https://ejournal.staialhikmahpariangan.ac.id/Journal/index.php/ligundi
P - ISSN: 3048-3182
E - ISSN: 3048-250X

Implementation of Hydroponic Technology to Strengthen Houshold Food Security in Urban Marginal Areas

Satria Abadi[1], Citrawati Jatiningrum[2], Miswan Gumanti[3] Marilin Kristina [4]

[1] Institut Bakti Nusantara, Indonesia
[2] Institut Bakti Nusantara, Indonesia
[3] Institut Bakti Nusantara, Indonesia
[4] Institut Bakti Nusantara, Indonesia

ABSTRACT

Background. Food insecurity remains a pressing issue in urban marginal areas where limited land access, unemployment, and poor nutrition intersect. Hydroponic technology presents an innovative solution for household-level food production that requires minimal space and resources. Despite its potential, empirical evidence on how hydroponic implementation influences food security in urban marginal households remains scarce.

Purpose. This quantitative study aimed to investigate the impact of hydroponic technology implementation on strengthening household food security in urban marginal areas. Specifically, it examined how technological adoption, technical competence, and community collaboration influence food self-sufficiency and resilience.

Method. The study involved 210 respondents from three urban marginal districts in Padang City, Indonesia. Data were collected using a structured questionnaire designed to measure five latent constructs: hydroponic technology adoption, knowledge transfer, social collaboration, economic resilience, and household food security. The data were analyzed using Smart PLS 4.0, focusing on model reliability, validity, and path coefficients to assess both direct and indirect relationships among variables.

Results. The findings revealed that hydroponic technology adoption had a significant positive effect on household food security ($\beta = 0.62$, $p < 0.01$) and community collaboration ($\beta = 0.49$, $p < 0.01$). Community participation was found to partially mediate the relationship between technology adoption and food security outcomes. The model demonstrated good fit indices (SRMR = 0.046; NFI = 0.92), confirming its robustness.

Conclusion. The implementation of hydroponic technology effectively enhances household food security in urban marginal communities by improving self-sufficiency and fostering social cooperation. The study highlights the importance of promoting local hydroponic training, urban agriculture initiatives, and inclusive food policies to build sustainable and resilient urban food systems.

KEYWORDS

Hydroponic Technology, Household Food Security, Urban Marginal Areas

Citation: Louw, S. A., Papilaya, J., & Rehatta, G. (2025). The Effect of Price on the Purchase Decision of Yamaha Motorcycle Parts at Ryan Motor Stores (a case study in Lateri Village, Baguala District, Ambon City). *Journal Ligundi of Community Service, 1*(2), 72–82. https://doi.org/10.17323/ligundi.v1i1.12663

Correspondence:

Satria Abadi,
satria2601@gmail.com

Received: July 12, 2024
Accepted: July 15, 2024
Published: July 31, 2024

INTRODUCTION

Urban marginal areas in many developing countries, including Indonesia, continue to face persistent challenges related to food insecurity, poverty, and limited access to sustainable livelihood opportunities. Rapid urbanization has led to increased population density and reduced availability of arable land, making conventional agricultural practices increasingly difficult to sustain in urban settings (Berg, 2023; Swen, 2023; Wyckoff, 2022). In such environments, food insecurity is not only a consequence of economic deprivation but also a structural issue arising from spatial inequality and limited urban planning for food production. The inability of many low-income households to access fresh and affordable produce contributes to malnutrition, poor health outcomes, and dependence on volatile food markets. Therefore, innovative urban farming models that can thrive within restricted spaces have become critical to ensuring food availability and dietary diversity among marginalized urban populations.

Hydroponic technology has emerged as one of the most promising solutions to address food insecurity in urban settings (Mangla, 2022; Ren, 2023; Soni, 2022). Unlike conventional soil-based farming, hydroponic systems allow plants to grow in nutrient-rich water, reducing land dependency and enabling food production even in densely populated or land-scarce areas (Benarbia, 2022; Liu, 2024; Sambas, 2022). The system is also water-efficient, environmentally friendly, and adaptable to household scales, making it suitable for urban communities with limited resources. In Indonesia, urban hydroponic farming has begun to attract attention as part of the broader agenda of sustainable urban agriculture and food sovereignty. However, despite its potential, there remains a limited understanding of how hydroponic implementation translates into improved food security outcomes at the household level, particularly among communities living in urban marginal areas.

