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Review

Emerging Technologies in Rural Development: A Scoping Review of Current Knowledge

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Abstract

Emerging technologies offer significant opportunities for sustainable rural development; however, their applications have not been systematically mapped across all dimensions of sustainability. This scoping review aims to identify, classify, and synthesize the literature on emerging technologies in rural development, structured around four pillars: economic, social, environmental, and governance. Eligible studies included English-language scientific articles published between 2015 and 2025 that propose solutions based on emerging technologies in rural contexts, identified in the Web of Science Core Collection database, following the Preferred Reporting Items for Systematic reviews and Meta-Analyses extension for Scoping Reviews (PRISMA-ScR) guidelines. Data extracted from the 129 eligible articles were synthesized in thematic tables and comparatively analyzed for each pillar. Results indicate an accelerated growth in publications after 2020, with machine learning, deep learning, and the Internet of Things dominating applications such as precision agriculture, telemedicine, and water management. Critical gaps persist in biodiversity monitoring, climate adaptation, elderly care services, and rural circular economy, with the governance pillar remaining the least represented. This study proposes an integrated framework and a knowledge map to guide future research and public policies toward balanced and sustainable rural transformation.

Keywords: rural development; emerging technologies; sustainable development goals; emerging future; development perspectives

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1. Introduction

Rural areas are home to approximately 42% of the global population and provide an essential share of the food, water, and ecological resources, upon which all of humanity depends [1]. Nevertheless, the gap between urban and rural areas remains one of the most persistent challenges of global development—traditionally, greater attention and resources have been allocated to urban areas, leaving rural communities behind [2].

Concretely, approximately 940 million people live without access to electricity, the vast majority in rural areas, and around 1.7 billion people remain unbanked, without access to basic financial services [2]. Access to healthcare, quality education, and adequate infrastructure continues to be severely limited in rural communities worldwide [2].

In this context, the international community adopted the 17 Sustainable Development Goals (SDGs) through the United Nations 2030 Agenda, providing an integrated framework for action towards poverty eradication, the reduction of inequalities, and sustainable development—with direct relevance for rural areas [3]. Achieving these goals requires meeting the current needs of rural communities without compromising the ability of future generations to meet their own needs [4]. Alongside traditional interventions, an increasing number of international organizations are exploring the potential of emerging technologies as complementary instruments for accelerating sustainable rural development [5–8].

Nevertheless, within the scope of the bibliographic searches conducted, no systematic analysis was identified that examines the distribution of these solutions across the four dimensions of sustainable rural development—economic, social, environmental, and governance—so as to determine which of these pillars receives less research attention in the literature.

The present study aims to address this question by offering a comparative perspective on the extent to which emerging technologies support, in a balanced or unequal manner, sustainable rural transformation across all four of its dimensions.

1.1. Conceptualization of Rural Space and Sustainable Rural Development

The concept of "rural" does not have a single definition accepted by specialists, as it depends on the geographical and social context [9,10]. Initially, rural areas were associated with small populations and a predominance of agricultural, animal husbandry, and forestry activities [11]. Over time, the definition evolved beyond a simple opposition to urban areas—rural spaces came to be understood as complex sets of activities, structures, and specific functions with their own identity, encompassing economic, demographic, ecological, and socio-cultural attributes that differentiate rural populations from urban ones [12,13].The specialized literature initially paid considerable attention to defining and understanding rural areas, and the deepening of these perspectives gradually led to the formulation and consolidation of the concept of rural development.

The concept of rural development emerged gradually from early 20th century community movements, was formalized through national programs in the 1950s–1970s, and has matured significantly in recent decades [14]. Various authors have defined rural development as a multidimensional process of general improvement in the quality of life of rural populations, encompassing agriculture and related activities, village industries, community services, socio-economic infrastructure, and human resources [15].

