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# ICTs and Smallholders: A Systematic Review of Case Studies and their Impact on ESG Outcomes

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**Abstract**

This systematic review explores the role of Information and Communication Technology in supporting smallholders who face significant challenges from socio-economic and environmental changes. The analysis includes 2,217 studies from the Scopus database, highlighting technologies such as IoT, AI, UAVs, and blockchain. These technologies improve monitoring, prediction, and decision-making processes in agriculture. ICT helps optimize resource use, enhances product quality, and improves traceability. Applications like irrigation decision support systems and real-time data platforms demonstrate notable gains in water savings and crop productivity for smallholders. The review also discusses the importance of making digital tools accessible, addressing technology adoption gaps and promoting sustainability. Additionally, it introduces an ESG (Environmental, Social, Governance) framework to assess the impact, emphasizing the potential of ICT to enhance socio-economic stability and sustainability in smallholder farming. This underscores the need for technology solutions tailored to the challenges of smallholders in a rapidly evolving agricultural sector.



*Keywords:* Smallholders; Information and Communication Technology (ICT); ESG; Sustainability, Internet of Things, Water Management

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## 1. Introduction

In an increasingly connected world, agriculture remains a key but vulnerable sector that requires innovative interventions to ensure sustainability and resilience. Smallholders represent a significant part of this sector and face unique challenges that need specific solutions, especially considering recent crises marked by strikes, discontent, and substantial product losses. The integration of Information and Communication Technology (ICT) offers promising solutions by enhancing the quality and traceability of agricultural products, reducing waste, and supporting farmers during crises [1]. Over the past two decades, the global agricultural sector has seen significant transformations. According to FAOSTAT data, primary crop production increased by 54% between 2000 and 2021, in response to a 29% rise in global population during the same period [2]. These gains, facilitated by advancements in farming technologies such as improved irrigation, pesticides, and fertilizers, are also offering novel challenges. Adverse climatic conditions, irregular weather patterns affecting crop yields, and global crises like the COVID-19 pandemic have tested the resilience of food systems. These factors underline the critical need for innovative solutions to support the often more vulnerable smallholder farmers. Integrating ICTs in agricultural practices offers a viable pathway to enhance sustainability, reduce waste, and improve supply chain traceability. The early months of 2024 have seen significant unrest within the European agricultural sector, especially in Italy, where widespread protests have underlined deep-seated crises. The dissatisfaction with the European Union's Common Agricultural Policy (CAP), especially its stance on synthetic foods and tax benefits, has pushed demands for a review of these policies. The protests, advocating for policies that support local products and traceability, have highlighted the alignment of environmental and economic needs with the practical realities of agriculture, urging a move towards more responsive and effective decision-making. ICT can address many of these issues, optimizing resource management and improving communication between farmers and political institutions. Moreover, events like "click days" in Italy, where farmers rush to apply for limited funds and subsidies through digital platforms, expose the digital divide and the need for accessible technological solutions to ensure fair resource distribution. The Italian government has established specific dates for click days in 2024: March 18, 21, and 25. The Decree of the President of the Council of Ministers (DPCM) of September 27, 2023, set the quotas for legal entry of foreign workers in Italy for the years 2023-2025, with 151,000 entries allocated for 2024 [3]. The INAIL initiative, which significantly increased funding to €90 million, aims to support the modernization and safety of agricultural machinery, thus enhancing the safety, sustainability, and environmental impact of agricultural practices [4]. Recent analyses indicate that farmer protests across Europe are driven by a complex interplay of factors, including low prices, rising production costs, and additional environmental regulations. Despite recent increases in agricultural incomes in the EU, there remains significant heterogeneity among farms, with smaller ones struggling to achieve a decent standard of living. This situation highlights the need for ICT solutions to meet the challenges faced by various farm types, ensuring that technological advancements benefit all farmers [5]. An editorial in "Nature Food" notes that these protests reflect deeper sectoral issues, exacerbated by global events like wars and trade negotiations, alongside subsidy cuts from EU policy reforms. These challenges necessitate a more sustainable, fair, and inclusive approach to food production, suggesting the need for pricing adjustments to reflect the true cost of food, which includes ecological and social impacts [6]. This review outlines how ICT technologies can improve agriculture for small-scale producers, enhancing efficiency and resource management in a time of growing climate and economic uncertainties, introducing the importance of ESG considerations, highlighting that ICT integration not only improves production and sustainability but also offers solutions to overcome the ongoing crises affecting the sector. The rest of this paper is structured as follows. Section 2 describes methodology adopted for the review phase, while the impacts of ESG practices are discussed in Section 3. Conclusions are in Section 4.