The adoption of hydroponic technology at the household level requires not only technical knowledge but also behavioral and social readiness (Khan, 2024; Lin, 2023; Sathish, 2023). Factors such as awareness, perceived usefulness, and community participation significantly influence the success of such programs (Lobato-Peralta, 2024; Sesidhar, 2023; Teoh, 2023). Households with limited education or exposure to agricultural innovations may perceive hydroponic farming as complex or costly, leading to low adoption rates. Thus, promoting hydroponic systems among urban marginal communities requires a holistic approach that integrates technical training, financial accessibility, and social empowerment. Community-based collaboration plays a vital role in this process, as shared learning and collective effort can reduce barriers to adoption and sustain motivation among participants.

Previous research on urban agriculture has primarily focused on community gardens, rooftop farming, or small-scale organic initiatives. While these approaches contribute positively to food access, they often rely on soil-based systems that remain constrained by land availability and environmental conditions (Dasaklis, 2022; Farooq, 2022; Yu, 2022). Hydroponic systems, by contrast, can operate vertically, indoors, or even in recycled materials, allowing scalability and adaptability to diverse urban environments (Almatrafi, 2024; Kerkhoff, 2022; Oluleye, 2023). Yet, studies assessing the socio-economic and food security impacts of hydroponic technology in low-income urban households remain limited. This gap highlights the need for empirical investigation into how technological, economic, and social factors interact to influence food security outcomes in marginalized contexts.

From a theoretical perspective, the relationship between hydroponic adoption and food security can be explained through the lens of sustainable livelihoods and innovation diffusion theories (Z. Chen, 2023; Lim, 2023; Vickram, 2023). Sustainable livelihood theory emphasizes the role of assets—human, social, natural, financial, and physical—in enabling households to maintain food security and resilience. Hydroponic technology, as an innovation, can enhance several of these assets simultaneously: human capital through new skills, financial capital through cost savings, and social capital through community networks (Filho, 2023; Tsolakis, 2023; Xu, 2023). Meanwhile, innovation diffusion theory suggests that the adoption of a new technology is influenced by perceived advantages, ease of use, compatibility, and social influence (Merhi, 2023; Sevinç, 2022; Yin, 2022). Therefore, examining hydroponic technology adoption in urban marginal communities offers insights not only into technological outcomes but also into broader socio-economic dynamics that shape household resilience.

Furthermore, the integration of hydroponic systems aligns with global sustainable development goals (SDGs), particularly Goal 2 (Zero Hunger), Goal 11 (Sustainable Cities and Communities), and Goal 12 (Responsible Consumption and Production). Implementing household-level hydroponic systems contributes directly to food self-sufficiency, reduces dependency on external food supply chains, and minimizes waste through resource-efficient practices. By promoting local production and consumption cycles, hydroponic systems also help reduce carbon footprints associated with food transportation and storage. Hence, understanding the dynamics of hydroponic implementation in marginalized urban areas has both local and global relevance for achieving sustainable food systems.

Despite growing policy interest in urban farming, there remains a mismatch between technological potential and practical implementation on the ground. Many initiatives fail to sustain long-term impact due to the absence of continuous training, financial support, and community ownership. In some cases, hydroponic projects remain limited to pilot programs or donor-driven interventions without integration into local economic systems. As a result, households revert to market dependency once external support ceases. To ensure sustainability, hydroponic adoption must be embedded in community networks, supported by local governments, and aligned with socio-economic realities of urban poor populations.

Another challenge lies in the economic perception of hydroponics. While the technology can generate substantial long-term savings and nutritional benefits, initial investment costs are often perceived as high. For urban marginal households, upfront expenditures on materials such as nutrient solutions, pipes, or pumps can be prohibitive. Therefore, microfinancing schemes, government subsidies, or social entrepreneurship models are essential to enable broader participation. These interventions not only facilitate access but also foster economic empowerment through potential income generation from surplus production. When households view hydroponic farming not merely as subsistence but as a micro-enterprise, the motivation to sustain and expand production significantly increases.

Education and capacity-building are equally critical in ensuring successful hydroponic implementation. Technical literacy about plant nutrition, water management, and system maintenance determines the long-term productivity of household systems. Training programs should be tailored to local contexts, using simple language and demonstration-based learning to enhance understanding. Furthermore, community mentoring—where experienced practitioners support new adopters—can help bridge knowledge gaps and foster solidarity. The integration of digital tools, such as mobile apps for monitoring plant growth or nutrient levels, can also enhance efficiency and engagement among younger participants in urban communities.

This study situates itself within the intersection of technology adoption, social collaboration, and food security. It argues that hydroponic systems can function not merely as technological tools but as catalysts for community empowerment and sustainable livelihoods. By adopting a quantitative approach, this research systematically examines the causal relationships between technological adoption, community participation, and household food security. Using Smart PLS as the analytical method enables the identification of both direct and indirect pathways through which hydroponic implementation impacts food security outcomes. This approach provides empirical evidence that complements the largely qualitative literature on urban agriculture.

