

Systematic Review

Digitalisation and Sustainable Agriculture: A PRISMA-Based Systematic Literature Review

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Abstract

This systematic literature review critically examines the impact of digitalisation on sustainable agricultural development, synthesising empirical evidence published between 2015 and 2026. Following the PRISMA 2020 guidelines, 62 empirical studies indexed in Scopus and Web of Science were identified and analysed using a combined deductive–inductive thematic approach. The analysis is structured around a triple-bottom-line framework encompassing economic, environmental, and social sustainability dimensions. The review addresses two research questions: the geographical and temporal distribution of research on digitalisation and agricultural sustainability, and the extent to which digitalisation yields both beneficial and adverse outcomes across all three dimensions. The findings reveal a sharp increase in scholarly attention after 2022, with strong geographical concentration in Asia, particularly China, while evidence from developing regions remains comparatively limited. Overall, existing research predominantly highlights positive effects, particularly productivity gains, efficiency improvements, and income growth, alongside enhanced environmental performance through resource optimisation and emission reduction. However, the evidence also documents uneven and context-dependent outcomes, especially within the social dimension, including labour displacement, rising inequality, and digital wage opacity. Crucially, integrative analyses that examine all three sustainability dimensions simultaneously remain scarce; fewer than 5% of included studies address economic, environmental, and social outcomes together, and potential trade-offs among dimensions are insufficiently explored. By synthesising fragmented empirical evidence through an explicit analytical framework, this review provides a comprehensive and critical foundation for understanding the complex, uneven, and context-dependent impacts of digitalisation on sustainable agriculture and identifies four priority directions for future research.



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1. Introduction

Agriculture occupies a structurally irreplaceable position in the global economy. It contributes approximately 24% of global gross domestic product, employs around 1.3 billion people (roughly 16% of the world's workforce), and underpins food security across approximately 1.2 to 1.5 billion hectares of cultivated land [1]. Yet the sector faces mounting pressure on multiple fronts: a growing global population, rising per capita food

demand, accelerating climate change, and persistent rural poverty [2]. These intersecting challenges have renewed the urgency of a question posed by the International Assessment of Agriculture, Science and Technology for Development (IAASTD): how can hunger and poverty be alleviated, rural livelihoods enhanced, and equitable, environmentally, socially, and economically sustainable development advanced through the generation and application of agricultural knowledge and technology [3]?

Over the past decade, one of the most prominent responses to this challenge has been the rapid digitalisation of the agricultural sector. Digital technologies, including information and communication technologies (ICTs), precision agriculture tools, artificial intelligence, remote sensing, and digital platforms, are increasingly regarded as instruments of agricultural transformation. Existing research identifies a convergence of drivers: economic pressures that reward efficiency gains, environmental imperatives that demand more precise use of resources, and social objectives that require the inclusion of smallholder farmers and rural communities in the benefits of technological change [4]. Studies from diverse national contexts reflect these dynamics: they document productivity gains in the Chinese agricultural sector [5,6], report increased adoption of modern practices among Saudi Arabian farmers following access to digital information [7], and link digital agriculture to reductions in agricultural carbon emissions [8]. Finally, the literature highlights that the transformative potential of digital tools depends critically on inclusive, co-created knowledge transfer among farmers, consultants, and other stakeholders [9]. Despite this growing body of work, the literature remains fragmented. Most studies focus on a single technology, country, or dimension of sustainability, typically the economic dimension. Integrative analyses that assess the impact of digitalisation across all three dimensions of sustainable development remain scarce, and potential trade-offs between dimensions are insufficiently explored [10]. The present study addresses this gap by analysing the impact of digitalisation on the sustainable development of agriculture through a systematic synthesis of empirical evidence and by identifying directions for future research.

To achieve this aim, three objectives were set: to conduct a PRISMA-compliant systematic review of empirical literature on digitalisation and sustainable agriculture; to systematically identify and compare the positive and negative effects of digitalisation on the economic, environmental, and social dimensions of agricultural sustainability; and to identify research gaps and priority directions for further enquiry. The study is guided by two research questions: (1) Which geographical regions have been the focus of research on digitalisation and agricultural sustainability, and how has the volume of related publications changed from 2015 to 2026? (2) Do all studies report positive sustainability outcomes associated with digitalisation, or have adverse effects also been documented?

Theoretical Framework

The analytical structure of this review is grounded in the concept of sustainable development, as defined by the World Commission on Environment and Development (the Brundtland Commission), which characterised sustainability as development that “meets the needs of the present without compromising the ability of future generations to meet their own needs” [11]. This foundational definition has since been operationalised through the triple-bottom-line framework, which recognises three interdependent dimensions of sustainability: economic, environmental, and social [12]. The framework is now embedded in the United Nations’ 2030 Agenda and its 17 Sustainable Development Goals (SDGs) [13]. Several of these, including SDG 2 (Zero Hunger), SDG 8 (Decent Work and Economic Growth), SDG 13 (Climate Action), and SDG 15 (Life on Land), are directly relevant to agriculture.

In the agricultural context, these three dimensions can be defined as follows. Economic sustainability is the capacity of agricultural systems to generate productive output, maintain profitability, and support rural livelihoods over the long term, as reflected in indicators such as total factor productivity, crop yields, income, and market participation. Environmental sustainability is the capacity to preserve natural resources and ecological functions, particularly through reduced carbon emissions, efficient use of land and water, and improvements in biodiversity and soil health. Social sustainability concerns the conditions under which agricultural labour is performed, including the distribution of income gains, equitable access to technology, the quality of working conditions, and the protection of rural communities from displacement or marginalisation.

This three-dimensional framework directly informs the review's organisational structure. The synthesis of empirical findings in Section 3 is organised around these three dimensions, enabling a systematic examination of whether digitalisation contributes to, detracts from, or produces uneven outcomes across economic, environmental, and social sustainability. Critically, the framework also highlights potential trade-offs between dimensions, for example, when gains in economic productivity come at the cost of labour displacement, or when environmental improvements require capital investments that disadvantage smallholders. Recognising these trade-offs is a central objective of this review and a distinctive contribution to the existing literature.

2. Materials and Methods

2.1. Overview and Design

This study employs a systematic literature review in line with the PRISMA 2020 guidelines [14], and the checklist could be found in the Supplementary Material. The PRISMA framework was selected for its transparent, reproducible protocol for identifying, screening, and synthesising empirical evidence, thereby minimising selection bias and enhancing the reliability of conclusions. The review adopts a combined deductive–inductive analytical approach: deductive methods were used to map the geographical and temporal distribution of research (RQ1), while inductive thematic analysis was applied to synthesise substantive findings across sustainability dimensions (RQ2). Data analysis drew on both quantitative methods, aggregating numerical indicators such as yield changes and productivity growth, and qualitative thematic coding, in which the 62 included studies were systematically categorised according to the economic, environmental, and social dimensions of the theoretical framework described in the “Theoretical Framework” section. A formal meta-analysis was not conducted because preliminary analysis revealed substantial heterogeneity across the included studies in outcome measures, research designs, analytical methods, and reported effect estimates. Consequently, calculating comparable pooled effect sizes and applying statistical methods for quantitative synthesis, including a funnel plot and Egger's test to assess publication bias, were not methodologically justified.

2.2. Data Sources and Search Strategy

A systematic search was conducted in two stages: the first stage was conducted on 29 January 2025 using a single electronic database; Scopus and Web of Science (WoS) was incorporated only in the second stage, the 2026 update (see Section 2.4).

Scopus was selected as the primary database for its extensive multidisciplinary coverage and strong performance in systematic search retrieval. WoS was included as a complementary source to broaden disciplinary coverage and reduce the risk of database-specific indexing gaps, consistent with best practice in systematic reviewing [14].

The search string actually executed in Scopus (Article title, Abstract, Keywords field) was the free-text phrase “digitalisation of agriculture”, which Scopus parsed as digitalisa-

tion AND of AND agriculture. The term “precision agriculture” was not used as a separate search term, as the review aimed to examine the broader phenomenon of agricultural digitalisation rather than a single technological approach. Precision agriculture was therefore treated as one form of agricultural digitalisation within the review’s broader conceptual scope. It is important to note that studies focused on precision agriculture and related technologies were identified through the search strategy and are represented among the 62 studies included in the final sample.

The following filters were then applied sequentially, with the resulting record counts: publication years 2015–2025 ($n = 1353$); subject areas Computer Science, Environmental Science, Agricultural and Biological Sciences, Social Sciences, Business, Management and Accounting, Economics, Econometrics and Finance, Decision Sciences, and Multidisciplinary ($n = 1233$); document language limited to English ($n = 1186$); source/document type limited to Journal and Conference Proceeding ($n = 927$); the Environmental Science subject category was then excluded to avoid duplication with other categories ($n = 717$).

2.3. Eligibility Criteria

Inclusion and exclusion criteria were developed collaboratively by all four authors (Zh.S., U.S., A.M., G.D.) before screening and are presented in Table 1. The criteria were designed to include only empirical studies that directly examined the impact of digitalisation on agricultural sustainability outcomes, while excluding review articles, theoretical or conceptual papers, and studies focused on non-agricultural sectors.

Table 1. Inclusion and exclusion criteria applied in the systematic literature review.

