.

Optimization algorithms continuously adjust pumping operations according to irrigation demand, energy availability, and water resource conditions. This dynamic approach improves overall system efficiency compared with conventional fixed-speed pumping operations.

IoT-Based Monitoring Infrastructure

The monitoring subsystem employs multiple sensor categories including:

- Soil moisture sensors
- Ambient temperature sensors
- Relative humidity sensors
- Solar radiation sensors
- Water flow sensors
- Reservoir level sensors

Data collected from these sensors are transmitted through wireless communication networks for real-time analysis. The integration of sensor networks aligns with recommendations presented by Ghareeb et al. (2023) and Ndunagu et al. (2022).

Irrigation Decision Support Engine

The decision-support module functions as the intelligence core of the system. Sensor data, weather information, crop requirements, and energy availability are analyzed to determine optimal irrigation schedules.

The system incorporates principles derived from irrigation scheduling research conducted by Fernández García et al. (2020), Poddar et al. (2020), Poddar et al. (2021a), and Poddar et al. (2021b).

Containerized Modular Platform

The container serves as a portable operational hub that houses:

- Control equipment
- Batteries
- Communication devices
- Monitoring systems
- Safety infrastructure
- Maintenance tools

Containerization provides significant logistical advantages. Systems can be transported between agricultural sites, rapidly deployed during emergencies, and scaled according to operational requirements.

3.4 Operational Workflow

The proposed system operates through a continuous closed-loop process:

Solar panels generate electricity and charge battery storage systems. Sensors continuously monitor environmental and agricultural conditions. Collected data are transmitted to the control unit for analysis. Decision-support algorithms determine irrigation requirements. Pumps are activated automatically according to calculated schedules. Performance data are recorded for future optimization.

This workflow enables autonomous operation while minimizing human intervention and resource wastage.

3.5 Sustainability Evaluation Dimensions

The proposed framework is evaluated according to four sustainability dimensions:

Environmental Sustainability

Environmental assessment considers reductions in carbon emissions, fossil fuel consumption, and water wastage. Renewable energy adoption contributes directly to environmental protection objectives identified by Aziz et al. (2024).

Economic Sustainability

Economic evaluation focuses on operational cost reductions, energy savings, maintenance expenditures, and long-term return on investment.

Social Sustainability

Social sustainability examines improvements in rural energy access, agricultural productivity, and technological inclusion.

Technical Sustainability

Technical sustainability assesses system reliability, scalability, maintainability, and adaptability to varying agricultural environments.

4. Results

The conceptual analysis suggests that the proposed Containerized Solar-Powered Irrigation Management System offers substantial advantages over conventional irrigation approaches. First, photovoltaic-powered operation significantly reduces dependence on diesel fuel and grid electricity, thereby lowering operational costs and greenhouse gas emissions. Second, the integration of battery storage enhances energy reliability and supports continuous irrigation operations under variable solar conditions.

The incorporation of IoT-enabled monitoring systems enables real-time assessment of crop water requirements, resulting in improved irrigation precision and reduced water losses. Sensor-driven scheduling mechanisms allow water application to closely match actual crop demand, thereby improving water-use efficiency. Furthermore, wireless monitoring infrastructure facilitates remote system management and performance evaluation.

Containerization introduces a unique operational advantage by enhancing mobility and deployment flexibility. Unlike conventional irrigation infrastructures that require permanent installation, the proposed framework can be transported to multiple agricultural locations. This characteristic is particularly beneficial for remote farms, seasonal agricultural operations, disaster-affected regions, and leased agricultural lands.

The integrated architecture also supports scalability. Additional photovoltaic modules, battery units, sensor networks, or irrigation zones can be incorporated without major infrastructure redesign. This modularity improves adaptability across different farm sizes and agricultural production systems.

The analysis further indicates that combining renewable energy technologies with intelligent irrigation management can contribute significantly to climate-resilient agriculture. By reducing dependence on external energy supplies and optimizing water utilization, farmers

may achieve greater resilience against environmental and economic uncertainties.

Nevertheless, implementation challenges remain. Initial capital investment requirements may be substantial, particularly for smallholder farmers. Battery replacement costs, technical maintenance requirements, communication infrastructure limitations, and environmental exposure risks may affect long-term system performance. These challenges highlight the need for continued technological innovation and supportive policy frameworks.

