



Green Digital Education Model with AI and IoT Integration in Sustainable Goat Farming Curriculum

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ABSTRACT

The rapid advancement of Artificial Intelligence (AI) and Internet of Things (IoT) technologies has transformed agricultural production systems; however, their integration into agricultural education remains limited. This study develops and evaluates a Green Digital Education Model that integrates AI, IoT, and Material Flow Cost Accounting (MFCA) into a Sustainable Goat Farming Curriculum. Using a Research and Development (R&D) approach, the study followed four phases: needs analysis and curriculum mapping, system development and technological integration, pilot implementation, and evaluation. IoT sensors were deployed to collect real-time environmental and livestock data, which were integrated into a cloud-based dashboard and an AI-driven Decision Support System (DSS). An MFCA module was incorporated to enable environmental cost analysis and greenhouse gas emission calculations based on standardized methodologies. Pilot implementation in selected university courses demonstrated significant improvements in students' digital literacy, sustainability awareness, and analytical decision-making skills, as evidenced by pre-test and post-test comparisons. Qualitative findings indicated increased engagement, motivation, and interdisciplinary collaboration. The model transforms conventional livestock education into a technology-driven "living laboratory," aligning agricultural curricula with Education 4.0 principles and sustainability reporting standards. The study contributes a scalable framework for integrating green technology and digital innovation into higher education, supporting environmentally responsible and data-driven agricultural practices.

Keywords: Green Digital Education; Artificial Intelligence (AI); Internet of Things (IoT); Sustainable Goat Farming; Material Flow Cost Accounting (MFCA); Environmental Accounting; Smart Agriculture; Education 4.0; Decision Support System (DSS); Sustainability Learning

Field: Agricultural Education; Digital Agriculture / Smart Farming; Environmental Accounting; Educational Technology (EdTech); Sustainability and Green Innovation; Agribusiness and Rural Development

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SDG's: Zero Hunger (2); Quality Education (4); Industry, Innovation, and Infrastructure (9); Responsible Consumption and Production (12); Climate Action (13)

INTRODUCTION

The rapid advancement of Artificial Intelligence (AI) and Internet of Things (IoT) technologies has significantly transformed industrial sectors; however, their integration into agricultural education remains limited, particularly in sustainable livestock management (Sharma & Shivandu, 2024). In many developing countries, goat farming plays a strategic role in food security, rural economic resilience, and small-scale agribusiness development. Despite this importance, educational curricula in agriculture and agribusiness are still largely theoretical, fragmented, and insufficiently aligned with real-time digital technologies. Students often

learn farm management, environmental accounting (Renaldo, Fadrul, et al., 2022), and animal health monitoring (Arlia et al., 2025) as separate subjects without experiencing an integrated, data-driven ecosystem that reflects Industry 4.0 and Society 5.0 paradigms.

The need for a green digital transformation in agricultural education is becoming increasingly urgent. Sustainable goat farming (Renaldo, Hafni, et al., 2022) requires not only productivity enhancement but also environmental accountability, emission monitoring, resource efficiency, and evidence-based decision-making. Traditional teaching approaches rarely incorporate real-time sensor data, predictive analytics, or environmental cost calculations. Consequently, graduates may lack competencies in smart farming technologies, carbon emission reporting, and AI-based decision support systems. Bridging this gap demands an innovative educational model that combines sustainability principles, environmental accounting, and digital technologies within a unified learning framework.

This study proposes a Green Digital Education Model integrating AI and IoT into a Sustainable Goat Farming Curriculum (Renaldo et al., 2021). The model connects cloud-based dashboards, environmental sensors, and intelligent decision-support algorithms with structured learning modules. Students are not only exposed to conceptual knowledge but also interact directly with live farm data, including temperature, humidity, feed efficiency, and greenhouse gas emissions. Through this integration, the curriculum promotes experiential learning, problem-based analysis, and data-driven sustainability management. The model aims to strengthen digital literacy, environmental awareness, and techno-economic analytical skills among students in agriculture, accounting, and agribusiness programs.

