Review

Harvesting a sustainable future: An overview of smart agriculture’s role in social, economic, and environmental sustainability

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ABSTRACT

As climate change and population growth intensify, the agricultural sector’s need for sustainable solutions is paramount. This paper presents an overview of smart agriculture, a strategy leveraging technology and data analytics, and its potential to advance sustainability socially, economically, and environmentally. Drawing on recent research, we examine the integration of smart technologies in agriculture, their impact on sustainability, and the architectural design and key factors influencing their adoption. We critically review the literature on the effectiveness of smart agriculture, illuminating how smart farming strategies can curb environmental harm, stimulate economic growth, and promote social inclusivity. We identify existing research gaps and propose directions for future investigation, emphasising the need for rigorous studies on implementation strategies and long-term impacts of smart agriculture on rural landscapes. Our comprehensive overview aims to engage and guide diverse stakeholders, enhancing understanding of sustainable agriculture practices and encouraging more sustainable farming implementations. This paper contributes to global efforts towards harvesting a sustainable future.

1. Introduction

The global population is expected to reach 10 billion by 2050 (Echegaray et al., 2022), leading to a corresponding increase in demand for agricultural commodities, particularly food (Terence and Purushothaman, 2020). This has resulted in a widening demand-supply imbalance (Leduc et al., 2021). Challenges such as reduced resources, environmental changes, and labour shortages further exacerbate this imbalance, compromising food security and overall agricultural productivity (Navarro et al., 2020). To address these issues, a sustainable approach to agriculture is necessary, utilising the latest technological advancements (Lytos et al., 2020). One potential solution is “smart farming,” which aims to enhance food production and meet the population’s needs sustainably (Bongomin et al., 2020). This aligns with the United Nations’ Sustainable Development Goals (SDGs), which call for ensuring food security through sustainable means (Krisnawijaya et al., 2022).

Smart farming, also known as smart agriculture, utilises advanced agricultural technologies to enhance farm management tasks (Triantafyllou et al., 2019). By integrating Industry 4.0 technologies, smart agriculture achieves sustainable outcomes such as increased productivity, resource conservation, and reduced carbon emissions (Lezoche et al., 2020). The Internet of Things (IoT) plays a pivotal role in smart agriculture by enabling farmers to monitor and regulate their products effectively (Farooq et al., 2020). Data analytics is also crucial for extracting meaningful insights from the vast amount of data generated by IoT devices (Javaid et al., 2022). The integration of modern digital technologies has transformed smart farming into a data-enabled and data-driven operation (Vimalajeewa et al., 2021). Given their interdependence, further exploration of both IoT and data analytics systems in the agricultural sector would be advantageous.

Google Trends data indicates a rising interest among internet users in sustainability, smart farming, and smart agriculture. The increasing search traffic for these terms over the past five years reflects growing awareness and concern regarding sustainability, as well as a desire to acquire more knowledge about it. Figs. 1 and 2 illustrate the
corresponding search traffic trends for “sustainability” and “smart farming” or “smart agriculture,” affirming the alignment in their rise and fall. These findings suggest that internet users are progressively recognising the potential of smart farming or smart agriculture in advancing sustainability.

In order to fully understand the relationship between sustainability and smart agriculture, a comprehensive examination of current research trends, areas of sustainability that can be improved through smart agriculture, factors that drive the adoption of sustainable smart agriculture, the efficacy of smart agriculture in promoting sustainability, and future research directions is essential. This will provide valuable insights and expand knowledge about both sustainability and smart agriculture for scholars, researchers, and agricultural producers alike. In light of this, the present paper endeavours to provide a comprehensive overview of the topic of smart agriculture and sustainability, highlighting its key aspects and interconnections.

The present paper is structured as follows. In Section 2, the methodology employed to gather relevant literature for review and the comparison of related works are outlined. Section 3 provides a comprehensive overview of smart agriculture and its integral components, including IoT and data analytics. The architecture of smart agriculture is then analysed in detail in Section 4. In Section 5, the correlation between smart agriculture and sustainability is thoroughly investigated. Section 6 explores future research opportunities for the sustainability of smart agriculture. In Section 7, the limitations of the current study are discussed. Finally, Section 8 offers a conclusion of the study, along with a few suggestions for future research.