Inclusion	Exclusion
Peer-reviewed journal articles, conference proceedings	Literature reviews (not classified as original research)
Articles published between 2015 and 2026	Studies unrelated to agriculture (i.e., focused on the effects of digital technologies in other sectors, such as education)
Use of artificial intelligence within the context of digitalization	Articles not addressing the impact assessment of digitalisation (e.g., those discussing only challenges and/or future prospects)
Focus on agriculture	
Original research	

Source: Page (2021) [14].

2.4. Study Selection

After database searches and deduplication, 739 records were retained for title and abstract screening. Screening was conducted independently by three authors (Zh.S., A.M., G.D.) using the eligibility criteria outlined in Section 2.3. Discrepancies between screeners were recorded: Zh.S. identified 42 eligible articles, A.M. 45, and G.D. 42. All discrepancies were resolved through discussion and consensus arbitration by the fourth author (U.S.). A total of 40 studies were included in the final synthesis. The full selection process is documented in the PRISMA 2020 flow diagram (Figure 1).

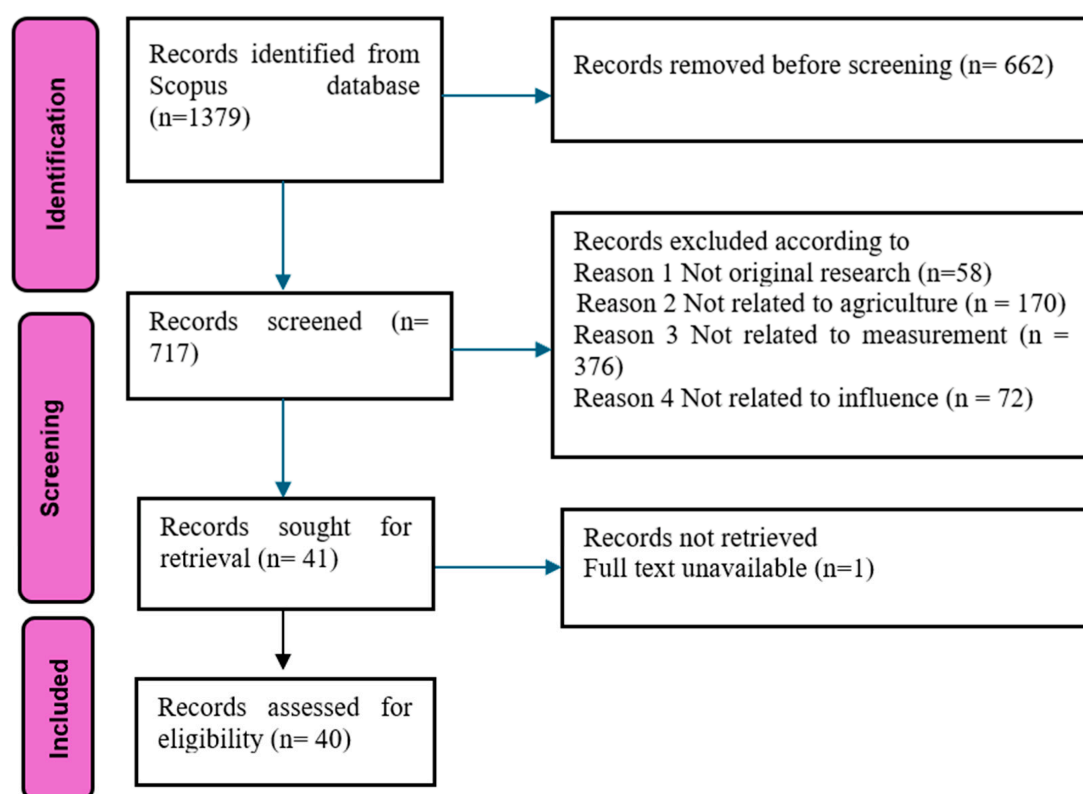


Figure 1. PRISMA flowchart illustrating the study selection process for the first search round (Round 1, Scopus, January 2025). See Table 2 for the second search round (Round 2, 2026 update). Source: (Page et al., 2021) [14].

Table 2. PRISMA-style flow for the second search round (Round 2, 2026 update), combining Scopus and Web of Science.

Stage	N	PRISMA Stage
Records identified, Scopus (2026 update, 5 Feb 2026)	278	Identification
Records identified, Web of Science (2015–2026, 17 Feb 2026)	259	Identification
Records combined (Scopus + WoS), before deduplication	537	Identification
Duplicate records removed	25	–
Records screened (278 Scopus + 234 WoS, distinct)	512	Screening
Records excluded at title/abstract and full-text screening (reasons not separately itemised in this round)	490	Screening
Studies included from Round 2	22	Included
Total included in review (Round 1 + Round 2)	62	40 + 22

Search Update (Round 2)

On 5 February 2026, the Scopus search was re-run, retrieving 278 additional records published in 2026. On 17 February 2026, Web of Science was searched for the first time, covering 2015–2026 and retrieving 259 records. The authors judged that a single-database search was insufficient for a comprehensive review and therefore incorporated WoS at this stage. The combined total of 537 records (278 Scopus + 259 WoS) was screened for duplicates; 25 duplicate records were identified and removed, leaving 512 distinct records (278 Scopus + 234 WoS) for screening against the eligibility criteria in Table 1. Applying these criteria to the 512 records identified 22 additional eligible studies, which were added to the 40 studies retained from the first search round, yielding a final total of 62 studies included in the review.

2.5. Data Extraction and Quality Assessment

Data from the 62 included studies were extracted by three authors (Zh.S., A.M., G.D.) using a standardised extraction template. For each study, the following information was recorded: author(s) and year; country/region of study; research design and data collection method; digital technology or intervention examined; sustainability dimension(s) addressed; key quantitative or qualitative findings; and direction of effect (positive, negative, or mixed). The full extraction is presented in the Appendix A.

No formal quality appraisal tool (such as the Mixed Methods Appraisal Tool, MMAT [15], or the Joanna Briggs Institute checklists) [16] was used in this review, given the heterogeneity of study designs and methodological approaches across the 62 included studies. This is acknowledged as a limitation of the review (see Section 4.5).

2.6. Synthesis Approach

Given the heterogeneity of study designs, geographic contexts, and outcome measures across the included studies, a narrative synthesis was adopted rather than a meta-analysis. Synthesis proceeded in two stages. First, a descriptive analysis mapped the distribution of studies by geographical region, publication year, and sustainability dimension addressed (addressing RQ1). Second, a deductive–inductive thematic analysis synthesised the substantive findings within each sustainability dimension (addressing RQ2). Initial codes were derived deductively from the three-dimensional theoretical framework (economic, environmental, and social sustainability). Sub-themes were then developed inductively from patterns emerging within each dimension. Coding was conducted by three authors (Zh.S., A.M., G.D.) and reviewed for consistency by the fourth (U.S.).

3. Results

This section is organised in accordance with the study's four guiding research questions. The first question provides contextual information on the digitalisation of agriculture, whereas the subsequent three questions focus on a detailed analysis of how digitalisation affects the sustainable development of the agricultural sector.

3.1. RQ1. Which Geographical Regions Have Been the Focus of Research on the Impact of Digital Technologies on Agricultural Sustainability, and How Has the Volume of Related Publications Evolved in Recent Years?

All studies included in this review were conducted in countries across three continents, Europe, Asia and Africa. However, the geographic distribution of studies was uneven across these regions (see Figure 2). Among the 37 studies conducted in Asia (59.7% of the studies), the overwhelming majority, 26 studies or 42% of the total sample, were conducted in China, which is not surprising. China is one of the world's largest producers of agricultural products and has been striving not only to expand production volumes but also to improve product quality. The Chinese government has strengthened agricultural land protection and implemented various incentives to promote agricultural production [17]. In addition, the country continues to liberalise trade in agricultural products [18]. As a result of these combined factors, China has effectively integrated digital technologies into both the production and trade sectors of its agriculture. Following China in the ranking are India (4.84%) and Kazakhstan (3.2%), both of which are major producers of staple crops such as rice and wheat. Other contributing countries include Indonesia (1.6%), Uzbekistan (1.6%), Vietnam (3.2%), Azerbaijan (1.6%) and members of the South Asian Association for Regional Cooperation (SAARC), including Bangladesh, Nepal, Pakistan, Bhutan, the Maldives, and Afghanistan (1.6%).