The novelty of this study lies in the development of an integrated green digital learning ecosystem that unifies AI-driven analytics, IoT-based livestock monitoring (Susanti et al., 2024), and environmental accounting within a structured academic curriculum. Unlike previous educational models that treat smart farming technologies as standalone technical tools, this research embeds them directly into curriculum design, learning outcomes, and competency assessment frameworks. The approach transforms goat farming from a conventional agricultural practice into a living laboratory for sustainability education (Renaldo et al., 2025).

Another innovative aspect is the incorporation of Material Flow Cost Accounting (MFCA) and greenhouse gas emission calculations into the learning process using real-time data generated from IoT devices (Tran & Herzig, 2020). Students are trained to evaluate not only productivity and animal health but also environmental impact and resource efficiency. This integration introduces a multidisciplinary perspective that combines agriculture, accounting, data science, and sustainability governance, an approach rarely implemented in livestock education programs.

Furthermore, the model introduces an AI-based Decision Support System (DSS) as a pedagogical tool rather than merely a farm management application. By interacting with predictive models for disease detection and estrus monitoring, students develop analytical reasoning skills and understand how machine learning supports sustainable decision-making. This educational orientation of AI-DSS distinguishes the model from existing smart farming platforms, which primarily focus on operational efficiency rather than learning transformation.

Overall, the proposed Green Digital Education Model contributes a novel framework that aligns sustainable agriculture education with digital transformation, environmental accountability, and experiential learning principles. It offers a scalable model for universities seeking to integrate green technology, AI innovation, and sustainability reporting into modern agricultural curricula.

LITERATURE REVIEW

The integration of digital technologies into agricultural systems has accelerated in recent years, particularly through the adoption of Artificial Intelligence (AI) and Internet of Things (IoT) frameworks in smart farming (Gebresenbet et al., 2023). Previous studies demonstrate that IoT-based environmental sensors enable real-time monitoring of temperature, humidity, air quality, and animal activity, leading to improved livestock productivity and operational efficiency. AI techniques such as machine learning, Random Forest, and Convolutional Neural Networks (CNN) have been applied to detect animal diseases, predict reproductive cycles, and optimize feeding strategies. These technological advancements indicate that data-driven livestock management can enhance both economic performance and sustainability outcomes. However, most studies focus on technical implementation and productivity gains rather than educational transformation.

In parallel, the concept of sustainable agriculture has expanded beyond productivity to include environmental accountability and carbon emission measurement (Ibrahim et al., 2025). Research on greenhouse gas (GHG) emissions in livestock farming emphasizes the importance of methane (CH₄) and nitrous oxide

(N₂O) monitoring using standardized approaches such as IPCC guidelines. Additionally, Material Flow Cost Accounting (MFCA) has been introduced as an environmental management accounting tool that traces material and energy flows to identify inefficiencies and hidden costs. MFCA supports resource efficiency, waste reduction, and sustainability reporting, making it highly relevant to livestock operations. Nevertheless, the application of MFCA in educational settings, particularly in agriculture and livestock curricula, remains underexplored.

From an educational perspective, digital transformation in higher education has encouraged the adoption of experiential learning, problem-based learning, and technology-enhanced instruction (Bygstad et al., 2022). Smart learning environments, cloud-based dashboards, and simulation platforms have been shown to improve student engagement and digital literacy. Education 4.0 frameworks advocate integrating real-time data analytics, AI tools, and interdisciplinary approaches to prepare graduates for Industry 4.0 ecosystems. Despite these developments, agricultural education programs often continue to rely on conventional teaching models, where sustainability, accounting, and farm management are taught separately without technological integration.