5. Discussion

The findings support the growing consensus that renewable energy and digital agriculture technologies represent complementary pathways toward sustainable agricultural development. Existing literature consistently demonstrates the benefits of photovoltaic-powered irrigation, energy storage integration, and smart irrigation management (Al-Smairan et al., 2024; Obaideen et al., 2022; Rana et al., 2022). The proposed containerized framework extends these concepts by introducing mobility and modularity as additional dimensions of sustainability.

From a theoretical perspective, the framework reinforces precision agriculture principles by combining real-time monitoring with adaptive irrigation scheduling. Similar to observations reported by Fernández García et al. (2020) and Poddar et al. (2022), efficient irrigation management depends on accurate environmental information and responsive control mechanisms. The proposed system operationalizes these principles within a renewable-energy-supported infrastructure.

The framework also contributes to renewable energy integration research by demonstrating how photovoltaic systems, battery storage technologies, and agricultural operations can function as a coordinated energy ecosystem. This finding aligns with previous studies emphasizing hybrid renewable-energy architectures for agricultural applications (Augustyn et al., 2021; Emezirinwune et al., 2024).

Practical implications are equally significant. Governments, agricultural cooperatives, development agencies, and private technology providers may utilize containerized irrigation systems to accelerate rural electrification and climate-smart agriculture initiatives. Such systems may be especially valuable in regions

experiencing water scarcity, unreliable grid access, or increasing climate variability.

However, trade-offs must be acknowledged. Increased technological sophistication may create maintenance challenges, particularly in regions with limited technical expertise. Dependence on electronic components and communication networks introduces vulnerabilities that are absent in conventional irrigation systems. Moreover, the economic feasibility of deployment will depend on local energy prices, water availability, financing mechanisms, and policy incentives.

Overall, the proposed framework demonstrates strong potential for supporting sustainable agricultural transformation while highlighting areas requiring further empirical investigation.

6. Conclusion

The growing demand for sustainable agricultural production requires innovative solutions capable of simultaneously addressing water scarcity, energy security, environmental sustainability, and operational efficiency. This study developed a comprehensive conceptual framework for a Containerized Solar-Powered Irrigation Management System (CSPIMS) that integrates photovoltaic energy generation, battery energy storage, intelligent irrigation scheduling, IoT-enabled monitoring, wireless sensor networks, and modular containerized infrastructure into a unified agricultural management platform.

The literature synthesis demonstrated that renewable energy technologies are increasingly becoming essential components of modern agricultural systems. Research on photovoltaic water pumping, hybrid renewable energy systems, smart irrigation technologies, and precision agriculture consistently indicates significant opportunities for improving agricultural sustainability. The proposed framework builds upon these developments by introducing a portable and scalable architecture capable of overcoming many limitations associated with conventional irrigation infrastructures.

The analysis revealed several important contributions of the CSPIMS framework. First, the use of solar energy substantially reduces dependence on fossil fuels and external electricity supplies, thereby supporting environmental sustainability objectives. Second, battery energy storage enhances operational reliability and enables continuous irrigation under varying climatic conditions. Third, intelligent monitoring and decision-

support systems improve irrigation precision, reducing unnecessary water consumption while maintaining crop productivity. Fourth, containerization introduces mobility, rapid deployment capability, and modular scalability, making the framework particularly suitable for remote, off-grid, and climate-sensitive agricultural environments.

The study also identified several implementation challenges that require consideration. These include high initial investment costs, battery replacement requirements, technical maintenance needs, communication infrastructure limitations, and environmental exposure risks. Addressing these challenges will require continued technological advancement, supportive policy frameworks, innovative financing mechanisms, and capacity-building initiatives for end users.

From a theoretical perspective, the research contributes to the growing body of knowledge on renewable-energy-powered precision agriculture by integrating energy sustainability, smart irrigation management, and modular infrastructure design within a single framework. From a practical perspective, the proposed model offers a potential pathway for governments, agricultural cooperatives, development organizations, and technology providers seeking to promote climate-resilient and resource-efficient farming systems.

Future research should focus on prototype development, field validation, techno-economic optimization, artificial intelligence integration, predictive irrigation algorithms, advanced battery technologies, and large-scale deployment assessments. Comparative studies across different climatic zones, crop systems, and agricultural scales would further strengthen understanding of operational performance and scalability.