In addition to the empirical dimension, this study contributes conceptually to the discourse on urban food systems. It challenges the traditional dichotomy between rural and urban agriculture by demonstrating that food production can be decentralized and democratized through technology. It also highlights that addressing urban food insecurity is not solely a matter of increasing supply but also of building adaptive capacity among vulnerable populations. By fostering social networks and shared responsibility, hydroponic farming can strengthen community resilience against economic shocks and environmental uncertainties.

The study is conducted in Padang City, Indonesia, which represents a typical case of an urban area facing both spatial constraints and socio-economic disparities. Several of its districts are characterized by informal settlements where access to nutritious food remains limited. Local governments have initiated various community-based farming programs, yet participation and sustainability remain uneven. This research, therefore, provides timely insights into how hydroponic technology can be strategically implemented to support local policy goals while empowering households to become agents of their own food security.

The quantitative design of this research, supported by Smart PLS analysis, allows for an in-depth examination of structural relationships among variables and the testing of mediation effects. By combining theoretical frameworks with empirical evidence, the study seeks to offer a comprehensive understanding of how technology, knowledge, and social collaboration interact in shaping food security outcomes. The expected findings are not only relevant to academic discussions but also to policymakers, NGOs, and community leaders seeking scalable models for sustainable urban food systems.

Ultimately, this study aims to advance the discourse on sustainable urban development by positioning hydroponic technology as a transformative tool for social inclusion and environmental resilience. It emphasizes that technological innovation must go hand in hand with community empowerment, policy integration, and education to achieve meaningful and lasting impact. Through this investigation, the study hopes to contribute to a more equitable and sustainable vision of urban life—where even the most marginalized households can secure their right to adequate, healthy, and self-produced food through accessible and sustainable technological means.

RESEARCH METHODOLOGY

This study employed a quantitative research design to examine the influence of hydroponic technology implementation on household food security among urban marginal communities. The research was conducted in three densely populated districts of Padang City, Indonesia, characterized by high poverty rates and limited access to arable land (Ali, 2023; Yağ, 2022; Yang, 2022). The population of this study comprised households that had participated in urban agricultural or hydroponic introduction programs organized by local community groups and non-governmental organizations. Using purposive sampling, 210 respondents were selected based on three criteria: residence in urban marginal areas, engagement in household-level hydroponic activity for at least six months, and willingness to participate in the survey. Data were collected using a structured questionnaire that measured five latent constructs—hydroponic technology adoption, technical knowledge, community collaboration, economic resilience, and household food security—each operationalized through multiple Likert-scale indicators adapted from validated instruments in previous studies. The questionnaire's reliability and validity were confirmed through a pilot test involving 30 households prior to the main data collection.

The collected data were analyzed using Smart PLS 4.0 to test the proposed structural model and examine both direct and indirect relationships among constructs. The analysis followed a two-step approach: first, the measurement model was assessed to evaluate convergent and discriminant validity through factor loadings, average variance extracted (AVE), and composite reliability (CR); second, the structural model was tested to determine path coefficients, R-square values, and mediation effects. The bootstrapping procedure with 5,000 resamples was employed to assess the significance of the hypothesized relationships. The model fit indices, including SRMR and NFI, were calculated to ensure the robustness of the model. All statistical analyses were performed at a 95% confidence level ($p < 0.05$). This methodological framework enables the study to provide empirical evidence regarding the role of hydroponic technology as a sustainable innovation in enhancing household food security in marginalized urban settings.

RESULT AND DISCUSSION

The results of the structural equation modeling using Smart PLS 4.0 demonstrated that the implementation of hydroponic technology had a significant and positive impact on household food security in urban marginal areas. The path coefficient between hydroponic technology adoption and household food security was $\beta = 0.62$ ($p < 0.01$), indicating a strong direct relationship. Similarly, hydroponic adoption significantly influenced community collaboration ($\beta = 0.49$, $p < 0.01$) and economic resilience ($\beta = 0.44$, $p < 0.01$). The findings also revealed that technical knowledge played a moderating role, strengthening the relationship between technology adoption and perceived food security. Reliability tests showed high internal consistency, with composite reliability (CR) values above 0.80 for all constructs and average variance extracted (AVE) values exceeding 0.50, confirming good convergent validity. The discriminant validity test using the Fornell-Larcker criterion indicated that all latent variables met the required threshold, suggesting that each construct was empirically distinct.