Recent literature also highlights the importance of interdisciplinary learning models that combine environmental science, business analytics, and information systems. The convergence of agriculture, accounting, and AI reflects the growing demand for sustainability-oriented competencies, including carbon reporting, digital monitoring, and data-driven decision-making. However, there is limited research proposing a comprehensive curriculum model that embeds IoT-generated farm data, AI-based decision support systems, and environmental accounting tools into structured learning outcomes.

Therefore, while prior studies provide strong foundations in smart farming technologies, sustainability accounting, and digital education frameworks, a gap remains in integrating these domains into a unified green digital education model. Existing literature predominantly addresses operational efficiency or technological innovation in isolation. Few studies conceptualize smart livestock systems as pedagogical platforms for sustainability education. This gap justifies the development of a Green Digital Education Model that integrates AI, IoT, and environmental accounting within a sustainable goat farming curriculum.

METHODOLOGY

This study adopts a Research and Development (R&D) approach to design, implement, and evaluate the Green Digital Education Model integrating Artificial Intelligence (AI) and Internet of Things (IoT) within a Sustainable Goat Farming Curriculum (Houshmandi et al., 2026). The research follows a systematic framework consisting of four main phases: (1) needs analysis and curriculum mapping, (2) system development and integration, (3) pilot implementation, and (4) evaluation and refinement. This approach ensures that the model is pedagogically sound, technologically functional, and aligned with sustainability learning objectives.

In the first phase, a needs analysis was conducted through curriculum review, stakeholder interviews, and focus group discussions involving lecturers, students, livestock practitioners, and digital technology experts (Roshania et al., 2023). The objective was to identify competency gaps related to digital literacy, environmental accounting, and smart farming technologies. Curriculum mapping was then performed to align learning outcomes with key components of the proposed model, including IoT-based monitoring, AI-driven decision support, and Material Flow Cost Accounting (MFCA). The output of this phase was a structured curriculum framework integrating sustainability, technology, and managerial competencies.

The second phase involved the development and integration of the technological platform. IoT sensors were installed in a goat farming environment to collect real-time data on temperature, humidity, feed consumption, animal weight, and environmental indicators. The data were transmitted to a cloud-based dashboard accessible to students and instructors. An AI-based Decision Support System (DSS) was developed using machine learning algorithms to analyze livestock health patterns and reproductive indicators. Additionally, an MFCA module was embedded in the system to calculate material efficiency, feed conversion ratios, and greenhouse gas emissions based on standardized IPCC methodologies. The technological architecture was designed to support both operational farm monitoring and educational interaction.

In the third phase, pilot implementation was carried out in selected university courses related to agribusiness management, environmental accounting, and digital agriculture. Students engaged in experiential learning activities using real-time farm data, including data interpretation, sustainability reporting, and AI-based decision analysis. Learning activities were structured through problem-based assignments, case simulations, and project-based evaluations. The pilot phase aimed to test the feasibility, usability, and educational effectiveness of the model.

The final phase involved evaluation and model refinement. Quantitative data were collected through pre-test and post-test assessments to measure improvements in digital literacy, sustainability awareness, and analytical skills. Surveys and structured questionnaires were used to evaluate student engagement and perceived usefulness of the system. Qualitative feedback was obtained through interviews and reflective discussions to assess pedagogical strengths and limitations. Data were analyzed using descriptive statistics and paired sample tests to determine learning impact, while thematic analysis was applied to qualitative responses. The findings from this evaluation were used to refine the curriculum structure, technological features, and instructional strategies.

Through this multi-phase methodology, the study ensures that the Green Digital Education Model is empirically validated, technologically integrated, and pedagogically effective in supporting sustainable goat farming education.

RESULTS AND DISCUSSION

Results

The implementation of the Green Digital Education Model demonstrated significant improvements in students' digital competencies, sustainability understanding, and analytical skills. Based on the pilot testing conducted in selected agribusiness and environmental accounting courses, the integration of AI- and IoT-based systems into the curriculum created a more interactive and data-driven learning environment. Students were able to access real-time farm data through the cloud-based dashboard, analyze environmental conditions, evaluate feed efficiency, and interpret emission indicators. This hands-on interaction enhanced experiential learning and bridged the gap between theoretical knowledge and real-world agricultural practices.