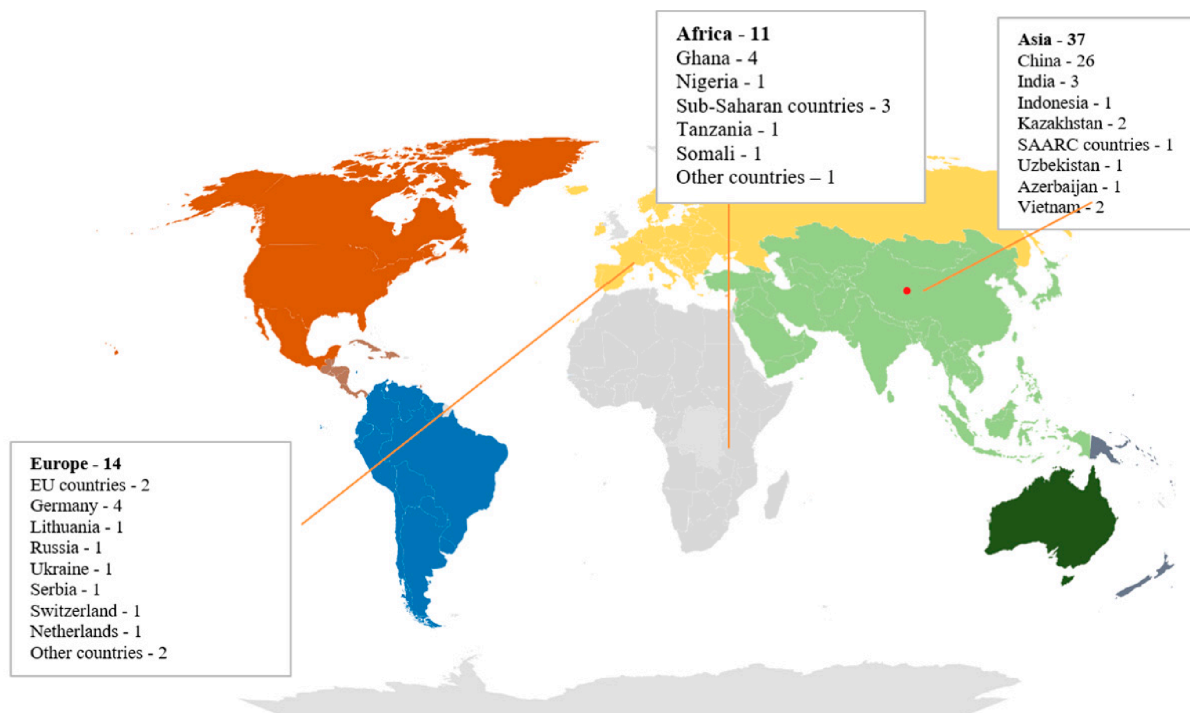


Figure 2. Geographical distribution of studies. Source: Author's elaboration using Bing Maps.

Europe accounts for 22.58% of the studies (14 articles), making it the second most represented continent. Germany stands out as the most researched country in Europe (6.45%). As one of the leading agricultural producers in the European Union [19], German researchers, citing previous studies, argue that nearly 50% of agricultural professional activities in the country could be replaced by digital technologies [20]. These trends have contributed to Germany's heightened interest in the digitalisation of its agricultural sector.

Africa ranks third in terms of the number of studies, accounting for 17.7% of the total. In Africa, the greatest interest in the impact of digitalisation on agriculture was shown by researchers in Ghana (6.45%) and Sub-Saharan African countries (4.84%). Additional studies were carried out in Tanzania (1.6%), Nigeria (1.6%), Somali (1.6%) and other African nations (1.6%). The focus on digital agriculture in Africa is largely motivated by the disproportionate concentration of digitalisation research in industrialised countries [21], and the recognised gap in empirical studies from developing nations [22]. The uneven geographical distribution of studies included in this review may reflect not only differences in the level of adoption of digital technologies in agriculture, but also differences in countries' research capacity, digital infrastructure development, publication activity, and the representation of scientific journals in international bibliographic databases. The predominance of studies conducted in China and other Asian countries may be related to more active development of digital technologies in agriculture, sustained government support for the digitalisation of the agricultural sector, and the development of digital infrastructure [23–25]. In contrast, the limited number of studies focused on Latin America and the Middle East may be related to differences in the level of digital infrastructure, characteristics of agricultural structure, where smallholder farms continue to predominate in many countries, as well as the limited representation of research from these regions in international bibliographic databases [26]. Consequently, the identified regional differences should be interpreted in light of the characteristics of the resulting evidence base, as they may reflect not only the actual level of agricultural digitalisation, but also differences in research activity, publication practices, and the international representation of scientific studies.

A temporal analysis of the publications revealed a clear upward trend in research dedicated to the impact of digitalisation on the sustainable development of agriculture (see Figure 3).

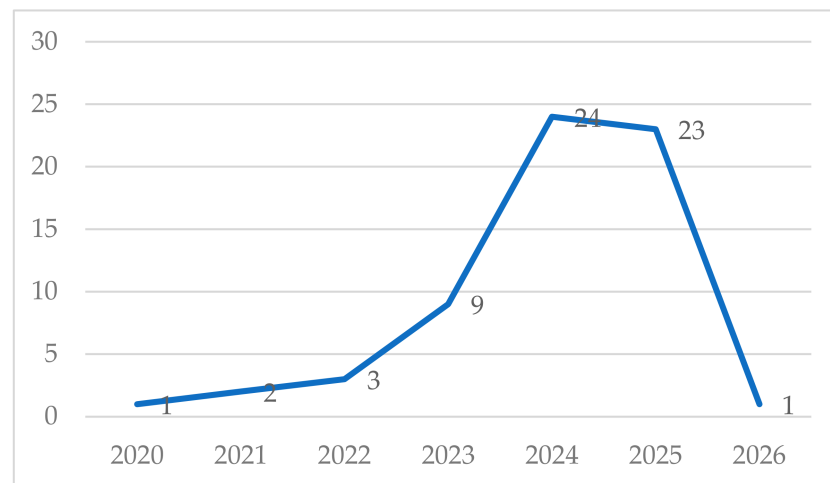


Figure 3. Temporal analysis of publications on agricultural digitalization.

Analysis of the 62 studies demonstrates that researchers have actively investigated the use and impact of digital technologies, specifically the relationship between their adoption in agriculture and the sector's sustainable development. The initial period (2020–2022) exhibited minimal research activity, with only six publications emerging during this time (2S, 7S, 13S, 39S, 44S, 57S) [19,27–31]. This slowdown can be attributed to the challenges of conducting field research during the COVID-19 pandemic (39S) [29]. Concurrently, agricultural producers were navigating the transition from traditional practices to digital farming systems (13S) [19], exploring, for example, the knowledge required by farmers operating on digitalised farms, how they acquire it, and sharing their experiences of implementing digital technologies (2S, 13S) [19,27].

Since 2022, the pace of research has accelerated. Only six articles were published between 2020 and 2022. In contrast, research activity increased in 2023, with nine new studies (11S, 15S, 17S, 29S, 33S, 38S, 40S, 55S, 61S) [20,32–39]. These studies began to more specifically quantify the economic effects of adopting various technologies, as reflected in increased productivity, gross output, export volume, and other indicators (11S, 15S, 17S, 40S) [32–34,37]. Environmental benefits were also observed, particularly in the context of promoting low-carbon agricultural development (15S, 29S, 55S) [33,35,38]. In parallel, digital technologies demonstrated social impacts, such as increased employment and reduced income inequality (15S, 33S) [33,36]. Nevertheless, at this stage, there remains a lack of empirical research directly addressing several key questions. This may be due to the fact that not all farmers were prepared to adopt innovative technologies in their operations. Older and more experienced farmers, those with lower incomes, or those operating with limited digital infrastructure tended to be sceptical about the potential benefits offered by digital technologies (38S) [20].

The number of publications in 2024 and 2025 nearly tripled that in 2023, with 24 and 23 studies published, respectively, indicating a rapidly growing scholarly interest in assessing the impact of digitalisation on agriculture. As the transformative potential of digital technologies became increasingly recognised, researchers began to examine their effects more systematically across economic, environmental, and social aspects of sustainability. In the economic sphere, studies mainly focus on productivity growth, output expansion, and efficiency improvements (2S, 6S, 9S, 11S, 16S, 17S, 18S, 23S, 28S, 32S, 34S,

37S, 40S, 41S, 50S, 57S, 43S, 19S, 1S, 12S, 30S) [18,21,23,27,31,32,34,37,40–52]. Environmental research emphasises the role of digitalisation in encouraging low-carbon agricultural development and enhancing green total factor productivity (22S, 29S, 44S, 49S, 51S, 52S, 55S, 58S, 59S, 60S, 62S, 27S, 45S, 21S, 8S, 10S, 54S) [17,24,25,30,35,38,53–63]. Meanwhile, the social dimension has been explored through indicators such as income growth, labour conditions, and broader welfare impacts (3S, 7S, 13S, 24S, 33S, 35S, 38S, 39S, 53S, 56S, 61S, 5W, 46S, 47S, 31S, 4S, 14W, 36W, 25W, 26S, 48S) [19,20,22,28,29,36,39,64–77].

Moreover, recent studies have gone beyond simple overall assessments by examining the effects of specific digital technologies (1S, 4S, 23S, 34S, 37S, 41S, 42S) [21,45–47,50,72,78], as well as their use in particular agricultural crops (6S, 9S, 16S) [40–42], thereby enabling more nuanced insights into sectoral dynamics. Overall, the environmental literature largely supports the role of digitalisation in promoting low-carbon agricultural transformation and enhancing green total factor productivity. However, this relationship is not consistent. Some studies indicate that the positive environmental impacts of digitalisation only emerge after reaching a certain threshold of technological adoption (58S) [54], while others demonstrate that digitalisation may, under specific conditions, lead to increased carbon emissions due to the energy-consuming nature of digital infrastructure (27S) [58]. Conversely, research on social sustainability remains relatively limited, mainly relying on established indicators such as farmers' income and working conditions. Nevertheless, emerging evidence highlights additional effects, including improvements in farmers' health, increased exposure to cyber risks, and growing structural inequality within the agricultural sector. These findings suggest that the social impacts of digitalisation are more complex and are less systematically documented in current research. Overall, the temporal analysis of the studies reveals a steadily increasing interest in exploring the topic in recent years.