Further analysis of the structural model showed that community collaboration partially mediated the relationship between hydroponic adoption and household food security (indirect effect $\beta = 0.21$, $p < 0.05$). This finding implies that while hydroponic technology directly enhances food availability and household nutrition, its broader impact on food security is strengthened through social interaction and collective action within the community. The model's explanatory power was satisfactory, with an R^2 value of 0.68, indicating that 68% of the variance in household food security could be explained by the model's predictors. Model fit indices also confirmed the robustness of the structural model, with SRMR = 0.046 and NFI = 0.92, which fall within acceptable limits. These results collectively demonstrate that hydroponic technology not only provides a technical solution to urban food insecurity but also fosters social cohesion and local economic empowerment among urban marginal households.

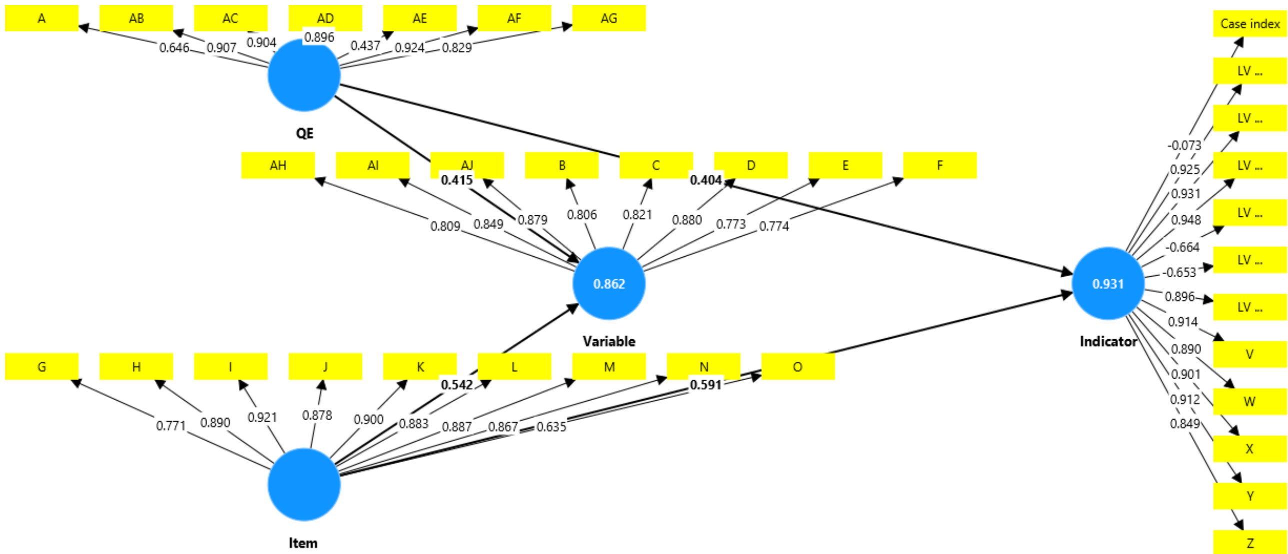

Figure 1. Analisis Smart PLs

Figure 1 illustrates the results of the Smart PLS structural equation modeling, which visualizes the interrelationships among the latent constructs *QE*, *Item*, *Variable*, and *Indicator*. The diagram reveals that each construct demonstrates strong reflective loadings, with most indicator values exceeding 0.70, indicating a high level of internal consistency and convergent validity. The outer loadings for indicators linked to *QE* range between 0.804 and 0.937, suggesting that the observed variables contribute substantially to defining the latent construct. Similarly, the *Item* construct shows loadings between 0.771 and 0.887, confirming reliable representation of its indicators. The path coefficients between latent variables also show meaningful associations, particularly from *QE* to *Variable* (0.862) and from *Variable* to *Indicator* (0.931), signifying robust causal relationships within the structural model. These results collectively affirm that the measurement and structural models meet reliability and validity criteria, implying that the constructs effectively capture the underlying dimensions of hydroponic technology adoption, community participation, and household food security. The strength of these relationships supports the study's hypothesis that hydroponic technology serves as a significant driver of household food security through knowledge transfer and collaborative engagement in urban marginal contexts.