## 2. Review Methodology

### 2.1. Bibliometric Analysis

The database used for the analysis was Scopus, the largest database of peer-reviewed literature, covering over 25,000 active titles and 7,000 publishers. Scopus provides a detailed overview of global research across various fields, including life, social, physical, and health sciences. To assess the impact of ICTs on agriculture, the authors used the query: (TITLE-ABS-KEY ("ict" OR "information and communication technolog*" OR "icts" OR "information communication technolog*") AND TITLE-ABS-KEY ("smallholder*") AND (LIMIT-TO (DOCTYPE, "re")). This search returned 2,217 publications, which were analyzed using the VOSviewer software, with the purpose to obtain a list of main technologies, that it is to say a list of keywords, to use in a second search in combination with the word "smallholder*". This step is important, as it is aimed at objective research into the use of technologies related to the ICT field in agriculture in general, to then go into more detail in the study and apply it to smallholders. VOSviewer displayed the relationships between major themes through clusters shown in different colors, connected by lines that show the strength or frequency of keyword connections. This visualization helped highlight the key areas where ICT intersects with agricultural practices, identifying the most relevant ICT applications for enhancing smallholder farming.

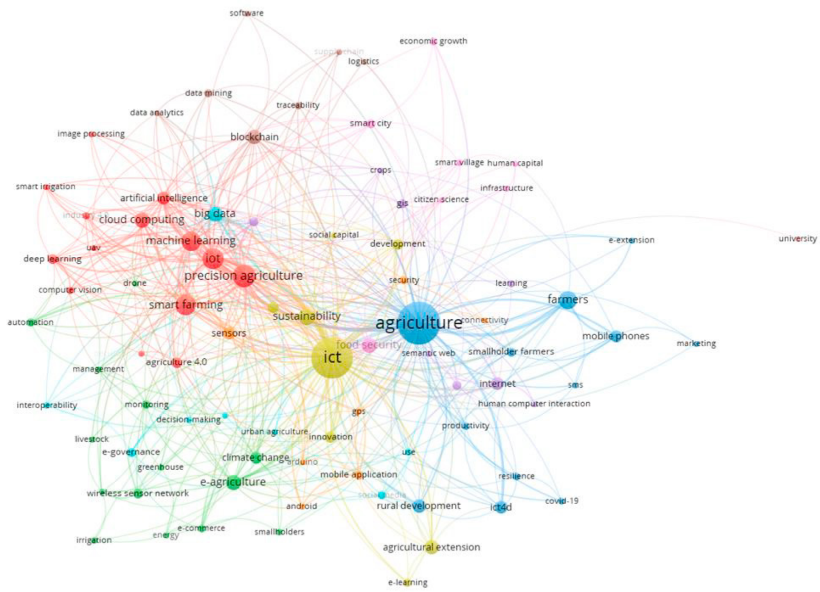


Fig. 1. VOSviewer analysis

The VOSviewer visualization, shown in Figure 1, reveals an interconnected landscape of technological integration within agriculture, organized into four primary clusters, each represented by a distinct colour and connected by the co-occurrence of key terms in scientific publications.

The **Red Cluster** focuses on the use of advanced technologies such as "precision agriculture", "IoT" (Internet of Things), "sensors", "artificial intelligence", "machine learning", and "big data", emphasizing their role in enhancing farming efficiency and productivity. Technologies like "UAV" and "blockchain" also play a part, suggesting an approach to modern farming that leverages computing and data analysis. The **Yellow Cluster** is centred around "ICT", linking directly to critical issues such as "food security", "semantic web", and "mobile applications". This cluster indicates a broad discussion on how ICT solutions can support agricultural activities and address global food security challenges by enhancing access to information and resources. The **Blue Cluster**, with "agriculture" at its core, includes terms such as "farmers", "mobile phones", "internet", and "human-computer interaction". It discusses the direct engagement of farmers with technology, exploring how digital tools and internet access can revolutionize traditional agricultural practices by providing timely and efficient access to information. The **Green Cluster**, though smaller, focuses on "e-agriculture", "innovation", "climate change" and "greenhouse" highlighting the use of technology in promoting sustainable agricultural practices and combating the effects of climate change. The **Red to Yellow** link, for example, shows how precision agriculture technologies contribute to food security through ICT. Similarly, the **Yellow to Blue** connection underscores the role of ICT in directly empowering farmers with technologies that enhance agricultural productivity. The **Blue to Green** link connects technological applications with innovative, sustainable practices, while the less direct **Red to Green** link indicates a shared focus on technology's role in environmental sustainability.