3.2. RQ2. Do All Studies Report Positive Outcomes Associated with Digitalisation, or Have Negative Implications Also Been Identified?

Analysis of the findings from the preceding research questions indicates that digitalisation in agriculture plays a significant role in addressing a variety of challenges related to achieving sustainable sectoral development. To enhance understanding of how digital technologies facilitate this complex and multifaceted concept of sustainability, this study evaluates their impact across the three principal dimensions of economic, environmental, and social sustainability.

3.2.1. The Impact of Digitalisation on the Economic Stability of Agriculture

The systematic literature review revealed a comparable number of studies examining the impact of digitalisation on both the economic and social dimensions of agriculture. However, the present analysis begins with the economic dimension (2S, 6S, 9S, 11S, 16S, 17S, 18S, 23S, 28S, 32S, 34S, 37S, 40S, 41S, 50S, 57S, 43S, 19S, 1S, 11S, 30S) [18,21,23,27,31,32,34,37,40–50,52], as economic outcomes are traditionally prioritised by farmers in decision-making processes (42S) [78] (see Table 3).

Table 3. Distribution of studies addressing the impact of digitalisation on the sustainable development of agriculture.

Impact of Digital Technologies on Sustainability Dimensions	(Paper #)	<i>n</i>
Economic sustainability	2S, 6S, 9S, 11S, 16S, 17S, 18S, 23S, 28S, 32S, 34S, 37S, 40S, 41S, 50S, 57S, 43S, 19S, 1S, 12S, 30S	21

Table 3. Cont.

Impact of Digital Technologies on Sustainability Dimensions	(Paper #)	<i>n</i>
Social sustainability	3S, 7S, 13S, 24S, 33S, 35S, 38S, 39S, 53S, 56S, 61S, 5W, 46S, 47S, 31S, 4S, 14W, 36W, 25W, 26S, 48S	21
Environmental sustainability	22S, 29S, 44S, 49S, 51S, 52S, 55S, 58S, 59S, 60S, 62S, 27S, 45S, 21S, 8S, 10s, 54S	17
All three dimensions (economic, social, and environmental)	15S, 42S, 20S)	3
Total		62

Note: “#” denotes the identification code assigned to each study and refers to the coding presented in the Appendix A.

The contribution to the economic sustainability dimension is concentrated around three main aspects (see Figure 4): labour productivity [15S, 17S, 23S, 28S, 34S] [21,23,33,34,45], crop yield [2S, 9s, 16S, 43S] [27,41,42,48], and production volume growth [6S, 34S, 50S, 20S] [18,40,45,79].

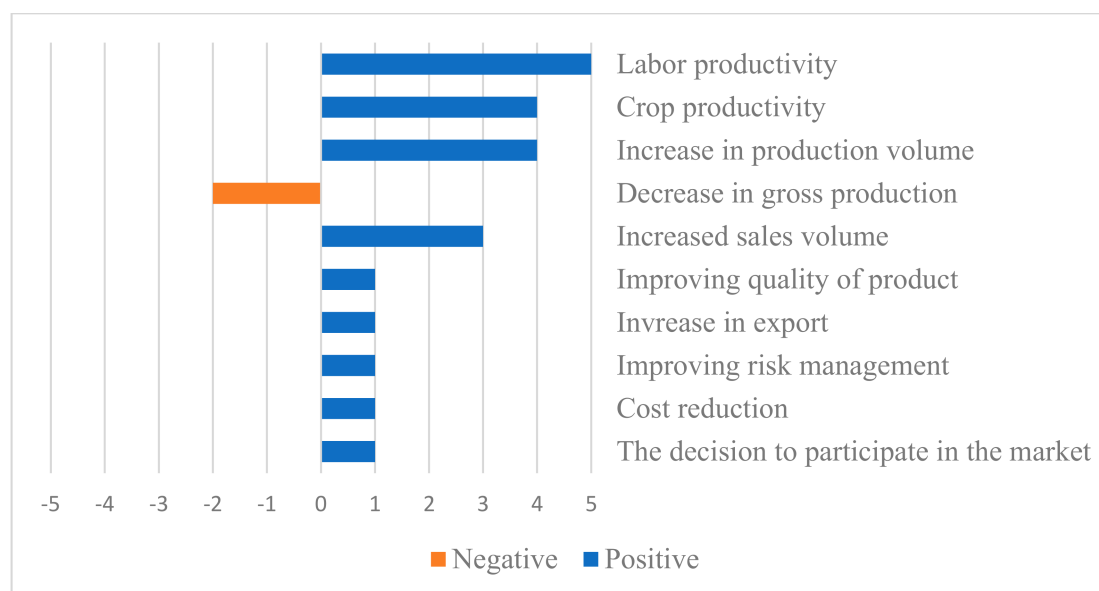


Figure 4. Key indicators reflecting the impact of digital technologies on economic sustainability, by number of mentions.

One of the key indicators reflecting the impact of digitalisation on the economic sustainability of agricultural production is labour productivity, including total factor productivity (TFP). Several studies indicate that increased investment in ICTs by agricultural enterprises, in conjunction with expanded access to rural broadband, contributes to TFP growth [17S, 28S] [23,34]. Mobile connectivity plays a particularly important role in enhancing productivity. An increase in mobile subscriptions has a statistically significant impact on TFP: long-term estimates suggest that a 1% rise in mobile subscriptions leads to a 0.027% increase in TFP [34S] [45]. Thus, the primary mechanism by which digitalisation enhances economic sustainability in agriculture is through productivity gains, particularly driven by ICTs, especially the Internet and mobile phones. Karacuka et al. (2024) [21], referencing prior research, explain that many of the technologies adopted in the agricultural sector are relatively simple and can be rapidly assimilated by most farmers. An illustrative example

is the use of mobile phones to access information on new seed varieties, agricultural inputs, and market opportunities, as well as for interacting with agricultural extension services. These practices enhance productivity by improving the informational environment of farm operations [23S] [21].

Empirical research findings provide compelling evidence that crop yield is the second most significant indicator reflecting the impact of digital technologies in the agricultural sector [2S, 9s, 16S, 43S] [27,41,42,48]. Improvements in this indicator are primarily achieved through the implementation of precision agriculture systems, digital platforms, and ICTs. For example, precision agriculture technologies enable stable, high-tech yields even under conditions of extreme drought. As demonstrated by Abuova et al. (2020) [27], in some cases, crop yields can exceed regional averages by up to 79.7%, underscoring the substantial potential of these systems to improve agricultural efficiency [2S] [27]. Digital platforms also contribute to increased yields by facilitating coordination among agri-food value chain participants and ensuring access to modern technologies and extension services. This highlights the importance of virtual integration, which serves as a critical complement to traditional physical infrastructure development [9s] [41]. Similarly to their effect on labour productivity, ICTs have a significant influence on crop yield. According to Hadiarto et al. (2024) [42], in Indonesia, farmers who utilise advanced ICT tools achieve yields four times higher than those who do not employ mobile technologies [16S] [42].

The next most frequently reported indicator of the impact of digitalisation is the increase in agricultural production volume (6S, 34S, 50S, 20S) [18,40,45,79]. Empirical evidence indicates that the use of mobile phones and Internet access has a significantly positive effect on cereal production, with particularly strong results observed in SAARC countries (6S, 34S) [40,45]. In this context, ICT components, such as mobile connectivity and broadband infrastructure, play a vital role in enhancing agricultural productivity, promoting sustainable practices, and strengthening food security. These effects are mainly driven by improved access to market information and the accelerated adoption of modern agricultural technologies (6S) [40].

Although economic sustainability is of central importance, some aspects remain underexplored in the literature, with only a few studies addressing certain dimensions. For example, a limited number of publications report that digitalisation has led to increased agricultural exports (19S) [49]. Other research highlights those digital technologies support economic stability in the agri-food sector by enhancing risk management and labour efficiency (32S) [44]. Additionally, digitalisation plays a significant role in shaping farmers' decisions to participate in markets as sellers (37S) [46]. Mobile technologies not only boost sales activity but also offer access to real-time price information and best practices for production. Given the high volatility of agricultural prices, often influenced by climatic factors, mobile communication acts as a key tool for timely information exchange and decision-making. Moreover, it reduces transaction costs and improves market efficiency (37S) [46].

In the livestock sector, digital technologies such as health monitoring systems and animal tracking have been linked to measurable productivity gains, including lower calf mortality, better weight gain, and enhanced farm profitability (41S) [47]. Digitalisation may also aid in production consolidation within livestock farming (18S) [43]. Beyond these effects, digital technologies are shown to improve the quality of agricultural products (30S) [52]. Several studies also report positive impacts on overall development indicators, such as GDP per capita, economic welfare, agricultural inputs, and output performance (40S, 57S, 11S) [31,32,37].

However, the literature does not portray a uniformly positive picture. While most studies identify beneficial effects of digitalisation on agricultural production, some evidence

points to negative or conflicting outcomes. For instance, certain studies (1S, 12S) [50,51] report a negative relationship between Internet use and food production volumes. These adverse effects may be attributed to factors such as time inefficiencies, reliance on unreliable or distorted information, reduced concentration caused by digital distractions, and cybersecurity risks. Furthermore, the inefficient use of digital technologies may increase energy consumption and lead to additional financial costs for agricultural enterprises (12S) [51].