Contemporary rural development has evolved from infrastructure-based, resource-intensive models toward more holistic, participatory, and technology-based approaches that emphasize sustainability, inclusion, and resilience. In this context, sustainability becomes a fundamental element, defined as a process that aims to meet the current needs of rural communities without compromising the ability of future generations to meet their own needs [4].

Integrating economic decisions with social and environmental well-being emerges as a central pillar for ensuring resilient development, recognizing the interdependencies between quality of life, environmental quality, and economic rationality, as illustrated by frameworks that define the pillars of sustainability as the environment, social aspects, and economic efficiency [16,17]. In addition, defining sustainability in relation to rural development highlights the role of the environment in providing the ecosystem services necessary for human life and development, which reinforces the need for holistic, participatory, and technology-based approaches capable of maximizing collective social, economic, and environmental value [18].

The recent literature also highlights the role of governance as a distinct pillar in sustainable rural development, alongside economic, social, and environmental factors. Governance encompasses the institutional mechanisms and decision-making processes that guide development, with an increasing emphasis on decentralized, participatory, and transparent models to ensure equitable and effective outcomes in rural areas [19–24].

The inclusion of governance as a distinct analytical pillar reflects its status as an autonomous domain of rural development intervention, not merely an enabling condition for economic, social, or environmental outcomes. Governance produces its own development results—transparent and accountable institutions, secure land tenure, effective public service delivery, and meaningful citizen participation are ends in themselves, not simply instruments for achieving other development objectives. These outcomes are analytically distinct from productivity gains, health improvements, or environmental conservation, and require dedicated research attention and policy investment in their own right [19,23].

Overall, the conceptual framework for sustainable rural development is organized into four major dimensions (see Figure 1). The environmental dimension encompasses the sustainable use of natural resources, biodiversity protection, and adaptation to climate change, ensuring that rural ecosystems remain resilient over time. The economic dimension includes equitable economic development, diversification of rural activities, technological innovation, and the expansion of income-generating opportunities for rural communities. The social dimension addresses quality of life, equitable access to education, health, and social services, the reduction of inequalities, and the preservation of cultural identity and community cohesion. The governance dimension highlights the role of transparent, effective, and accountable institutions, participatory decision-making, policy coherence, and administrative capacity in supporting sustainable rural development.