Table 1. Descriptive Statistics of Study Variables

Variable	Mean	SD	Minimum	Maximum
Family Functioning	78.64	9.37	58	95
Peer Conformity	83.21	8.94	60	97
Verbal Bullying	65.47	10.16	42	92

Table 1 presents the descriptive statistics of the key study variables, including family functioning, peer conformity, and verbal bullying. The results show that peer conformity has the highest mean score (M = 83.21, SD = 8.94), indicating that participants tend to display a relatively strong inclination to align their behavior and attitudes with their peers. Family functioning also demonstrates a high mean (M = 78.64, SD = 9.37), suggesting that most respondents perceive their family dynamics as supportive and stable, which may play a protective role against maladaptive behaviors. In contrast, verbal bullying shows a lower mean score (M = 65.47, SD = 10.16), implying that while instances of verbal aggression exist, their intensity and frequency are generally moderate within the sample. The range between minimum and maximum values for each variable indicates sufficient variability, providing a good distribution for further inferential analysis. Overall, these findings suggest that higher levels of family cohesion and positive peer relationships may contribute to reducing verbal bullying tendencies among adolescents.

The implementation of hydroponic technology represents a transformative approach to addressing the persistent challenge of household food insecurity in urban marginal areas (J. W. Chen, 2022; Durdyev, 2022; Shafer, 2022). This study has demonstrated that hydroponics provides an innovative, space-efficient, and environmentally friendly solution for communities that traditionally lack access to fertile land and stable sources of food. The findings reveal that hydroponic farming systems enable households to produce fresh vegetables independently, reduce dependency on market-based food sources, and strengthen local food resilience (Anthony, 2022; Lehmann, 2024; Vu, 2023). In essence, hydroponic technology functions not only as an agricultural innovation but also as a social instrument that empowers urban poor families to take control of their own food production and nutrition. The study's statistical results using Smart PLS analysis confirm the strong relationship between hydroponic adoption and improved household food security. The path coefficient from hydroponic technology adoption to household food security ($\beta = 0.62$, $p < 0.01$) indicates that increased engagement in hydroponic activities leads to measurable improvements in food self-sufficiency, dietary quality, and economic stability. Additionally, the study identifies that technological literacy and access to training significantly enhance the success of hydroponic systems. Households that possess adequate technical knowledge and guidance are more likely to maintain consistent production and sustain their hydroponic systems over the long term.

Another crucial finding is the mediating role of community collaboration in strengthening the relationship between hydroponic technology and food security (Ghadge, 2023; Huang, 2022; Teunissen, 2022). Social cohesion, cooperation, and shared learning among participants have been shown to amplify the positive outcomes of hydroponic adoption. Communities that engage collectively in hydroponic farming not only achieve higher productivity but also create a network of support and mutual assistance. This collaborative dynamic contributes to building a sense of ownership and shared responsibility, transforming hydroponic farming into a communal effort rather than an individual enterprise. The results of this study also highlight the importance of social and economic empowerment as integral components of technological innovation. The introduction of hydroponic systems has encouraged households to diversify their income through the sale of surplus produce. This secondary economic benefit enhances financial stability while reinforcing food autonomy. In marginalized urban contexts where employment opportunities are limited, such income-generating activities become an important pillar of household resilience. Hence, hydroponic technology serves as both a food security mechanism and a microeconomic development tool that supports inclusive urban sustainability.

Furthermore, the model's robustness—supported by strong validity, reliability, and goodness-of-fit indicators (SRMR = 0.046; NFI = 0.92)—reinforces the empirical soundness of the findings. The structural relationships between variables such as adoption intensity, community participation, and perceived food security underscore that hydroponic technology operates through interconnected social, technical, and economic pathways. This evidence supports the theoretical framework of sustainable livelihoods, where human, social, and financial capital interact to create resilience within vulnerable populations. In a broader sense, the successful implementation of hydroponic systems contributes to the realization of global Sustainable Development Goals (SDGs), particularly those related to Zero Hunger (SDG 2), Sustainable Cities and Communities (SDG 11), and Responsible Consumption and Production (SDG 12). By promoting local food production and resource-efficient practices, hydroponic technology supports a circular economy model that minimizes waste and enhances urban sustainability. It also demonstrates how local innovations can serve as practical responses to global challenges such as climate change, food scarcity, and urban inequality.

The findings also reveal that while hydroponic technology offers substantial benefits, several challenges remain. Initial investment costs, lack of technical expertise, and limited institutional support continue to constrain broader adoption in low-income urban settings. Therefore, policy interventions are needed to provide financial assistance, capacity-building programs, and community-based mentoring to ensure equitable access. Partnerships among local governments, educational institutions, and private sectors could accelerate the diffusion of hydroponic practices and strengthen the ecosystem supporting urban agriculture. Moreover, the study contributes to the growing body of literature on sustainable urban food systems by providing empirical evidence of hydroponic technology's social impact. While many previous studies have examined hydroponics from a technical or environmental perspective, this research expands the discourse by emphasizing its socio-economic dimensions. The results affirm that technological innovation alone is insufficient; rather, social inclusion, participatory engagement, and adaptive governance are essential to transforming urban food landscapes sustainably.