3.2.2. The Influence of Digital Technologies on Environmental Sustainability

A review of the literature on the environmental implications of digital technologies highlights three main patterns. First, digitalisation has both positive and negative impacts on low-carbon agricultural development (29S, 49S, 51S, 52S, 58S, 59S, 60S, 62S, 10S, 21S, 27S, 45S, 54S, 8S) [17,24,25,35,54–63]. Second, digital technologies support the progress of green agricultural development (22S, 44S) [30,53]. Third, they are linked to enhancements in fuel efficiency and resource use efficiency (55S) [38] (see Figure 5).

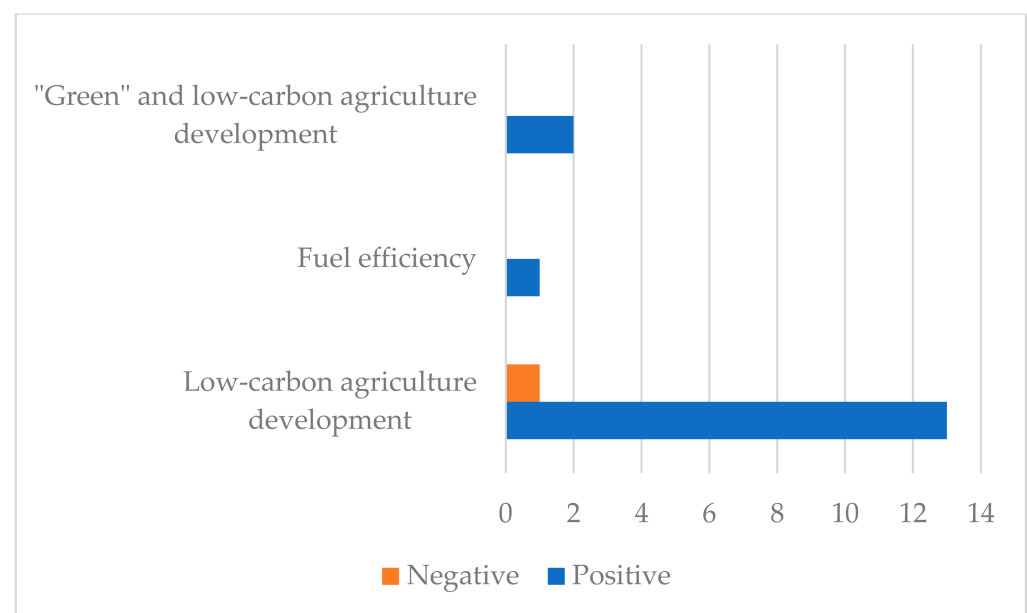


Figure 5. Key indicators reflecting the impact of digital technologies on environmental sustainability, by number of mentions.

The main indicator of the ecological impact of digital technologies is the reduction in carbon dioxide (CO₂) emissions. Evidence shows that this effect is achieved through several interconnected mechanisms. First, the development and use of digital technologies increase farmers' environmental awareness and strengthen local ecological governance, thus contributing to emission reductions (29S, 49S) [24,35]. Second, the growth of the digital economy reduces agricultural carbon emission intensity by improving logistical efficiency and supporting industrial modernisation (62S) [57]. Studies also identify specific digital technologies that help reduce emissions, including Internet-based solutions (51S, 55S) [17,38] and precision agriculture technologies (52S, 59S, 60S) [25,55,56]. However, the environmental effects of digitalisation are not always positive. Growing evidence suggests that its impact varies across different stages of technological adoption (10S, 58S) [54,62].

In early stages, digital transformation can lead to higher energy use and increased operational costs, which may counteract environmental benefits. This is especially true in cases where agricultural businesses start digitalising from a low technological base, requiring significant initial investment in digital infrastructure. Such investments often raise electricity consumption and can temporarily intensify environmental pressure. However,

as digitalisation continues, marginal costs decrease, input–output efficiency improves, and both pollution and carbon emissions tend to fall, resulting in long-term environmental advantages (58S) [54].

Furthermore, the environmental impacts of individual digital technologies may vary over time. For instance, in the short term, the expansion of Internet use is often linked to a larger ecological footprint, reflecting heightened economic activity and scale effects that exert additional pressure on the environment. In contrast, over the longer term, digital technologies tend to promote environmental improvements through increased efficiency, technological innovation, and more effective resource management (8S) [61]. Simultaneously, some studies report a consistently positive correlation between digitalisation and carbon emissions in agriculture (27S) [58]. This seemingly counterintuitive result is probably connected to the energy-consuming nature of digital infrastructure, including data centres, telecommunications networks, and the production of electronic devices.

The second major environmental impact of digitalisation is the promotion of green growth in agriculture. Empirical evidence shows that the development of digital technologies, especially Internet-based solutions, supports environmentally sustainable agricultural progress, notably through improvements in logistical infrastructure (44S) [30]. Additionally, higher levels of digital agriculture development are linked to reduced use of pesticides and fertilisers, thereby improving agricultural eco-efficiency (22S) [53]. A third significant environmental effect is enhanced fuel and resource efficiency. Earlier research (55S) [38] suggests that this is mainly driven by better Internet connectivity, which facilitates the exchange of information and resource flows, resulting in more efficient utilisation of inputs. Digital platforms allow the swift dissemination of agricultural knowledge, helping to overcome temporal and spatial barriers. Consequently, rural producers gain timely access to advanced technologies and best farming practices, improving both production management and energy efficiency. Overall, the environmental impact of digitalisation varies and depends on context. It can lead to both positive and negative outcomes (27S) [58], and its net effect often depends on threshold conditions and the stage of technological adoption (10S, 21S, 49S, 55S, 58S) [24,38,54,60,62].

3.2.3. The Effects of Digital Transformation on Social Sustainability in the Agricultural Sector

The primary indicator of how digital technologies influence the social sustainability of the agricultural sector is the increase in the incomes of agricultural workers (3S, 5W, 7S, 24S, 33S, 53S, 56S, 61S, 46S, 47S, 31S) [28,36,39,64–71] (see Figure 6). This effect is evident not only in immediate income growth but also in broader socio-economic advantages, such as alleviating poverty and narrowing income disparities between rural and urban areas.

It was found that the average monthly household income of digital technology users is significantly higher than that of non-users. This outcome is explained by the fact that access to and use of modern digital technologies helps reduce transaction costs by lowering expenses related to accessing resources, services, and information associated with agricultural production and marketing [3S] [64]. Empirical evidence further indicates that e-commerce platforms, due to their lower transaction costs compared to offline trading, help agricultural producers, such as rice farmers, secure better prices. These price improvements ultimately lead to higher producer incomes [7S] [28]. Another important conclusion drawn from research confirming the positive impact of digital technologies on farm income is that the integration of innovative technologies into agriculture improves the quality of output, which, in turn, enhances the earnings of farmers [24S, 61S] [39,65].

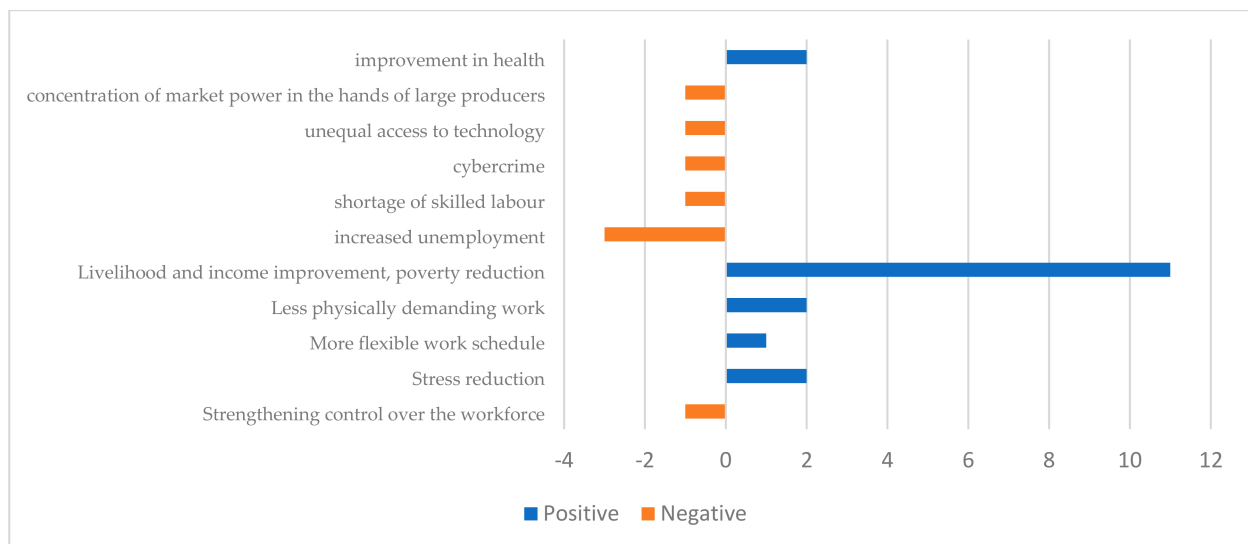


Figure 6. Set of indicators representing the impact of digital transformation on the formation and maintenance of social sustainability in agriculture, by number of mentions.