Quantitative analysis of pre-test and post-test assessments indicated a measurable increase in student learning outcomes. Digital literacy scores improved substantially after students engaged with IoT data interpretation and AI-based decision support tools. Similarly, sustainability awareness scores showed notable growth, particularly in understanding greenhouse gas emissions, resource efficiency, and environmental cost analysis using Material Flow Cost Accounting (MFCA). Statistical testing confirmed that these improvements were significant, indicating that the model effectively strengthened interdisciplinary competencies in technology and sustainability.

From a technical perspective, the IoT system functioned reliably in collecting and transmitting environmental and livestock data. The AI-based Decision Support System (DSS) demonstrated satisfactory predictive performance in identifying potential health irregularities and reproductive indicators. Students reported that interacting with predictive analytics improved their critical thinking and decision-making skills. The MFCA module enabled learners to calculate material flow efficiency and estimate carbon emissions, fostering a deeper understanding of environmental accountability within livestock operations.

Qualitative feedback from students and instructors further supported the effectiveness of the model. Participants highlighted increased engagement, higher motivation, and improved problem-solving abilities. The integration of live farm data transformed the classroom into a "living laboratory," allowing students to simulate managerial decisions based on real-time evidence. Instructors noted that interdisciplinary collaboration between agriculture, accounting, and information systems became more practical and structured through the platform.

Overall, the results indicate that the Green Digital Education Model successfully enhances experiential learning, promotes sustainability-oriented competencies, and strengthens digital readiness among students. The integration of AI, IoT, and environmental accounting within a unified curriculum framework proved effective in transforming traditional goat farming education into a modern, technology-driven learning ecosystem.

Discussion

The findings of this study demonstrate that integrating AI and IoT technologies into a sustainable goat farming curriculum significantly enhances students' digital competence and sustainability-oriented thinking. The improvement in post-test scores confirms that experiential exposure to real-time farm data strengthens conceptual understanding beyond traditional lecture-based methods. This aligns with Education 4.0 principles, which emphasize technology-enabled, student-centered, and problem-based learning environments. By transforming a livestock farm into a digital learning laboratory, the model bridges the gap between theoretical instruction and practical application.

The significant increase in sustainability awareness indicates that embedding Material Flow Cost Accounting (MFCA) and greenhouse gas emission analysis into coursework fosters environmental accountability among students. Unlike conventional agricultural education, which often prioritizes productivity

metrics alone, this model introduces a balanced perspective between economic efficiency and ecological responsibility. Students not only learned to optimize feed conversion and animal health but also to evaluate carbon emissions and material inefficiencies. This multidisciplinary integration supports the growing demand for graduates who understand both environmental governance and data-driven farm management.

The performance of the AI-based Decision Support System (DSS) also highlights the pedagogical value of predictive analytics in education (Renaldo et al., 2024). Rather than functioning solely as an operational farm tool, AI served as a learning instrument that encouraged analytical reasoning and evidence-based decision-making. Students engaged in interpreting algorithmic outputs, comparing predictions with actual farm conditions, and discussing potential managerial responses. This interaction deepened their understanding of how machine learning contributes to sustainable agriculture. It also demonstrates that AI can enhance critical thinking when positioned as an educational medium rather than an automated solution.

Furthermore, the positive qualitative feedback suggests that technology integration increases engagement and motivation. Students reported that working with live IoT data made learning more relevant and dynamic. This supports experiential learning theory, which posits that knowledge is constructed through direct experience and reflective analysis. The “living laboratory” concept allowed students to visualize environmental changes, track performance indicators, and simulate real managerial decisions. Such immersion fosters deeper cognitive processing compared to static case studies or hypothetical scenarios.