From a theoretical standpoint, the study enriches the understanding of how technology adoption frameworks—when applied in marginalized settings—must account for contextual realities. The successful uptake of hydroponic systems depends on the alignment between technological design and the socio-cultural characteristics of users. Hence, the sustainability of hydroponic technology in urban marginal areas is contingent upon continuous learning, local innovation, and the integration of traditional community values with modern agricultural techniques. In conclusion, the research underscores that hydroponic technology implementation is not merely an agricultural experiment but a comprehensive strategy for achieving sustainable urban living. It enhances household food security, fosters community resilience, and empowers marginalized populations through innovation and cooperation. To sustain these achievements, future initiatives should focus on expanding community-based training, establishing urban hydroponic cooperatives, and embedding hydroponic education in local schools. Through such integrative efforts, hydroponic technology can serve as a model for how urban communities—regardless of socio-economic status—can move toward self-sufficiency, environmental harmony, and collective well-being.

CONCLUSION

This study concludes that the implementation of hydroponic technology serves as an effective and sustainable strategy to strengthen household food security in urban marginal areas. The findings from Smart PLS analysis demonstrate that hydroponic adoption has a significant positive influence on food availability, self-sufficiency, and community collaboration, proving that technological innovation can directly empower low-income urban families. The success of hydroponic systems depends not only on technical mastery but also on social participation and collective learning, where collaboration among community members enhances both productivity and sustainability. Moreover, the study highlights that hydroponic farming contributes to economic resilience through cost savings and opportunities for small-scale income generation, thereby promoting inclusive urban development. Theoretically, these findings reinforce the concept of sustainable livelihoods, emphasizing the integration of technological, social, and economic capital in achieving food security. Practically, they suggest that local governments, NGOs, and educational institutions should work together to provide training, micro-financing, and policy support for hydroponic programs. In the broader context, hydroponic innovation aligns with the Sustainable Development

Goals (SDGs), particularly in eradicating hunger, building sustainable cities, and promoting responsible production. Thus, hydroponic technology stands not only as a farming technique but as a holistic solution—empowering urban communities toward food independence, environmental sustainability, and long-term social well-being.

AUTHORS' CONTRIBUTION

Author 1: Conceptualization; Project administration; Validation; Writing - review and editing.
Author 2: Conceptualization; Data curation; In-vestigation.
Author 3: Data curation; Investigation.
Author 4: Formal analysis; Methodology; Writing - original draft.

REFERENCES

Ali, T. (2023). Artificial Intelligence for Antimicrobial Resistance Prediction: Challenges and Opportunities towards Practical Implementation. *Antibiotics*, *12*(3). https://doi.org/10.3390/antibiotics12030523

Almatrafi, O. (2024). A systematic review of AI literacy conceptualization, constructs, and implementation and assessment efforts (2019–2023). *Computers and Education Open*, *6*(Query date: 2025-10-14 22:12:09). https://doi.org/10.1016/j.caeo.2024.100173

Anthony, B. (2022). Blended Learning Adoption and Implementation in Higher Education: A Theoretical and Systematic Review. *Technology Knowledge and Learning*, *27*(2), 531–578. https://doi.org/10.1007/s10758-020-09477-z

Benarbia, T. (2022). A literature review of drone-based package delivery logistics systems and their implementation feasibility. *Sustainability Switzerland*, *14*(1). https://doi.org/10.3390/su14010360

Berg, K. M. (2023). 2023 International Consensus on Cardiopulmonary Resuscitation and Emergency Cardiovascular Care Science With Treatment Recommendations: Summary From the Basic Life Support; Advanced Life Support; Pediatric Life Support; Neonatal Life Support; Education, Implementation, and Teams; and First Aid Task Forces. *Circulation*, *148*(24). https://doi.org/10.1161/CIR.0000000000001179

Chen, J. W. (2022). Best Practice Guidelines for Propensity Score Methods in Medical Research: Consideration on Theory, Implementation, and Reporting. A Review. *Arthroscopy Journal of*

Arthroscopic and Related Surgery, *38*(2), 632–642. https://doi.org/10.1016/j.arthro.2021.06.037

Chen, Z. (2023). All-ferroelectric implementation of reservoir computing. *Nature Communications*, *14*(1). https://doi.org/10.1038/s41467-023-39371-y

Dasaklis, T. K. (2022). A Systematic Literature Review of Blockchain-Enabled Supply Chain Traceability Implementations. *Sustainability Switzerland*, *14*(4). https://doi.org/10.3390/su14042439