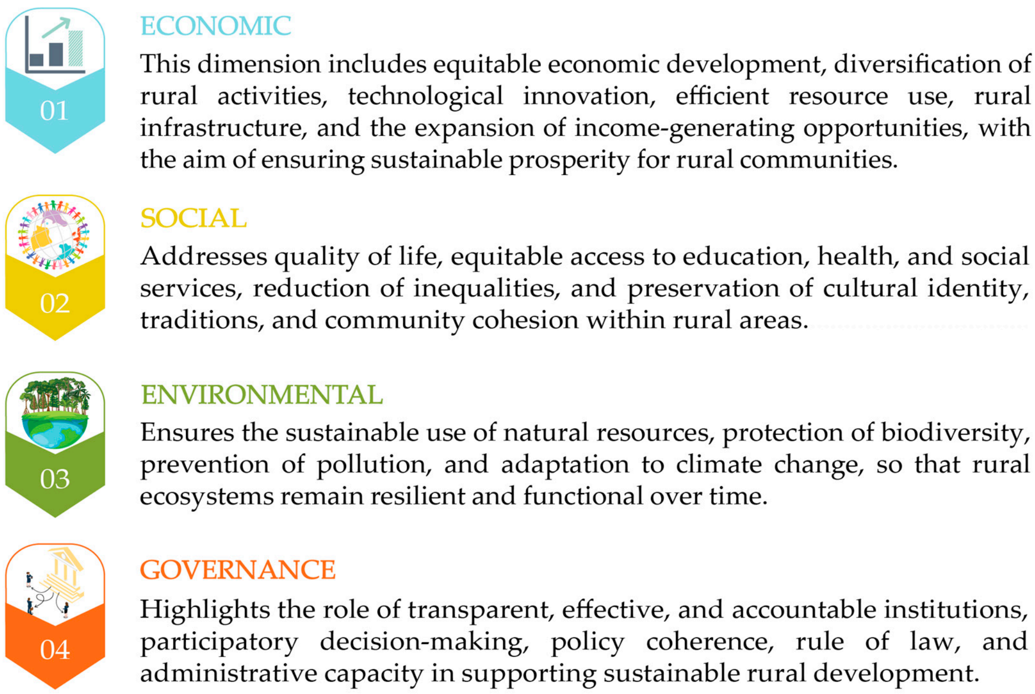

Figure 1. The dimensions of sustainable rural development.

Seventeen Sustainable Development Goals (SDGs) have been designed for the four pillars of sustainable rural development, brought together under the United Nations 2030 Agenda [3]. The goals provide an integrated framework detailing the directions for action (see Figure 2) necessary to achieve sustainability, and are presented in the following form:

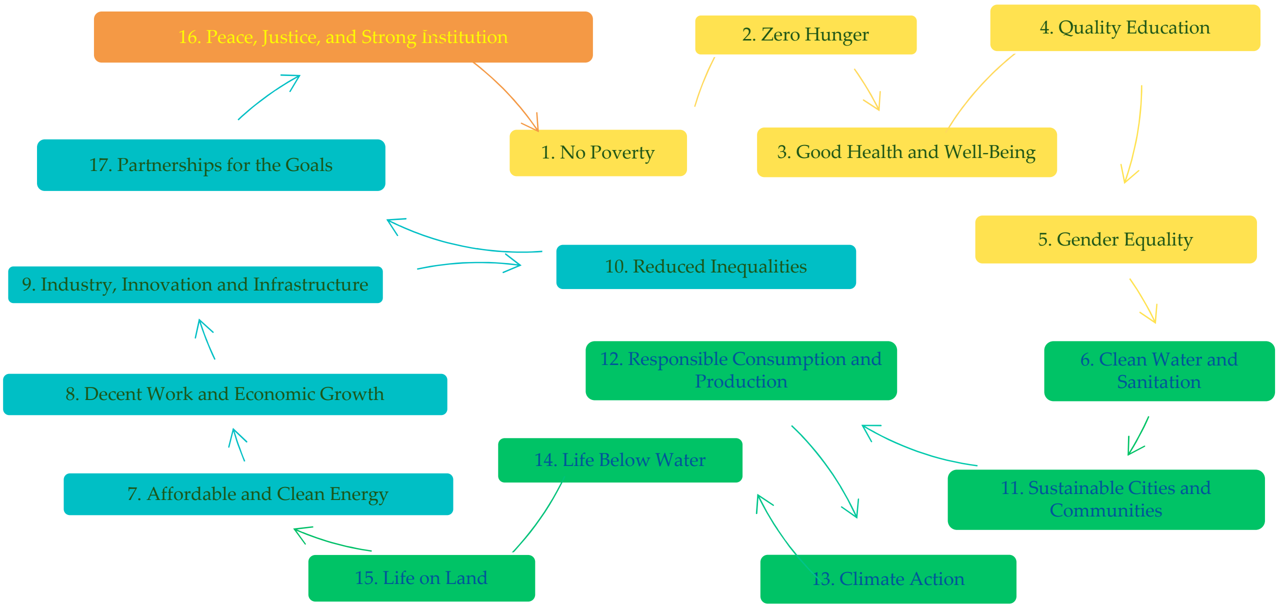

Figure 2. The Sustainable Development Goals set out in the United Nations 2030 Agenda.

To achieve these objectives, major international organizations have developed comprehensive programs targeting rural development across multiple dimensions. The World Bank supports public administration programs, agricultural market systems, agricultural extension services, social protection mechanisms, and transportation infrastructure for rural populations [2,5].