In summary, this visualization demonstrates the role of technology in modern agriculture, emphasizing the potential for ICT to enhance productivity, sustainability, and socio-economic outcomes. It also highlights areas for further research and application of these technologies in agriculture, pointing towards a reality where technology is expected to solve complex agricultural challenges and enhance the viability of farming practices.

### *2.2. Document Analysis*

Searching for links between "smallholders" and advanced technological terms reveals a landscape in which innovation is strongly increasing in small-scale agriculture. Sensors are the most numerous, in fact 116 articles were carried out, indicating their central role in collecting data for precision agriculture. AI and ML are close, with 90 and 106 articles respectively, suggesting strong interest in enhancing these technologies for intelligent decision-making and predictive analytics to improve crop productivity. IoT applications, while less prevalent with 22 articles, along with GPS technology cited 35 times, indicate an evolving adoption of technology that offers real-time insights and data. Despite lower frequencies, "cloud computing" and "big data" are still present, potentially due to their ability to process and store large amounts of data. Drones are present in 48 articles, illustrating their growing importance in crop monitoring and management, while the 11 blockchain cases suggest its applications to secure transactions and supply chains. The total of all the cases shows a significant and growing interest between small-scale agriculture and new technologies, with the aim of transforming traditional practices into more efficient and sustainable systems.

The search with the query (TITLE-ABS-KEY ("iot*" OR "internet of thing*" OR "sensor*" OR "AI" OR "artificial

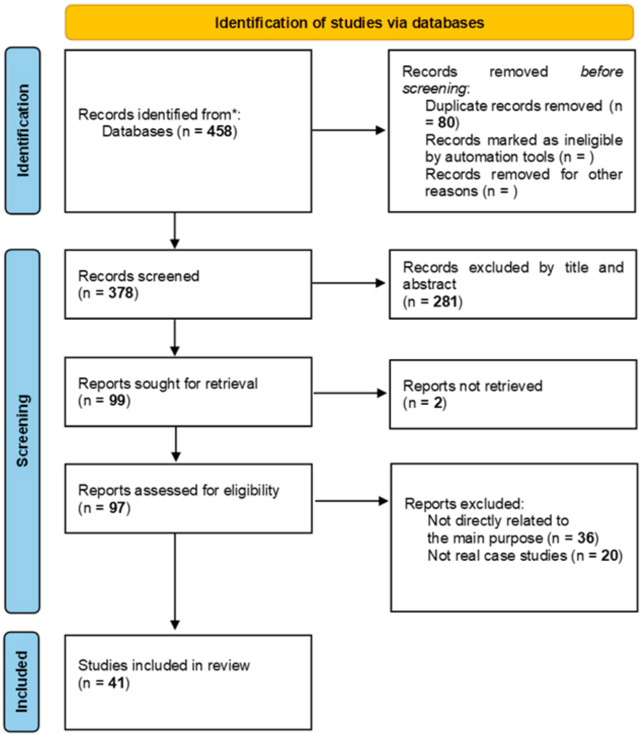


Fig. 2. PRISMA methodology

intelligence" OR "cloud computing" OR "big data" OR "machine learning" OR "blockchain" OR "gps" OR "global positioning system" OR "uav" OR "unmanned aerial vehicle*" OR "drone*") AND TITLE-ABS-KEY ("smallholder*")) AND (LIMIT-TO (DOCTYPE, "ar")) AND (LIMIT-TO (PUBSTAGE, "final")) AND (LIMIT-TO (LANGUAGE, "English")) AND (LIMIT-TO (SRCTYPE, "j")) has yielded a collection of 378 papers. It is clear that the total number of separate searches appears greater than the total produced by the complete query. This discrepancy can be attributed to overlaps, where some items feature multiple technologies. Therefore, the final total to consider is 378.

This systematic review of the literature includes 458 articles. The PRISMA process was used to identify the research questions and discussion points raised in the field of ICT technologies used for smallholders. Figure 2 gives a summary of the iterative process of PRISMA.

An initial selection of the articles was carried out by analysing the abstracts according to defined criteria. This preliminary filtering aimed to identify studies demonstrating the application and benefits of ICT in smallholder agricultural contexts. The criteria aimed to ensure that the selected articles showed direct improvements in agricultural management, productivity and decision-making processes that significantly improved the livelihoods of smallholder farmers. Additionally, any articles that did not demonstrate a clear impact on smallholder communities or that focused on broader agricultural technologies without specific relevance to smallholder needs were excluded. Furthermore, the study focused on research that are more oriented on the use of technologies for smallholders than on parallel problems or research evaluating current technologies. The last filter is related to the specifical field of agriculture, in fact a relevant number of papers was composed from studies like livestock feeding or artificial insemination. This approach through abstract analysis ensured that the articles chosen for review were consistent with each other and contributed constructively to the understanding of the impact of ICT on smallholder agriculture.