In addition to the clearly documented improvements in farmer income and well-being resulting from digital adoption, studies highlight other social benefits. These include reduced physical labour intensity [13S, 14W] [19,73], greater flexibility in work schedules [13S] [19], lower stress levels [38S, 3S] [20,64], and enhanced control over labour management [39S] [29]. For example, thanks to the use of robots, farmers describe their work as less physically demanding, as robotic systems have replaced traditionally manual, labour-intensive tasks [13S] [19]. The reason for increased work flexibility lies in the integration of robots and computers into unified, remotely controlled systems. The time saved through automation can be reallocated to other tasks, business activities, or personal rest and recovery [13S, 42S] [19,78]. Farmers also report lower professional stress levels in both crop and livestock production settings. This improvement appears to be linked to the automation of repetitive tasks that previously required significant manual effort [38S] [20]. Another significant benefit of digitalisation is the enhancement of farmers' health (3S, 4S) [64,72]. This benefit is mainly due to greater access to mobile-based health services, including enrolment in mobile health insurance schemes and remote medical consultations via telephone (4S) [72].

In contrast to the predominantly positive impacts observed in the areas of economic and environmental sustainability, the analysis of the social effects of digitalisation reveals more negative aspects than positive ones. A review of empirical evidence shows that while digital technologies have enabled greater work schedule flexibility, perceived by farmers as a positive development, the adoption of these technologies also imposes the demand for continuous online presence. This is due to the necessity of maintaining reliable connectivity with the digital infrastructure and being able to respond immediately to technical malfunctions detected by automated systems. Such operational conditions are viewed by farmers as the only viable way to ensure the uninterrupted functioning of agricultural enterprises, but this 'always-on' mode is often experienced as burdensome and is perceived negatively by practitioners [13S] [19].

A major disadvantage of digital agriculture is that its adoption reduces the demand for agricultural labour, leading to fewer employment opportunities for farmworkers [35S, 38S, 48S] [20,22,77]. Implementing digital technologies often causes farmers to rely less on manual labour, which decreases overall employment among agricultural workers. This reflects the dual nature of digitalisation: it expands access to information but also accelerates

labour substitution with capital. Consequently, unemployment has risen, especially among rural youth who previously found stable farming jobs [35S] [22]. These negative aspects of digitalisation align somewhat with the findings of Barki & Rachmah (2024) [10], who also observe that technological change in agriculture tends to diminish reliance on human labour, thereby contributing to rising unemployment as machines replace workers. This also results in a shortage of skilled labour. Additionally, retaining qualified workers remains a challenge; even when recruitment succeeds, workforce instability often hampers production continuity and reduces the effectiveness of digital transformation (26S) [76]. Meanwhile, the spread of new technologies has increased the need for farmers to acquire new skills and knowledge to operate these systems effectively [38S] [20].

Another significant drawback is the 'opacity' of digital technologies for hired workers. The digitalisation of labour processes in the agricultural sector allows employers to minimise labour costs, especially when employing seasonal workers. Modern digital tools enable precise tracking of hours worked and harvest volumes, ensuring payroll efficiency from the employer's perspective. However, this system creates a power imbalance in labour relations: workers who lack control over the digital systems are placed in a vulnerable position. In this context, digital technologies contribute to labour intensification, reduced worker autonomy, and increased administrative control. Additionally, seasonal workers increasingly express doubts about the accuracy of wage calculations made via digital systems. The automation of data registration decreases transparency for workers and makes it harder for them to verify payment records independently [39S] [29]. Furthermore, a paradoxical effect of digitalisation on the social aspect of agricultural sustainability has been identified. Digital tools, particularly mobile technologies, enhance farmers' sense of financial security through mechanisms such as mobile payment systems and digital wallets, while also making them more vulnerable to financial cybercrime, including exposure to fraud and scams (4S) [72].

Overall, the effect of digitalisation on the agricultural sector varies and heavily depends on farm characteristics, especially size. Positive impacts are more evident on small farms when technologies are accessible, simple, and easy to operate. Conversely, complex and capital-intensive digital solutions often surpass the financial and organisational capacities of smallholders. Larger farms, however, are better positioned to adopt advanced digital systems because they have greater access to financial and technical resources (36W) [74]. This imbalance could worsen structural inequalities within the agricultural sector, leading to the concentration of market power among large agribusinesses and reducing the inclusiveness of digital transformation processes (25W) [75]. Importantly, these challenges are mainly social, arising from unequal access to financial capital, education, and technological resources among agricultural producers.

Overall, the review shows that the effects of digitalisation vary across distinct groups of participants in the agricultural sector. Larger agricultural enterprises tend to realise more pronounced economic benefits, owing to greater access to financial resources and the capacity to invest in digital technologies, whereas smallholder farms more frequently face financial, infrastructural, and human resource constraints that hinder their adoption of these technologies. For agricultural workers, digitalisation is accompanied not only by reduced physical strain and improved occupational safety, but also by increasing demands for digital competencies and the risk of job losses. At the same time, the impact of digitalisation on women employed in agriculture remains insufficiently studied in the existing literature, indicating a research gap and the need for further investigation.

Although most of the studies reviewed analyse the economic, environmental, and social effects of digitalisation separately, considerably less attention is devoted to the interconnections among these dimensions of sustainable development. For example, increases

in agricultural productivity and efficiency may be accompanied by a reduction in labour requirements; however, such interconnections are addressed in only a limited number of studies. Thus, the review shows that the analysis of potential synergies and trade-offs among the economic, environmental, and social dimensions of sustainable development remains underdeveloped and represents a promising direction for further research.

To quantitatively summarise the results of the thematic analysis, the positive and negative effects identified during thematic coding were systematised across the three dimensions of sustainable development (Table 4).

Table 4. Distribution of positive and negative digitalisation effects across the three dimensions of agricultural sustainability.

Sustainability Dimension	Positive Effects, <i>n</i>	Negative Effects, <i>n</i>	Total Coded Effects, <i>n</i>	Positive Effects, %	Negative Effects, %
Economic	21	2	23	91.3%	8.7%
Environmental	14	1	15	93.3%	6.7%
Social	18	8	26	69.2%	30.8%

Positive effects predominate across all three dimensions of sustainability, though their distribution is uneven. The highest proportions of positive effects were observed in the environmental (93.3%) and economic (91.3%) dimensions. The social dimension showed a more mixed picture: positive effects accounted for 69.2% of coded effects, while negative effects accounted for 30.8%. This result provides quantitative confirmation of the asymmetry in sustainability outcomes discussed in Section 4.1.

4. Discussion and Conclusion

4.1. Asymmetry Across Sustainability Dimensions

One of the most consequential findings of this review is the asymmetry in how the three sustainability dimensions are evidenced. Economic and environmental outcomes are each supported by positive findings across diverse national contexts. By contrast, the social dimension is the only one in which negative findings outnumber positive ones, documenting labour displacement, digital wage opacity, skill gaps, and growing inequality between large and small farms across multiple contexts.

This asymmetry is partly methodological: economic and environmental outcomes are more readily quantified using administrative records and remote sensing, whereas social outcomes require qualitative fieldwork or worker-level survey data, which are considerably more difficult and costly to collect. The literature is therefore likely to underestimate the social costs of agricultural digitalisation, not because those costs are minor, but because they are harder to measure. A second explanation lies in publication incentives: studies documenting productivity gains readily reach agricultural economics and environmental science audiences, whereas studies documenting labour displacement or worker vulnerability circulate in rural sociology and development studies, communities that systematic reviews of “digitalisation and agriculture” may not adequately capture. The result is systematically skewed evidence that a policymaker relying on this literature would not easily detect.

When interpreting the identified asymmetry across the three dimensions of sustainability, the methodological characteristics of the studies included in the analysis should be taken into account. The economic effects of digitalisation are predominantly assessed using quantitative methods based on econometric modelling, statistical analysis, and the evaluation of production efficiency. The most common approaches include fixed-effects models, panel regressions, quantile and threshold models, ARDL, propensity score matching, and

efficiency and productivity assessment methods employing DEA and investment analysis. Environmental effects, in turn, are predominantly assessed using quantitative approaches based on panel data analysis, econometric modelling, and methods for evaluating environmental efficiency, including DEA and Super-SBM models, the Malmquist index, and the calculation of indicators such as Agricultural Green Total Factor Productivity (AGTFP), Agricultural Eco-efficiency, and carbon emission intensity. Social effects of digitalisation, by contrast, are analysed using both quantitative and qualitative methods. The most common approaches include questionnaire surveys followed by statistical and econometric analysis, as well as in-depth interviews, focus groups, qualitative content analysis, and digital ethnography, which make it possible to examine the influence of digitalisation on well-being, working conditions, digital competencies, and the quality of life of the rural population. The identified differences in the methodological approaches employed complicate direct comparison of research findings across the different dimensions of sustainability and limit the possibility of their generalisation and quantitative synthesis.

4.2. Positive Bias and the Conditions Under Which Digitalisation Fails

Across all three dimensions, 81% of included studies report predominantly positive outcomes or omit discussion of negative effects. This figure warrants critical scrutiny. It does not necessarily indicate that digitalisation is predominantly beneficial; it may reflect publication bias, in which null or negative results are less likely to be submitted or accepted (Barki & Rachmah, 2024) [10]. The studies documenting negative effects, including a negative relationship between Internet use and food production in Azerbaijan and Somalia (1S, 12S), early-stage increases in carbon emissions during infrastructure build-up (58S), and systematic labour displacement in automated farming systems (35S, 38S, 48S), should not be treated as outliers. They describe conditions that characterise a substantial proportion of the world's agricultural producers: unreliable infrastructure, low digital literacy, limited capital, and weak institutional protection for workers.