In conclusion, the Containerized Solar-Powered Irrigation Management System represents a promising framework for sustainable and portable agricultural water management. By combining renewable energy technologies with intelligent irrigation control and modular infrastructure design, the proposed system has the potential to support the transition toward more resilient, efficient, and environmentally responsible agricultural production systems.

References

1. Containerized Solar-Powered Irrigation Management System: A Sustainable and Portable Framework for Smart Agricultural Water Control
2. Augustyn G, Mikulik J, Rumin R, Szyba M, 2021. Energy self-sufficient livestock farm as the example of agricultural hybrid off-grid system. *Energies* 14:7041.
3. Aziz G, Sarwar S, Waheed R, Khan MS, 2024. The significance of renewable energy, globalization, and agriculture on sustainable economic growth and green environment: Metaphorically, a two-sided blade. *Nat Resour Forum* 48:763-783.
4. Beerge R, Sachin D, 2024. Diesel-powered engine and agriculture. In: H. Koten, editor. *Diesel engines – Current challenges and future perspectives*. IntechOpen.
5. Bhattacharjee J, Subhasis R, 2024. Significance of renewable energy in water management and irrigation. In: S. Suriyanarayanan, H.P. Shivaraju and D. Jenkins, editors. *Water management in developing countries and sustainable development*. Singapore, Springer. pp. 235-252.
6. El Mezouari A, El Fazziki A, Sadgal M. 2022. Smart irrigation system. *IFAC-PapersOnLine* 55:3298-3303.
7. Emezirinwune MU, Adejumbi IA, Adebisi OI, Akinboro FG, 2024. Off-grid PV/biomass/DG/battery hybrid renewable energy as a source of electricity for a farm facility. *e-Prime-Adv Electr Eng Electron Energy* 10:100808.
8. Fernández García I, Lecina S, Ruiz-Sánchez MC, Vera J, Conejero W, Conesa MR, Montesinos P, 2020. Trends and challenges in irrigation scheduling in the semi-arid area of Spain. *Water* 12:785.
9. García AM, Gallagher J, Díaz JAR, McNabola A, 2024. An economic and environmental optimization model for sizing a hybrid renewable energy and battery storage system in off-grid farms. *Renew Energy* 220:119588.
10. García AM, Gallagher J, Díaz JAR, McNabola A, 2024. An economic and environmental optimization model for sizing a hybrid renewable energy and battery storage system in off-grid farms. *Renew Energy* 220:119588.
11. Ghareeb AY, Gharghan SK, Mutlag AH, Nordin R, 2023. Wireless sensor network-based artificial intelligent irrigation system: challenges and limitations. *J Techn* 5:26-41.
12. Ibrahim WI, Mohamed MR, Ismail RMTR, Leung PK, Xing WW, Shah AA, 2021. Hydrokinetic energy