To summarize the main characteristics of the documents, a table has been organized. Table 1 includes four main columns, with each row capturing the references of papers analyzed and categorized by year. The "REFERENCES" column lists the analysed documents. The "TECHNOLOGIES" column details the specific technologies discussed in the papers, considering the main fields of interest derived from the bibliometric analysis, including IoT, Sensors, AI, Cloud Computing, Big Data, Machine Learning, Blockchain, GPS, UAV, and Other. Furthermore, there are the "CASE STUDY" column, that identifies the individual case studies, and the "LOCATION" column, that specifies where these studies were conducted.

Table 1. Overview of Analyzed Documents by Technology, Case Study and Location

| References | | Technologies | | | | | | | | | | Case study | Location |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | IoT | Sensors | AI | Cloud Computing | Big Data | Machine Learning | Blockchain | GPS | UAV | Other | | |
| 2024 | [7] | | | | ✓ | | ✓ | | | ✓ | ✓ | Crop mapping in smallholder farms | South Africa |
| | [8] | | | | | | ✓ | | | | ✓ | Smallholder wheat production | China |
| | [9] | | | | | | ✓ | | | ✓ | | Maize CWSI estimation using UAV data | South Africa |
| 2023 | [10] | | ✓ | | | | | | | | | Temperature regulation in grape facilities | China |
| | [11] | ✓ | ✓ | | | | | | | | ✓ | Data-driven irrigation practices using AGVs | India |
| | [12] | | ✓ | | | | | | | | ✓ | Solar-powered smart irrigation control system | Uganda |
| | [13] | ✓ | ✓ | | | | | | | | | Low-cost IoT modules for subsistence farming | Romania |
| | [14] | | ✓ | | | | | | | ✓ | ✓ | UAV-based drought damage assessment | Indonesia |
| | [15] | ✓ | ✓ | | ✓ | | | | ✓ | | | IoT platform for smallholder farmers | Nepal |
| | [16] | | | ✓ | | | ✓ | | | | | Diagnostic tool for crop disease detection using ML | Uganda |
| | [17] | | ✓ | | | | ✓ | | | ✓ | | Maize LAI via UAV and machine learning | South Africa |
| | [18] | | ✓ | | | | ✓ | | | ✓ | | E-agriculture tool for cocoa intensification using remote sensing | Papua New Guinea |
| | [19] | | ✓ | | | ✓ | | | ✓ | ✓ | ✓ | UAVs and multi-criteria for oil palm sustainability | Malaysia |
| | [20] | ✓ | ✓ | | | | | | | | ✓ | NDVI sensor for rice productivity assessment | Tanzania |

| | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | [21] | | ✓ | | | | ✓ | | ✓ | ✓ | ✓ | Weed detection in maize via UAV and PlanetScope | South Africa |
| 2022 | [22] | | | ✓ | | | ✓ | | | | ✓ | Rice yield estimation for smallholder farms | China |
| | [23] | | | | | | | ✓ | | | ✓ | Blockchain applications for smallholder agriculture | Africa |
| | [24] | ✓ | ✓ | | | | | | ✓ | | | Handheld water turbidity meter for smallholders | Indonesia |
| | [25] | | ✓ | | | | | | | | ✓ | Rice yield prediction via reflectance and weather data | Cambodia |
| | [26] | ✓ | | | ✓ | ✓ | ✓ | | | | | Platform for farmers to support decision-making | Spain |
| | [27] | | ✓ | | | | ✓ | | ✓ | ✓ | ✓ | Maize temperature and conductance estimation via UAV for water stress | South Africa |
| | [28] | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | | | | ✓ | Irrigation efficiency for smallholder farmers | Algeria |
| | [29] | ✓ | ✓ | | ✓ | ✓ | | ✓ | | | ✓ | Smart Agricultural Futures Market (SAFM) | Sri Lanka |
| 2021 | [30] | ✓ | | ✓ | | | | | ✓ | | | Digital tools for tractor hire in India | India |
| | [31] | | ✓ | | | | ✓ | | | ✓ | ✓ | Deep learning model for plant disease ID via UAV | Turkey |
| | [32] | | ✓ | | | | ✓ | | | ✓ | | Maize leaf water content estimation via ML and UAV | South Africa |
| | [33] | ✓ | ✓ | | | | | | | | ✓ | Smart irrigation systems for water conservation | Italy |
| | [34] | ✓ | ✓ | | | | | | | | ✓ | IoT for alternate wetting and drying (AWD) irrigation | Vietnam |
| | [35] | | ✓ | ✓ | ✓ | ✓ | ✓ | | ✓ | ✓ | ✓ | Modeling soil nitrogen content in maize farms using ML | South Africa |
| 2020 | [36] | | ✓ | | | | ✓ | | | | | Grain storage in smallholder farms | Zimbabwe |
| | [37] | | ✓ | | | ✓ | | | ✓ | ✓ | ✓ | Yield variability via UAV indices and biophysical data | Nigeria |
| | [38] | | ✓ | | | ✓ | | | ✓ | | | Fertilizer Optimization Tool (FOT) for farmers | Uganda |
| | [39] | | ✓ | | | | | | | ✓ | ✓ | Comparison of leaf vs canopy approaches | Zimbabwe |
| | [40] | | ✓ | | | | | | | | | Laboratory calibration of soil moisture sensors | India |
| | [41] | | ✓ | | | | | | ✓ | ✓ | ✓ | Precision agriculture management systems | Portuguese-Spanish border |
| | [42] | | ✓ | | | | | | ✓ | ✓ | ✓ | UAV-based remote sensing tools to support agriculture | Tanzania |
| 2019 | [43] | ✓ | ✓ | | | | | | | | ✓ | Adaptation of disease warning models for vineyards | Spain |
| | [44] | | ✓ | | | ✓ | | | ✓ | | | Open-source remote sensing for precision agriculture | Ghana |
| 2018 | [45] | | | | ✓ | | | | | | ✓ | Irrigation management for smallholder farms | China |
| | [46] | | ✓ | | | | | | | | ✓ | Nature-based solutions for sustainable agriculture | Bolivia, Nepal, Burkina Faso |
| 2015 | [47] | | ✓ | | | | | | | ✓ | | UAV-based monitoring of oil palm tree growth via spectral indices | Malaysia |

### *2.3. Summary and Comparison of Analysed Studies*

The papers present an overview of technological and methodological innovations designed to support smallholder farmers. These innovations not only offer practical solutions to existing problems but also open new perspectives for more sustainable and intelligent agricultural management. These studies can be grouped into three main categories: monitoring and prediction technologies, decision support systems, and solutions for irrigation and water management.

#### *2.3.1. Monitoring and Prediction Technologies*

Several studies have explored the transformative potential of advanced technologies such as UAVs (Unmanned Aerial Vehicles), machine learning, and sensors in enhancing crop monitoring and yield predictions. These technologies are pushing the boundaries of agricultural practices by providing high-resolution data and predictive insights that were previously unachievable. For instance, it has been demonstrated the effectiveness of UAVs combined with geospatial cloud computing for mapping land use and crop distribution in smallholder farms, achieving an impressive overall accuracy of 91% [7]. This high level of accuracy not only aids in precise agricultural planning but also helps in optimizing resource allocation, thereby reducing wastage and increasing efficiency. Similarly, convolutional neural networks (CNNs) were employed to estimate rice yield [22]. This approach significantly outperformed traditional methods, showcasing the potential of deep learning algorithms in capturing the complex patterns and variables that influence crop yields. Another application using deep learning involved a model for identifying plant diseases from UAV images, which improved diagnostic accuracy and operational efficiency in Turkey [31]. Additionally, the use of UAVs equipped with multispectral sensors for monitoring crop health was shown to provide detailed information on various aspects of crop vitality, such as chlorophyll content and plant stress levels, enabling early detection of potential issues [47]. These indices provide detailed information on various aspects of crop health, such as chlorophyll content and plant stress levels, enabling early detection of potential issues.

These advanced monitoring and prediction technologies not only enhance the precision of yield predictions but also offer robust tools for crop management and risk mitigation. By integrating real-time data and predictive analytics, farmers can make informed decisions that enhance productivity and sustainability. The ability to predict and respond to issues proactively helps in mitigating risks associated with pests, diseases, and adverse weather conditions, ensuring more stable and reliable crop production. Overall, the integration of UAVs, machine learning, and multispectral imaging in agriculture marks a significant leap towards precision farming, offering scalable solutions that can be tailored to the specific needs of smallholder farmers. These technologies represent an important component in the journey towards more efficient, sustainable, and resilient agricultural systems.