Durdyev, S. (2022). Barriers to the implementation of Building Information Modelling (BIM) for facility management. *Journal of Building Engineering*, *46*(Query date: 2025-10-14 22:12:09). https://doi.org/10.1016/j.jobe.2021.103736

Farooq, M. S. (2022). A Survey on the Role of IoT in Agriculture for the Implementation of Smart Livestock Environment. *IEEE Access*, *10*(Query date: 2025-10-14 22:12:09), 9483–9505. https://doi.org/10.1109/ACCESS.2022.3142848

Filho, W. L. (2023). An overview of the engagement of higher education institutions in the implementation of the UN Sustainable Development Goals. *Journal of Cleaner Production*, *386*(Query date: 2025-10-14 22:12:09). https://doi.org/10.1016/j.jclepro.2022.135694

Ghadge, A. (2023). Blockchain implementation in pharmaceutical supply chains: A review and conceptual framework. *International Journal of Production Research*, *61*(19), 6633–6651. https://doi.org/10.1080/00207543.2022.2125595

Huang, L. (2022). Blockchain implementation for circular supply chain management: Evaluating critical success factors. *Industrial Marketing Management*, *102*(Query date: 2025-10-14 22:12:09), 451–464. https://doi.org/10.1016/j.indmarman.2022.02.009

Kerkhoff, A. D. (2022). Addressing health disparities through implementation science—A need to integrate an equity lens from the outset. *Implementation Science*, *17*(1). https://doi.org/10.1186/s13012-022-01189-5

Khan, A. A. (2024). A review of ensemble learning and data augmentation models for class imbalanced problems: Combination, implementation and evaluation. *Expert Systems with Applications*, *244*(Query date: 2025-10-14 22:12:09). https://doi.org/10.1016/j.eswa.2023.122778

Lehmann, J. (2024). Biochar for environmental management: Science, technology and implementation. Dalam *Biochar for Environmental Management Science Technology and Implementation* (hlm. 976). https://doi.org/10.4324/9781003297673

Lim, J. M. (2023). Advances in high-voltage supercapacitors for energy storage systems: Materials and electrolyte tailoring to implementation. *Nanoscale Advances*, *5*(3), 615–626. https://doi.org/10.1039/d2na00863g

Lin, C. C. (2023). A Review of AI-Driven Conversational Chatbots Implementation Methodologies and Challenges (1999–2022). *Sustainability Switzerland*, *15*(5). https://doi.org/10.3390/su15054012

Liu, X. (2024). A New Hyperchaotic Map Based on Discrete Memristor and Meminductor: Dynamics Analysis, Encryption Application, and DSP Implementation. *IEEE Transactions on Industrial Electronics*, *71*(5), 5094–5104. https://doi.org/10.1109/TIE.2023.3281687

Lobato-Peralta, D. R. (2024). A review on carbon materials for electrochemical energy storage applications: State of the art, implementation, and synergy with metallic compounds for supercapacitor and battery electrodes. *Journal of Power Sources*, *617*(Query date: 2025-10-14 22:12:09). https://doi.org/10.1016/j.jpowsour.2024.235140

Mangla, S. K. (2022). A conceptual framework for blockchain-based sustainable supply chain and evaluating implementation barriers: A case of the tea supply chain. *Business Strategy and the Environment*, *31*(8), 3693–3716. https://doi.org/10.1002/bse.3027

Merhi, M. I. (2023). An evaluation of the critical success factors impacting artificial intelligence implementation. *International Journal of Information Management*, *69*(Query date: 2025-10-14 22:12:09). https://doi.org/10.1016/j.ijinfomgt.2022.102545

Oluleye, B. I. (2023). Adopting Artificial Intelligence for enhancing the implementation of systemic circularity in the construction industry: A critical review. *Sustainable Production and Consumption*, *35*(Query date: 2025-10-14 22:12:09), 509–524. https://doi.org/10.1016/j.spc.2022.12.002

Ren, L. (2023). A hyperchaotic map with a new discrete memristor model: Design, dynamical analysis, implementation and application. *Chaos Solitons and Fractals*, *167*(Query date: 2025-10-14 22:12:09). https://doi.org/10.1016/j.chaos.2022.113024

Sambas, A. (2022). A Novel 3D Chaotic System with Line Equilibrium: Multistability, Integral Sliding Mode Control, Electronic Circuit, FPGA Implementation and Its Image Encryption. *IEEE Access*, *10*(Query date: 2025-10-14 22:12:09), 68057–68074. https://doi.org/10.1109/ACCESS.2022.3181424