The environmental evidence further illustrates this point. The relationship between digitalisation and carbon emissions is nonlinear: early adoption can increase energy consumption and emissions before efficiency gains materialise (10S, 21S, 58S). This threshold dynamic has clear parallels in the Environmental Kuznets Curve literature, and its implication is that short-term environmental costs should be accounted for in policy design, rather than assumed away by long-run projections.

4.3. The Missing Conversation: Trade-Offs Across Dimensions

The most significant analytical gap revealed by this review is the near absence of integrative analyses that examine interactions and trade-offs across the three sustainability dimensions. Fewer than 5% of included studies addressed all three dimensions simultaneously. This is a critical deficiency in a literature that claims to address sustainable development, a concept defined by the interdependence of its economic, environmental, and social components.

The trade-offs are not hypothetical. Labour displacement, a social cost, is structurally linked to productivity gains, an economic benefit. Precision agriculture's environmental advantages are disproportionately available to larger, capital-endowed farms, systematically excluding smallholders from both environmental and economic dividends (25W, 36W). Stricter environmental regulations, a mechanism for achieving environmental sustainability, may increase production costs in ways that further disadvantage smallholder producers. These interactions occur simultaneously within the same agricultural systems, yet they are almost never studied together. Future research must move beyond single-dimensional

analyses and take seriously the possibility that gains in one dimension come at the cost of another.

Farm-size heterogeneity compounds this problem. The literature's dominant pattern is aggregation, with findings reported at the national or regional level, thereby masking distributional effects. Where farm-size differentiation is examined, a consistent pattern emerges: simple, accessible tools generate measurable benefits even on small farms, whereas complex, capital-intensive systems remain effectively available only to large agribusinesses (36W, 42S). If productivity and income gains are disproportionately concentrated among large farms, aggregate positive findings may obscure a growing intra-sectoral inequality, and the current literature is not designed to detect it.

4.4. Contributions, Research Priorities, and Policy Implications

This review makes three contributions to the existing literature. First, it offers the most geographically comprehensive synthesis to date of empirical evidence on digitalisation and agricultural sustainability across Asia, Europe, and Africa. Second, it applies an explicit triple-bottom-line framework that enables systematic comparison across economic, environmental, and social dimensions within a single analytical structure. Third, and most distinctively, it surfaces structural asymmetries and integrative gaps in the evidence base itself, identifying not only what the literature has found but also where and why it is likely to be systematically incomplete.

Six research priorities follow. Empirical studies from underrepresented regions, including Latin America, Central Asia, the Middle East, and the Pacific, are urgently needed before regional policy recommendations can be made with confidence. Qualitative and mixed-methods research centred on hired farmworkers, seasonal labourers, women in agriculture, and smallholder operators in low-infrastructure contexts is needed to counterbalance the current literature's quantitative productivity orientation. Longitudinal study designs are needed to track nonlinear dynamics in environmental outcomes and labour market trajectories that cross-sectional studies cannot capture. Finally, integrative research designs that model interactions and trade-offs across all three sustainability dimensions should be treated as a field-wide priority.

A promising direction for further research is to conduct comparative studies that take into account regional differences in the digital transformation of agriculture. For countries with a high level of digital development, it would be advisable to focus on the long-term effects of digital technology adoption and on analysing the interrelationships between the economic, environmental, and social dimensions of sustainable development. For developing countries, priority should be given to research on the factors determining the accessibility of digital technologies, the development of digital infrastructure, institutional support, and the digital competencies of agricultural producers. In addition, future research should more thoroughly account for the differences between large agricultural enterprises and small farms, since the scale of production significantly affects the possibilities for adopting digital technologies and the resulting economic, environmental, and social effects.

Although most of the studies reviewed analyse the economic, environmental, and social effects of digitalisation separately, considerably less attention is paid to the interrelationships between these dimensions of sustainable development. For example, increased productivity and efficiency in agricultural production may be accompanied by a reduction in labour demand; increased yields do not always lead to higher farmers' incomes; and the adoption of innovations does not always result in a reduced physical workload. Yet such interrelationships are examined in only a limited number of studies. The review shows that the analysis of potential synergies and trade-offs among the economic, environmental,

and social aspects of sustainable development remains underdeveloped and represents a promising direction for further research.

For policymakers, the central implication is that digitalisation is not a self-executing pathway to sustainable agriculture. Its benefits are real but conditional on infrastructure, digital literacy, institutional support, and inclusive access. A policy framework that subsidises complex digital systems without addressing distributional consequences risks concentrating gains among large agribusinesses while deepening the marginalisation of smallholder farmers and agricultural workers. Effective digitalisation policy requires complementary investment in worker protection, smallholder support, digital literacy programmes, and transparent data governance that gives agricultural workers meaningful visibility into the systems that manage their labour and wages. At the same time, public policy measures should be developed with due regard for differences in the scale of agricultural production and regional characteristics. For smallholder farms, priority directions should include expanding access to digital technologies, providing targeted financial support, and developing digital competencies. With regard to large agricultural enterprises, public policy should be oriented towards encouraging the adoption of advanced digital solutions.

4.5. Limitations

This review is subject to limitations that qualify its conclusions. The search was restricted to peer-reviewed articles indexed in Scopus and Web of Science, excluding grey literature and policy reports that may contain relevant evidence. Restricting the search to English-language publications, while necessary for analytical consistency, excludes research published in Chinese, Spanish, French, and other languages, a limitation that may itself contribute to the geographical bias identified above. Thematic coding involved interpretive judgements that carry some degree of subjectivity despite team-based screening protocols. No formal quality appraisal of included studies was conducted, so methodologically weaker studies carry equal weight in the synthesis. Finally, the Scopus search string used in the first search round (a free-text phrase search for “digitalisation of agriculture”) was narrower than recommended in systematic-review practice, and likely missed relevant studies that did not use these exact terms in the title, abstract, or keywords; this is reported transparently in the Methods (Section 2.2) and should be addressed with a broader Boolean string in any future update of this review. These limitations underscore the priorities identified above and point towards a future review that is geographically broader, methodologically more inclusive, and analytically more attentive to the full spectrum of sustainable development objectives.

Supplementary Materials: The following supporting information can be downloaded at <https://www.mdpi.com/article/10.3390/su18157807/s1>. The PRISMA checklist are available online [80].

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Abbreviations

The following abbreviations are used in this manuscript:

SDGs	Sustainable Development Goals
PRISMA	Preferred Reporting Items for Systematic reviews and Meta-Analyses
ICTs	Information and communication technologies
TFP	Total Factor Productivity
SAARC	South Asian Association for Regional Cooperation
IAASTD	International Assessment of Agriculture, Science and Technology for Development

Appendix A. Codification of Papers Included in the Systematic Review

Appendix A provides the codification of all studies included in the systematic review to ensure the transparency and reproducibility of the review process. Each study was assigned a unique identification code used throughout the analysis. The prefix “S” indicates studies retrieved from the Scopus database, while the prefix “W” indicates studies retrieved from the Web of Science database. For each study, bibliographic information, publication year, and article title are reported. Appendix A contains all 62 studies included in the final systematic review, comprising 40 studies identified in the first search round (Figure 1) and 22 additional studies identified in the second search round (Table 2).

Table A1. Codification of Papers included in the Systematic Review.

Code	Reference	Year	Title
1S	Abdi, A. H., Khalif, A. A., & Ahmed, A. M. [50]	2025	Advancing Somali agriculture through digitalization: Assessing the impacts of ICT and foreign direct investment on food production.
2S	Abuova A.B, Tulkubayeva S.A, Tulayev Y.V., Somova S.V., Kizatova M.Z [27]	2020	Sustainable development of crop production with elements of precision agriculture in Northern Kazakhstan.
3S	Addison M, Bonuedi I, Arhin A A, Wadei B, Owusu-Addo E, Fredua Antoh E, Mensah-Odum N. [64]	2024	Exploring the impact of agricultural digitalization on smallholder farmers’ livelihoods in Ghana.
4S	Asiedu, E. M., & Shortland, S. [72]	2025	Digitalizing agriculture and the improvement of farming business practices: How rural farmers in Ghana employ mobile phone technology.
5W	Bhaskara, S., & Bawa, K. S. [68]	2021	Societal Digital Platforms for Sustainability: Agriculture.
6S	Chandio A. A., Amin A, Khan I, Rehman A, Memon A [40]	2024	Can digitalization improve agriculture? Exploring the impact of ICT on grain food production in SAARC countries.
7S	Chaudhary S, Suri P K [28]	2022	The impact of digitalisation on the agricultural wholesale prices to aid agrarian income.
8S	Doytch, N., Nguyen, C. P., & Ashraf, A. [61]	2025	Do structural transformation and ICT development reduce the ecological footprints of nations?
9s	Durmanov A, Farmanov T, Nazarova F, Khasanov B, Karakulov F, Saidaxmedova N, Mamatkulov M, Madumarov T, Kurbanova K, Mamasadikov A, Kholmatov Z [41]	2024	Effective Economic Model for Greenhouse Facilities Management and Digitalization.