### *2.3.2. Decision Support Systems*

Another significant category involves the development of decision support systems (DSS) aimed at optimizing agricultural practices and enhancing overall farm management. These systems leverage real-time data and advanced analytics to provide actionable insights that help farmers make informed decisions. Examples of web-based irrigation decision support system were studied [45], illustrating how real-time data integration can drastically improve water use efficiency and boost agricultural productivity. This system leverages environmental and crop-specific data to offer precise irrigation recommendations, ensuring that water resources are used optimally. The implementation of such a system not only saves water but also maximizes crop yields, demonstrating a significant advancement in sustainable farming practices. Similarly, a digital platform was designed to aggregate data from various sources to support smallholder farmers in the Andalusian region [26]. This platform enhances transparency and trust in agricultural decision-making processes by providing a centralized repository of information that farmers can rely on. By facilitating access to diverse datasets, the platform empowers farmers with comprehensive insights, enabling them to make better-informed decisions that can lead to improved productivity and profitability. Decision support systems like a fertilizer optimization tool developed by exemplifying the impact of targeted recommendations on agricultural outcomes. This tool provides farmers with specific fertilizer use recommendations based on their financial capabilities, thus promoting efficient and cost-effective nutrient management [38]. The tool has been shown to significantly improve crop yields and positively influence farmers' attitudes towards fertilizer use, fostering a more informed and proactive approach to farm management.

These DSS innovations play a significant role in modern agriculture by integrating complex datasets and advanced analytics to support decision-making. They bridge the gap between traditional farming practices and modern technology, offering scalable solutions that can be customized to the unique needs of smallholder farmers. By enhancing transparency, optimizing resource use, and providing tailored recommendations, these systems contribute to more sustainable, efficient, and resilient agricultural practices.

### *2.3.3. Solutions for Irrigation and Water Management*

Water use efficiency has emerged as a relevant theme in several agricultural studies, underscoring the need for sustainable water management practices in farming [48]. Several innovative approaches have demonstrated significant advancements in this area. The transformative potential of IoT technology was showcased in implementing AWD (Alternate Wetting and Drying) irrigation methods [34]. This research revealed that IoT-enabled AWD systems could achieve substantial water savings while simultaneously enhancing rice yields. By providing precise control over irrigation schedules and monitoring soil moisture levels in real-time, these systems optimize water usage, ensuring that crops receive the right amount of water at the right time. This not only conserves the hydric resource but also promotes healthier crop growth and higher productivity. Similarly, others developed a decision support system (DSS) tailored for optimizing water use in small farms in Southern Italy [33]. This DSS integrates real-time environmental data with advanced irrigation models to deliver precise irrigation recommendations. The implementation of this system resulted in notable improvements in irrigation efficiency, demonstrating its effectiveness in enhancing water management practices at the farm level. By reducing water waste and ensuring optimal water delivery, the DSS supports both sustainable farming practices and increased crop yields. Also the use of low-cost sensors for soil moisture management was explored, evaluating the performance of various sensor types [40]. The findings highlighted that capacitive sensors, while more precise, come at a higher cost. In contrast, resistive sensors, despite being less precise, offer significant benefits due to their affordability. The study demonstrated that even with reduced precision, resistive sensors can provide valuable data for effective soil moisture management, making advanced irrigation technologies accessible to smallholder farmers with limited financial resources.

These studies collectively emphasize the critical role of advanced technologies in improving water use efficiency in agriculture. By leveraging IoT, DSS, and affordable sensor technologies, farmers can achieve a balance between resource conservation and crop productivity. These innovations not only address the immediate needs of water management but also contribute to the long-term sustainability and resilience of agricultural systems. In summary, the integration of IoT, DSS, and low-cost sensor technologies in irrigation practices represents a significant leap forward in sustainable agriculture. These approaches enable precise water management, reduce resource wastage, and enhance crop yields, aligning with the broader goals of environmental sustainability and efficient resource utilization in farming.

## 3. Impact on ESG

This study demonstrates a strong connection between agricultural technological innovations and key sustainability frameworks. ESG practices, fundamental across various sectors including agriculture, aim to integrate environmental conservation, social well-being, and ethical governance into sustainability efforts. The analysis of the papers identifies significant contributions of discussed technologies and practices to these areas, suggesting a targeted review of their impacts.

The data is categorized into three primary ESG themes - Environmental, Social, and Governance - each subdivided into specific clusters based on the frequency, significance, and sustainability impact identified in the analyzed papers.