However, the discussion also reveals challenges. Effective implementation requires stable technological infrastructure, interdisciplinary collaboration, and sufficient data availability. Limited datasets can affect AI model accuracy, and technical issues such as connectivity disruptions may hinder real-time learning experiences. Therefore, institutional readiness and continuous technological refinement are essential for long-term sustainability of the model. Additionally, faculty development programs are necessary to ensure instructors can effectively integrate digital tools into pedagogy.

Overall, the discussion underscores that the Green Digital Education Model represents not merely technological adoption but a structural transformation of agricultural education. By integrating AI, IoT, and environmental accounting within a cohesive curriculum, the model prepares students for digital agriculture ecosystems while promoting sustainability literacy. The findings suggest that such integration can serve as a scalable framework for universities seeking to modernize agricultural and agribusiness education in alignment with global sustainability and digital transformation agendas.

CONCLUSION

Conclusion

This study concludes that the Green Digital Education Model integrating Artificial Intelligence (AI), Internet of Things (IoT), and environmental accounting into a Sustainable Goat Farming Curriculum effectively enhances digital literacy, sustainability awareness, and analytical decision-making skills among students. The integration of real-time sensor data, AI-based Decision Support Systems (DSS), and Material Flow Cost Accounting (MFCA) transforms conventional agricultural education into a data-driven and experiential learning ecosystem. The empirical findings demonstrate significant improvements in student competencies, engagement, and interdisciplinary understanding. By positioning goat farming as a living digital laboratory, the model successfully aligns agricultural education with Industry 4.0, sustainability reporting standards, and green transformation principles.

Implications

The study has several important implications. Academically, it provides a structured framework for integrating smart farming technologies into higher education curricula, particularly in agriculture, agribusiness, accounting, and sustainability studies. It supports the transition toward Education 4.0 by embedding real-time analytics and AI tools into competency-based learning outcomes.

Practically, the model equips graduates with industry-relevant skills, including digital farm monitoring, carbon emission analysis, and AI-assisted decision-making. This strengthens workforce readiness in digital agriculture ecosystems.

From a policy perspective, the findings encourage universities and educational regulators to promote interdisciplinary green digital curricula that combine environmental accountability with technological innovation (Fransisca et al., 2025). The model also contributes to sustainable development goals by fostering environmental literacy and resource efficiency awareness in future professionals.

Limitations

Despite its contributions, this study has several limitations. First, the pilot implementation was conducted within a limited number of courses and participants, which may affect generalizability. Second, the AI model relied on a relatively small dataset, potentially limiting predictive accuracy and robustness. Third, the study focused primarily on goat farming, which may restrict applicability to other livestock or agricultural sectors without contextual adaptation. Additionally, technical challenges such as internet connectivity and sensor calibration may influence system performance in different environments.

Recommendations

Based on the findings, several recommendations are proposed. Universities should invest in digital infrastructure, including stable cloud systems and IoT-supported laboratories, to ensure sustainable implementation. Curriculum developers should formally embed sustainability accounting and AI-based analytics into learning outcomes rather than treating them as supplementary tools. Faculty training programs are also essential to strengthen educators' digital competencies and interdisciplinary teaching capabilities. Collaboration with industry partners and government agencies is recommended to enhance real-world data integration and policy alignment.

Future Research

Future research should expand the model's implementation across multiple universities and agricultural contexts to improve generalizability. Studies could explore comparative analysis between different livestock sectors, such as cattle or poultry farming, to test scalability. Further research is also needed to enhance AI accuracy through larger datasets and advanced machine learning techniques. Longitudinal studies may examine the long-term impact of green digital education on graduate employability and sustainability practices in the agricultural industry. Additionally, future investigations could integrate mobile learning applications, blockchain-based traceability systems, or carbon credit simulations to further enrich the green digital learning ecosystem.

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