2. Review methodology

2.1. Method

In the present study, a robust and systematic methodology was adopted to carry out a comprehensive review of scholarly literature published between 2018 and 2022. The primary objective was to rigorously explore the relationship between sustainable smart agriculture and emerging technologies, such as IoT and data analytics. Advanced searches were performed on two major academic databases, Scopus and Web of Science, to yield the most current and pertinent literature in the field.

In Scopus, the search was fine-tuned using an advanced query in the title, abstract, and keyword fields with the string: “TITLE-ABS-KEY (iot OR ‘internet of things’) AND TITLE-ABS-KEY (agriculture OR sustainability)”. In a similar vein, Web of Science was queried using the targeted string: “TS=((IoT OR internet of things) AND ‘data analytics’) AND TS=(agriculture OR sustainability)”. These queries were designed to ensure a focused and relevant collection of scholarly works for analysis. We found 514 documents on Scopus and 403 on Web of Science.

The eligibility criteria for article inclusion encompassed: 1) fully published articles, 2) English-language publications, 3) availability of full text, and 4) direct relevance to the thematic focus on both smart agriculture and sustainability. Articles were excluded based on the following criteria: 1) Article in press, 2) non-English language, 3) unavailability of full text, 4) lack of direct pertinence to the research themes under investigation, 5) non-article type. As a result, 395 documents we excluded from Scopus and 232 from Web of Science. Upon meticulous examination of the full-text papers, a further 119 articles from Scopus and 115 from Web of Science were ultimately excluded from the study. Consequently, 77 articles were retained for in-depth review, after accounting for duplicates across both databases. This final corpus of highly relevant articles was assembled to provide a comprehensive and focused analysis, aligned with the study’s primary objective of exploring the nexus between sustainable smart agriculture and emerging technologies.

It is worth noting that the scope of the search was limited to the past five years to ensure the inclusion of contemporary findings and perspectives, particularly given the fast-paced advancements in the technology-related aspects of agriculture. This temporal limitation enhances the study’s relevance to both current discourse and future inquiries. Access to the full-text articles was predominantly enabled by academic subscriptions, although some papers remained inaccessible. To address this limitation, supplementary searches were conducted on alternative platforms, such as Google Scholar and ResearchGate (limited to only final articles listed in the inclusion criteria). Despite these efforts, a minority of articles remained elusive and were thus excluded.

2.2. Related works

The literature review conducted for this study highlights the scarcity of publications investigating the connection between smart farming and sustainability. Although numerous studies have explored smart farming concepts and enabling technologies, only a limited number have examined the impact of these technologies on sustainability. This study aims to bridge this gap by conducting a comprehensive examination of the relationship between smart farming and sustainability. Table 1 presents a comparison between twelve relevant studies on smart farming in agriculture and the current study.

3. Smart agriculture

3.1. Internet of things (IoT)

IoT integration plays a vital role in smart agriculture, enabling communication among agricultural sensors through wireless sensor networks (WSNs) (Yadav et al., 2022). This facilitates the collection of extensive data related to agricultural productivity and the environment (Bourianis et al., 2022). The data encompasses a range of essential parameters such as air, soil, water quality, livestock health, crop growth, sunlight, fertilisers, and pesticide application (Vangala et al., 2021). By providing this valuable information, IoT serves as a crucial enabler for data analytics in agriculture. Additionally, IoT enables control of agricultural operations, as exemplified in smart greenhouses that utilise WSNs to monitor and regulate climatic conditions (Abdollahi et al., 2021). Implementing IoT in smart agriculture relies on key enabling technologies, including WSNs and communication protocols. WSNs, comprising multiple sensors, monitor environmental conditions in agriculture and wirelessly transmit data to designated locations (Dayioglu and Turker, 2021). Communication protocols such as ZigBee, LoWPAN, Bluetooth, GSM, and WiFi enable IoT devices to connect to the Internet and communicate with one another. These technologies are

![Fig. 1. Relative worldwide search traffic for the term sustainability on Google over the last five years. Data was accessed from Google Trends on January 15, 2023.](image-url)