In the **Environmental** category, the focus is on the efficient use of natural resources, water management, and climate change mitigation. This encompasses several key areas: **Resource Management**, which aims to enhance agricultural efficiency and minimize environmental impacts through optimized use of resources such as soil and crops; **Water Management**, which addresses water scarcity and climate-related challenges by improving water efficiency through technologies like precision irrigation and real-time soil moisture monitoring; and **Climate Impact and Mitigation**, which involves employing technologies and strategies to forecast, mitigate, and adapt to the effects of climate change, incorporating predictive environmental models and crop resilience strategies.

In the **Social** category, the emphasis is on the human and community aspects, enhancing farmer empowerment, disease and pest management, and food security. This includes **Farmer Empowerment and Education**, which provides farmers with necessary skills and knowledge through training and educational technologies; **Disease and Pest Management**, which promotes healthy crop maintenance and productivity using sustainable practices and reduced chemical usage; and **Food Security and Livelihoods**, focusing on initiatives aimed at improving food availability, economic stability, and community well-being, thus boosting socio-economic resilience.

Eventually, in the **Governance** category, the focus is on ethical management and responsible practices. This involves enhancing transparency in agricultural practices through technologies like blockchain for traceability and verification, as part of **Transparency and Accountability**. It also includes **Policy and Decision Support**, which supports policymaking and strategic decisions with data-driven tools and systems for sustainable and effective governance. This structured approach provides a comprehensive examination of how agricultural innovations align with ESG frameworks, highlighting specific contributions of each paper to sustainable agricultural practices.

Table 2. ESG Impact

| REFERENCES | | ENVIRONMENTAL | | | SOCIAL | | | GOVERNANCE | |
|---|---|---|---|---|---|---|---|---|---|
| | | RESOURCE MANAGEMENT | WATER MANAGEMENT | CLIMATE IMPACT AND MITIGATION | FARMER EMPOWERMENT AND EDUCATION | DISEASE AND PEST MANAGEMENT | FOOD SECURITY AND LIVELIHOODS | TRANSPARENCY AND ACCOUNTABILITY | POLICY AND DECISION SUPPORT |
| 2024 | [7] | ✓ | | | ✓ | | ✓ | ✓ | ✓ |
| | [8] | ✓ | | ✓ | ✓ | | ✓ | ✓ | ✓ |
| | [9] | ✓ | | | ✓ | | | ✓ | ✓ |
| 2023 | [10] | ✓ | | | ✓ | | ✓ | ✓ | ✓ |
| | [11] | ✓ | ✓ | | ✓ | | ✓ | ✓ | |
| | [12] | ✓ | ✓ | | ✓ | | ✓ | ✓ | |
| | [13] | ✓ | ✓ | | ✓ | | ✓ | ✓ | |
| | [14] | ✓ | | | ✓ | | ✓ | ✓ | ✓ |
| | [15] | ✓ | ✓ | | ✓ | | ✓ | ✓ | |
| | [16] | ✓ | | | ✓ | ✓ | ✓ | ✓ | |
| | [17] | ✓ | | | ✓ | | ✓ | ✓ | |
| | [18] | ✓ | | ✓ | ✓ | | ✓ | ✓ | ✓ |
| | [19] | ✓ | | ✓ | ✓ | | ✓ | ✓ | ✓ |
| | [20] | ✓ | ✓ | | ✓ | | ✓ | ✓ | ✓ |
| | [21] | ✓ | | ✓ | ✓ | | ✓ | ✓ | |
| 2022 | [22] | ✓ | | | ✓ | | ✓ | ✓ | |
| | [23] | ✓ | | | ✓ | | ✓ | ✓ | ✓ |
| | [24] | | ✓ | | ✓ | | ✓ | ✓ | |
| | [25] | ✓ | ✓ | | ✓ | | ✓ | ✓ | |
| | [26] | ✓ | | | ✓ | | ✓ | ✓ | ✓ |
| | [27] | ✓ | ✓ | | ✓ | | ✓ | ✓ | |
| | [28] | ✓ | ✓ | | ✓ | | ✓ | ✓ | |
| | [29] | ✓ | | | ✓ | | ✓ | ✓ | |
| 2021 | [30] | ✓ | | | ✓ | | ✓ | ✓ | |
| | [31] | ✓ | | | ✓ | ✓ | ✓ | ✓ | |
| | [32] | ✓ | ✓ | | ✓ | | ✓ | ✓ | |
| | [33] | ✓ | ✓ | | ✓ | | ✓ | ✓ | |
| | [34] | ✓ | ✓ | | ✓ | | ✓ | ✓ | ✓ |
| | [35] | ✓ | | | ✓ | | ✓ | ✓ | |
| 2020 | [36] | ✓ | | | ✓ | ✓ | ✓ | ✓ | |
| | [37] | ✓ | | | ✓ | | ✓ | ✓ | |
| | [38] | ✓ | | | ✓ | | ✓ | ✓ | ✓ |
| | [39] | ✓ | | | ✓ | | ✓ | ✓ | |
| | [40] | ✓ | ✓ | | ✓ | | ✓ | ✓ | |
| | [41] | ✓ | ✓ | | ✓ | | ✓ | ✓ | |
| | [42] | ✓ | | | ✓ | | ✓ | ✓ | |
| 201 | [43] | ✓ | | | ✓ | ✓ | ✓ | ✓ | |

| | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| | [44] | ✓ | ✓ | | ✓ | ✓ | ✓ | ✓ | |
| 2018 | [45] | ✓ | ✓ | | ✓ | | ✓ | ✓ | |
| | [46] | ✓ | | | ✓ | | ✓ | ✓ | |
| 2015 | [47] | ✓ | | | ✓ | | ✓ | ✓ | |

Table 2 provides an overview of ESG contributions across various studies, categorized by relevant aspects and reflecting a focus on sustainable agricultural practices over several years.

The studies consistently prioritize resource management, including water management and climate impact mitigation. The persistence of these topics from 2015 through 2024 underscores the agricultural sector's ongoing efforts to address environmental challenges through improved resource efficiency and targeted climate action. This focus is particularly prevalent in studies from 2020 onwards, reflecting heightened global attention toward climate change and environmental sustainability in agriculture.

The environmental aspect of ESG contributions, as reflected in the table, consistently highlights the resource management, that is a persistent priority, emphasizing the importance of efficient and responsible use of natural resources like water and soil. This includes adopting technologies and practices that minimize environmental impact and promote biodiversity, contributing to the long-term sustainability of the sector.

Social aspects, particularly farmer empowerment and education, along with food security and livelihoods, are consistently addressed across the studies. These categories underscore the sector's dedication to enhancing farmers' abilities and supporting their livelihoods, which are relevant for the long-term sustainability of agricultural communities. The ongoing attention to these themes across the years showcases the importance of social stability and community resilience as fundamental to achieving sustainable agricultural development.

On the governance side, transparency and accountability are prominent themes, indicating a growing focus on these areas within the agricultural sector. This trend highlights the increasing demand for accountability and clarity in resource management and decision-making processes, aimed at promoting sustainable and equitable agricultural policies.

The clustering of these interests in the papers suggests that technological innovations and advancements in agricultural practices are increasingly aligned with ESG goals, focusing on creating sustainable, efficient, and equitable farming systems. This approach not only addresses immediate agricultural needs but also contributes to broader societal and environmental objectives, aligning with global sustainability agendas.

## 4. Discussion and Conclusions

The integration of ICTs in smallholder farming practices, as detailed in the systematic review, offers considerable benefits for sustainability and efficiency. However, the discussion and conclusions highlight both the achievements and the challenges that come with this technological integration.

The adoption of technologies such as IoT, AI, UAVs, and blockchain has demonstrated potential in improving water management and crop monitoring, which are relevant for sustainable farming practices. These technologies enable precise resource management, which can lead to significant environmental benefits such as reduced water use and decreased reliance on chemical pesticides and fertilizers. Socially, these tools can empower farmers by providing them with access to real-time data, enhancing decision-making and increasing crop yields. However, the effective use of these technologies requires adequate digital literacy among farmers, which remains a significant challenge. Additionally, the initial cost and maintenance of such advanced technologies can be prohibitive for many smallholders. The review reveals that while ICT can revolutionize smallholder farming, there are substantial barriers that need addressing. The limitations include the high cost of technology, the need for farmer education in ICT, and the challenges in data governance. Addressing these limitations requires collaborative efforts from various stakeholders, including governments, technology providers, and agricultural organizations. Future developments should focus on making these technologies more affordable and accessible to smallholder farmers across the globe. This can be achieved through subsidies, grants, and scalable technology solutions tailored to the needs of smallholders. Additionally, more robust training programs and support networks should be established to improve digital literacy and technology adoption among farmers. Moreover, policymakers need to create comprehensive data governance frameworks that protect farmer data and ensure it is used ethically and beneficially. This will help build trust in these technologies and encourage their adoption.

In conclusion, the potential of ICT to improve smallholder agriculture is limitless, but realizing this potential fully requires overcoming significant economic, educational, and ethical barriers. By addressing these challenges, the agricultural sector can move towards a more sustainable and productive future, leveraging ICT to benefit smallholder farmers worldwide.

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