Table A1. Cont.

Code	Reference	Year	Title
10s	Feng, Y., Wang, S., & Cao, F. [62]	2025	The Impact of Rural Digital Economy Development on Agricultural Carbon Emission Efficiency: A Study of the N-Shaped Relationship.
11s	Gautam R S, Rastogi S, Thakur S, Patole H D, Revankar V N, Barge P [32]	2023	Indian economic development: The impact of digitalization and financial technologies.
12s	Gazanfarli, M. Kh. [51]	2024	How digitalisation affects agricultural progress in Azerbaijan: Evidence from panel data approach.
13S	Goller M, Caruso C, Harteis C [19]	2021	Digitalisation in agriculture: Knowledge and learning requirements of German dairy farmers.
14W	Groher, T., Heitkämper, K., Walter, A., Liebisch, F., & Umstätter, C. [73]	2020	Status quo of adoption of precision agriculture enabling technologies in Swiss plant production.
15S	Ha L.T. [33]	2023	An investigation of digital integration's importance on smart and sustainable agriculture in the European region.
16S	Hadiarto A, Firdaus M, Novianti T. [42]	2024	IMPACT OF ICT USAGE LEVEL ON THE SMALL-SCALE CHILI PRODUCTIVITY IN INDONESIA
17S	Hrosul V, Kruhlova O, Kolesnyk A [34]	2023	Digitization of the Agricultural Sector: The Impact of ICT on the Development of Enterprises in Ukraine.
18S	Hua J, Ma C, Li W, He Z, Zhu P [43]	2024	Effects and mechanisms of digitalization to enhance the resilience of the hog breeding industry: evidence from China.
19S	Huang, W., & Huang, Y. [49]	2025	Enhancing sustainable agricultural export performance through digitalization: The distinct roles of domestic and foreign inputs.
20S	Huyen, N.T.T., Thanh, T.T., & Ha, L. T. [79]	2025	Digital integration toward smart and sustainable agriculture in the European region.
21S	Jiang, W., & Chen, C. [60]	2025	The impacts of rural digitization on agricultural carbon emission efficiency: Evidence from 30 provinces in China over 2011–2022.
22S	Jiang Y, Feng Z, Bo Y [53]	2024	Mechanisms and Impact Effects of Digital Agriculture Development on Agricultural Eco-Efficiency in China
23S	Karacuka M, Myovella G, Haucap J [21]	2024	Productivity paradox in Africa: Does digitalization foster labor productivity in African economies?
24S	Kitole F A, Mkuna E, Sesabo J K [65]	2024	Digitalization and agricultural transformation in developing countries: Empirical evidence from Tanzania agriculture sector.
25W	Kljajić, N., Paraušić, V., & Subić, J. [75]	2024	Socio-environmental aspects of digitalisation in Serbian agriculture: Farmers' perceptions.
26S	Koca, D., & Van Deursen, A. [76]	2025	Exploring labor market dynamics in digital transformations: The perspective of Dutch SMEs.
27S	Lai, N. T., & Nguyen, T. H. [58]	2025	Digitalization, Net-Zero Strategies, and Sustainable Economic Growth in Vietnam.
28S	Li Y. [23]	2024	How does the development of rural broadband in China affect agricultural total factor productivity? Evidence from agriculture-related loans.

Table A1. Cont.

Code	Reference	Year	Title
29S	Liu Y, Deng Y, Peng B [35]	2023	The Impact of Digital Financial Inclusion on Green and Low-Carbon Agricultural Development.
30S	Liu, J., Wen, J., Huang, L., & Ren, X. [52]	2025	Digital Economy and New Agricultural Productivity—The Mediating Role of Agricultural Modernization.
31S	Lu, Z., Yang, L., Gou, D., & Wu, Z. [71]	2025	Promotion of rural industrial revitalization through the development of the rural digital economy.
32S	MacPherson J, Rosman A, Helming K, Burkhard [44]	2025	A participatory impact assessment of digital agriculture: A Bayesian network-based case study in Germany.
33S	Mamman S O, Sohag K [36]	2023	Inclusive Growth and Structural Transformation: The Role of Innovation and Digitalisation Spillover.
34S	Matsvai S, Hosu Y [45]	2024	ICT and Agricultural Development in South Africa: An Auto-Regressive Distributed Lag Approach.
35S	Miine L K, Akorsu A D, Boampong O, Bukari S [22]	2024	Digital agriculture and decent working conditions of smallholder farmers and farmworkers in Ghana.
36W	Ndekwa, A. G., Kalugendo, E., Sood, K., & Grima, S. [74]	2023	An Analysis of Agribusiness Digitalisation Transformation of the Sub-Saharan African Countries Small-Scale Farmers' Production Distribution.
37S	Nwangwu K N, Onyenekwe C S, Opata P I, Ume C O, Ume N N C [46]	2024	Can digital technology promote market participation among smallholder farmers?
38S	Pfaff S, Thomas A, Schüle H, Knierim [20]	2023	Effects of digital technologies in everyday farm life from the perspective of farmers in Baden-Württemberg.
39S	Prause L [29]	2021	Digital agriculture and labor: A few challenges for social sustainability.
40S	Purnamawati I G A, Yuniarta G A, Jie F [37]	2023	Strengthening the role of corporate social responsibility in the dimensions of sustainable village economic development.
41S	Ryskeldi O, Shelomentseva V, Mirkovic M [47]	2024	The economics of digital tools in Kazakh agriculture
42S	Šermukšnytė-Alešiūnienė K, Melnikienė R [78]	2024	The Effects of Digitalization on the Sustainability of Small Farms.
43S	Shen, X [48]	2025	Digitalization Practices Flourish Rural Revitalization: Evidence from China. In A. J. Tallón-Ballesteros (Ed.)
44S	Shen Z, Wang S, Boussemart J-P, Hao Y [30]	2022	Digital transition and green growth in Chinese agriculture
45S	Song, Y., & Liu, M. [59]	2025	Empowering Sustainable Farming: Harnessing Digital Technology for Green and Low-Carbon Agricultural Practices.
46S	Su, F., Wu, B., Zhang, H. et al. [69]	2025	Examining Digital Village Construction's Impact on Farmers' Common Prosperity in China: Dynamic and Spatial Perspectives.

Table A1. *Cont.*

Code	Reference	Year	Title
47S	Tang, Y., & Tang, L. [70]	2025	Digital technology adoption and farm household income in ethnic minority areas: Evidence from Xinjiang, China.
48S	Uddin, M., Ali, A., & Siddik, A. B. [77]	2026	Employment in the digital economy: Role of artificial intelligence and technological innovation.
49S	Wang D, Chen C, Zhu N, Xu X [24]	2024	Impact of agricultural digitalization on carbon emission intensity of planting industry: Evidence from China
50S	Wang F, Chen W [18]	2024	Exploring the path of development of international trade of agricultural products in the context of digitalization
51S	Wang H, Li Z [17]	2024	Can the digitalization level of agriculture improve its ecological efficiency under carbon constraints: Evidence from China.
52S	Wang H, Wu Y, Zhu N [25]	2024	Measurement and spatio-temporal heterogeneity analysis of coupling coordination between development of digital economy and agricultural carbon emission performance.
53S	Wang Z, Liu X, Qin Y, Zhang Y [66]	2024	How Rural Digitization Promote Coordinated Urban–Rural Development: Evidence from a Quasi-Natural Experiment in China.
54S	Wenyan, Y., Chenghan, L., & Fangzhou, L. [63]	2025	Digital agriculture drives carbon emission reduction in China.
55S	Wu H, Wang B, Lu M, Irfan M, Miao X, Luo S, Hao Y [38]	2023	The strategy to achieve zero-carbon in agricultural sector: Does digitalization matter under the background of COP26 targets?
56S	Xiaoyan D, Jiangnan Z, Xuelian G, Ali M [67]	2024	The impact of informatization on agri-income of China’s rural farmers: ways for digital farming.
57S	Xiumei X, Xianghui T [31]	2022	Research on the Relationship of Coupling Coordination between Digitalization and Agricultural Sustainable Development
58S	Yuan Y, Guo X, Shen Y [54]	2024	Digitalization drives the green transformation of agriculture-related enterprises: A case study of a-share agriculture-related listed companies.
59S	Zeng F, Zhou Y, Wei B [55]	2024	Empowering sustainable development: revolutionizing agricultural green total factor productivity through rural digitalization.
60S	Zhang Q, Yang Y, Li X, Wang P [56]	2024	Digitalization and agricultural green total factor productivity: evidence from China.
61S	Zhang X, Fan D [39]	2023	Can agricultural digital transformation help farmers increase income? An empirical study based on thousands of farmers in Hubei Province
62S	Zhou F [57]	2024	The impact of digital economy development on agricultural carbon emissions—empirical research based on Chinese data

Appendix B. PRISMA Flow Diagram

The PRISMA 2020 flow diagram illustrating the study selection process is presented in Figure 1 and Table 2 of the main manuscript.

Appendix C. Complete Search Strings Used in Scopus and Web of Science

The search string actually executed in **Scopus** (Article title, Abstract, Keywords field) was the free-text phrase “digitalisation of agriculture”, which Scopus parsed as digitalisation AND of AND agriculture. **Web of Science**—the same search phrase “digitalisation of agriculture”.

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