- harnessing technologies: A review. *Energy Rep* 7:2021-2042.
13. İnada AA, Arman S, Safaei B, 2022. A novel review on the efficiency of nanomaterials for solar energy storage systems. *J Energy Storage* 55:105661.
 14. Irshad AS, Ludin GA, Masrur H, Ahmadi M, Yona A, Mikhaylov A, Senjyu T, 2023. Optimization of grid-photovoltaic and battery hybrid system with most technically efficient PV technology after the performance analysis. *Ren Energy* 207:714-730.
 15. Mainuddin M, Kirby M, Chowdhury RAR, Shah-Newaz SM, 2015. Spatial and temporal variations of, and the impact of climate change on, the dry season crop irrigation requirements in Bangladesh. *Irrig Sci* 33:107-120.
 16. Yusupjanova Munira Abdukhamid qizi. (2026). Early Diagnosis Of Oral Leukoplakia As A Key Factor In The Prevention Of Malignant Transformation. *International Journal of Medical Science and Public Health Research*, 7(01), 17–20. <https://doi.org/10.37547/ijmsphr/Volume07Issue01-04>
 17. Ndunagu JN, Ukhurebor KE, Akaaza M, Onyancha RB, 2022. Development of a wireless sensor network and IoT-based smart irrigation system. *Appl Environ Soil Sci* 2022:7678570.
 18. Neethirasu A, Perumalsamy I, Kannan K, Mani R, Rajaram RS, Victor K, 2024. Examining agrovoltaic system: impacts on energy yield and crop productivity. In: P. Pathak, S. Ilyas, R.R. Srivastava, J. Dar and S. Kothandaraman, editors. Cham, Springer. pp. 373-390.
 19. Obaideen K, Yousef BA, AlMallahi MN, Tan YC, Mahmoud M, Jaber H, Ramadan M, 2022. An overview of smart irrigation systems using IoT. *Energy Nexus* 7:100124. 1.
 20. Zokirova Muborakkhon Bobir kizi. (2026). Combined Effect Of COL1A1 And EDN1 Gene Polymorphisms On The Risk Of Developing Cardiological Complications. *International Journal of Medical Science and Public Health Research*, 7(01), 27–33. <https://doi.org/10.37547/ijmsphr/Volume07Issue01-06>
 21. Obalalu AM, Bajaj M, Salalwu SO, Singh AR, Vishnuram P, Abbas A, Adeshola AD, 2025. Optimizing solar water pumps for irrigation: the impact of aluminum–titanium hybrid nanofluid on thermal efficiency and performance. *Multiscale Multidiscip Model Exp Des* 8:53.
 22. livkar PR, Katekar VP, Deshmukh SS, Palatkar SV, 2022. Effect of sensible heat storage materials on the thermal performance of solar air heaters: State-of-the-art review. *Renew Sustain Energy Rev* 157:112085.
 23. Pacesila M, Burcea SG, Colesca SE, 2016. Analysis of renewable energies in European Union. *Renew Sustain Energy Rev* 56:156-170.
 24. Poddar A, Kumar N, Kumar R, Shankar V, Jat MK, 2020. Evaluation of non-linear root water uptake model under different agro-climates. *Curr Sci* 119:485-496.
 25. Poddar A, Kumar N, Shankar V, 2021a. Evaluation of two irrigation scheduling methodologies for potato (*Solanum tuberosum* L.) in north-western mid-hills of India. *ISH J Hydraul Eng* 27:90-99.
 26. Poddar A, Kumar N, Kumar R, Shankar V, 2022. Application of regression modeling for the prediction of field crop coefficients in a humid subtropical agro-climate: a study in Hamirpur district of Himachal Pradesh (India). *Model Earth Syst Environ* 8:2369-2381.
 27. Shakhnoza Badriddinovna Daminova, & ZiyodaFurkatovna Kurbanova. (2026). Prognostic Significance Of The Immune-Stress Index In Assessing Dental Risk In Children With Hearing Impairment. *International Journal of Medical Science and Public Health Research*, 7(01), 69–74. <https://doi.org/10.37547/ijmsphr/Volume07Issue01-13>
 28. Poddar A, Shankar V, Kumar N, 2021b. Estimating crop water requirements for irrigation scheduling in different crops in humid subtropical agro-climate of Western Himalayas. *J Agrometeorol* 23:356-359.
 29. Rana MM, Uddin M, Sarkar MR, Shafiullah GM, Mo H, Atef M, 2022. A review on hybrid photovoltaic - Battery energy storage system: Current status, challenges, and future directions. *J Energy Storage* 51:104597.
 30. Rekioua D, 2023. Energy storage systems for photovoltaic and wind systems: A review. *Energies* 16:3893.
 31. Rodríguez-Pérez ÁM, García-Chica A, Caparros-Mancera JJ, Rodríguez CA, 2024. Turbine-based generation in greenhouse irrigation systems. *Hydrology* 11:149.
 32. Singla MK, Gupta J, Gupta A, Safaraliev M, Zeinoddini-Meymand H, Kumar R, 2025. Empowering rural farming: agrovoltaic applications

- for sustainable agriculture. *Energy Sci Eng* 13:35-59.
33. Wang T, Ng AK, Wang J, Chen Q, Pang J, Tang J, 2024. Adaptation planning of container ports in the context of typhoon risks: The case of Ningbo-Zhoushan port in China. *Ocean Coast Manage* 257:107303.
34. Musashaykhov H.T., & Musashaykhov U.Kh. (2026). Clinical Significance Of The C-786t Polymorphism Of The Nos3 Gene In Purulent-Necrotic Lesions Of The Lower Extremities Associated With Diabetes Mellitus. *International Journal of Medical Science and Public Health Research*, 7(01), 62–64. <https://doi.org/10.37547/ijmsphr/Volume07Issue01-11>