The International Fund for Agricultural Development (IFAD) focuses on five interconnected areas: support for vulnerable people through poverty reduction and social inclusion, environmental protection and climate change adaptation, market functioning and agricultural value chains, sustainable agriculture, and resilience-building measures that strengthen rural institutions and local governance [6].

The Food and Agriculture Organization (FAO) implements programs in over seventeen countries in Europe and Central Asia, aimed at transforming agri-food systems into efficient, inclusive, and sustainable systems, promoting climate change adaptation, food security, value chain strengthening, and the strengthening of local institutions [25].

These organizations also run digitalization-focused programs, including the Global Farmer Field School Platform [26], the Participatory Small-scale Irrigation Development Programme II [27], the Nigeria Rural Access and Agricultural Marketing Project [28], and the Digital Villages Initiative [29]. The continued expansion of these programs confirms that rural development challenges remain incompletely resolved and require sustained, multidisciplinary intervention.

The four-pillar framework adopted in this review is grounded in established rural development theory, drawing on participatory development traditions that position communities as active agents rather than passive beneficiaries, endogenous development perspectives that emphasize local resources and capacities, resilience theory that addresses the ability of rural systems to absorb and adapt to shocks, and community-led development approaches that prioritize locally-driven processes. These theoretical traditions collectively inform the conceptual boundaries of the economic, social, environmental, and governance pillars as applied in the present analysis.

1.2. Emerging Technologies and the Transformation of Rural Areas

While conventional rural development initiatives have focused primarily on infrastructure, service delivery, and capacity building, the increasing complexity of rural challenges requires more adaptive and innovative approaches. In addition to traditional interventions, organizations are promoting the use of emerging technologies [7,8,30,31] to solve problems, marking a major shift in the rural development paradigm towards smart, connected, and sustainable models.

Scientific literature increasingly highlights a shift towards solutions based on emerging technologies, with transformative potential in multiple areas of rural space.

Emerging technologies can be defined as a set of technologies whose development and application areas are still expanding rapidly, and whose technical and value potential is still largely unrealised [32], with significant capacity to transform existing economic, social, environmental, and institutional systems.

Emerging technologies encompass a wide range of solutions [32,33], including:

- Data collection and monitoring: drones, aerial imaging, Internet of Things (IoT);
- Analytical and computational tools: artificial intelligence (AI), big data analytics, digital twins, edge computing, cloud computing;
- Immersive technologies: virtual and augmented reality, spatial computing;
- Infrastructure innovations: wireless energy transfer, advanced materials;
- Governance mechanisms: blockchain, tokenized crowdfunding.

However, these categories are not equivalent in terms of technological maturity, implementation feasibility, infrastructure dependency, or governance complexity. Da-ta collection and monitoring technologies—particularly IoT sensors and UAVs—represent relatively mature solutions already deployed at scale in rural contexts, with moderate infrastructure requirements and low governance complexity. Analytical and computational tools such as ML and Deep Learning are likewise technically mature, highly scalable, but require substantial data infrastructure and technical capacity that remain unevenly distributed across rural regions.

By contrast, governance mechanisms such as blockchain and decentralized autonomous organizations (DAOs) are still largely experimental in rural settings, demanding not only digital infrastructure but also significant institutional adaptation and legal frameworks that most rural administrations are not yet equipped to provide. Immersive technologies and infrastructure innovations occupy an intermediate position, showing promise in pilot applications but facing considerable barriers to scalability and widespread adoption. Recognizing these distinctions is essential for avoiding a homogeneous treatment of emerging technologies and for designing context-sensitive rural development interventions.

Now commercially available and continuously expanding their applications, these technologies show great promise for economic growth, social development, and sustainability, with forecasts indicating their essential role in achieving the SDGs globally [34].

Recent studies indicate that these technologies are already being tested or implemented in various sectors and are constantly evolving, with new features being introduced and expanding domains of application. However, their successful implementation is closely linked to end-user acceptance and engagement [35]. In agriculture, drones and multispectral imaging are used to monitor crop health and apply precision treatments [36–38], while IoT sensors enable the optimization of irrigation and resource consumption [39].