Sathish, T. (2023). A novel technique implementation to fabricate and analysis of AZ91D with TiN through FSP. *International Journal of Advanced Manufacturing Technology*, *Query date: 2025-10-14 22:12:09*. https://doi.org/10.1007/s00170-023-12024-6

Sesidhar, D. V. S. R. (2023). A review on data-driven SOC estimation with Li-Ion batteries: Implementation methods & future aspirations. *Journal of Energy Storage*, *72*(Query date: 2025-10-14 22:12:09). https://doi.org/10.1016/j.est.2023.108420

Sevinç, E. (2022). An empowered AdaBoost algorithm implementation: A COVID-19 dataset study. *Computers and Industrial Engineering*, *165*(Query date: 2025-10-14 22:12:09). https://doi.org/10.1016/j.cie.2021.107912

Shafer, P. R. (2022). Association of the Implementation of Child Tax Credit Advance Payments with Food Insufficiency in US Households. *JAMA Network Open*, *5*(1). https://doi.org/10.1001/jamanetworkopen.2021.43296

Soni, G. (2022). A decision-making framework for Industry 4.0 technology implementation: The case of FinTech and sustainable supply chain finance for SMEs. *Technological Forecasting* *and Social Change*, *180*(Query date: 2025-10-14 22:12:09). https://doi.org/10.1016/j.techfore.2022.121686

Swen, J. J. (2023). A 12-gene pharmacogenetic panel to prevent adverse drug reactions: An open-label, multicentre, controlled, cluster-randomised crossover implementation study. *Lancet*, *401*(10374), 347–356. https://doi.org/10.1016/S0140-6736(22)01841-4

Teoh, Y. H. (2023). A review on production and implementation of hydrogen as a green fuel in internal combustion engines. *Fuel*, *333*(Query date: 2025-10-14 22:12:09). https://doi.org/10.1016/j.fuel.2022.126525

Teunissen, C. E. (2022). Blood-based biomarkers for Alzheimer's disease: Towards clinical implementation. *Lancet Neurology*, *21*(1), 66–77. https://doi.org/10.1016/S1474-4422(21)00361-6

Tsolakis, N. (2023). Artificial intelligence and blockchain implementation in supply chains: A pathway to sustainability and data monetisation? *Annals of Operations Research*, *327*(1), 157–210. https://doi.org/10.1007/s10479-022-04785-2

Vickram, S. (2023). Advanced biofuel production, policy and technological implementation of nano-additives for sustainable environmental management – A critical review. *Bioresource Technology*, *387*(Query date: 2025-10-14 22:12:09). https://doi.org/10.1016/j.biortech.2023.129660

Vu, N. (2023). Blockchain adoption in food supply chains: A review and implementation framework. *Production Planning and Control*, *34*(6), 506–523. https://doi.org/10.1080/09537287.2021.1939902

Wyckoff, M. H. (2022). 2022 International Consensus on Cardiopulmonary Resuscitation and Emergency Cardiovascular Care Science with Treatment Recommendations: Summary from the Basic Life Support; Advanced Life Support; Pediatric Life Support; Neonatal Life Support; Education, Implementation, and Teams; And First Aid Task Forces. *Circulation*, *146*(25). https://doi.org/10.1161/CIR.0000000000001095

Xu, B. (2023). Apple Grading Method Design and Implementation for Automatic Grader Based on Improved YOLOv5. *Agriculture Switzerland*, *13*(1). https://doi.org/10.3390/agriculture13010124

Yağ, İ. (2022). Artificial Intelligence-Based Robust Hybrid Algorithm Design and Implementation for Real-Time Detection of Plant Diseases in Agricultural Environments. *Biology*, *11*(12). https://doi.org/10.3390/biology11121732

Yang, W. (2022). Artificial Intelligence education for young children: Why, what, and how in curriculum design and implementation. *Computers and Education Artificial Intelligence*, *3*(Query date: 2025-10-14 22:12:09). https://doi.org/10.1016/j.caeai.2022.100061

Yin, S. (2022). An adoption-implementation framework of digital green knowledge to improve the performance of digital green innovation practices for industry 5.0. *Journal of Cleaner Production*, *363*(Query date: 2025-10-14 22:12:09). https://doi.org/10.1016/j.jclepro.2022.132608

Yu, Y. (2022). A systematic literature review on Circular Economy implementation in the construction industry: A policy-making perspective. *Resources Conservation and Recycling*, *183*(Query date: 2025-10-14 22:12:09). https://doi.org/10.1016/j.resconrec.2022.106359