In rural healthcare, wearable devices with advanced sensors and the IoT support disease diagnosis and patient monitoring in isolated areas [40,41].

In the environmental sector, satellites, change detection algorithms, and predictive models contribute to monitoring soil quality, biodiversity, and climate risks [42–44].

Rural energy utilizes smart microgrids, advanced energy storage materials, and autonomous consumption flow management solutions [45–47].

Technologies can transform local governance by creating transparent and inclusive platforms. In Nepal, a blockchain-based framework enabled by self-sovereign identity allows for immutable records, automates cadastral updating processes, and incentivizes citizen participation with a token system [48].

Similarly, recent initiatives in artificial intelligence and decentralized governance highlight the potential of these technologies to strengthen institutional resilience and digital justice by integrating blockchain, decentralized autonomous organizations, and data cooperatives, which facilitate decision-making transparency, data sovereignty, and the involvement of local communities in governance processes [49].

The diversity of the initiatives presented above indicates that emerging technologies no longer represent mere experimental solutions, but rather structural trends contributing to the redefinition of the sustainable development potential of rural areas. In this context, academic and institutional interest in integrating these technologies into rural development processes has grown significantly over the last decade.

1.3. Research Aim and Contribution to the Literature

The aim of the present scoping review is to systematically map the literature on the application of emerging technologies in rural development, by integrating these technologies into a conceptual framework grounded in the four pillars of sustainable rural development: economic, social, environmental, and governance.

Although the existing literature includes in-depth analyses focused on individual technologies—such as Big Data in smart farming [36], IoT in agriculture [37], IoT in rural healthcare [40], AI in environmental monitoring [43], and AI-powered rural electrification solutions [46]—or on specific sectors of rural development [38], within the scope of the bibliographic searches conducted, no study was identified that offers a systematic cross-pillar mapping simultaneously addressing economic, social, environmental, and governance dimensions within a unified analytical framework grounded in sustainable rural development theory. Specifically, the study pursues the following objectives: (i) classifying the applications of emerging technologies according to the four pillars; (ii) identifying current trends and existing gaps in the literature; (iii) formulating an orientative intervention framework capable of guiding future research, innovation, and public policy initiatives towards insufficiently covered areas, with a view to supporting integrated and balanced rural development.

Through this approach, the study makes an original contribution to the literature, as it provides a systematic analysis that integrates and correlates research on emerging technologies in relation to all dimensions of sustainable rural development. At the same time, the paper proposes an intervention-oriented perspective, highlighting underaddressed domains and suggesting potential directions for the development and implementation of emerging technologies. This approach aims to support the balanced and simultaneous advancement of all dimensions of sustainable rural development, ultimately contributing to a more equitable and resilient rural transformation.

2. Materials and Methods

2.1. Methodological Approach

This study adopts a scoping review methodology, given the emerging and fragmented nature of the field of emerging technologies applied to rural development, which spans multiple disciplines—agronomy, environmental science, public health, information technology, and governance. This method presents several advantages: it allows for the systematic mapping of a research field that is still taking shape, facilitates the development and refinement of conceptual frameworks, and supports the in-depth analysis of the relationships between emerging technologies and the various dimensions of sustainable rural development. Although the review followed systematic search and selection procedures, its primary objective—mapping the breadth and diversity of existing knowledge across the four pillars of sustainable rural development—aligns it methodologically with the scoping review approach, in accordance with the PRISMA-ScR guidelines [50]. The search strategy, selection criteria, and data extraction process are described in detail in Sections 2.2 and 2.3.

A scoping review was selected as the most appropriate methodological approach for the research question addressed—namely, mapping the breadth and distribution of emerging technology applications across the four pillars of sustainable rural development. Unlike a conventional systematic review, which is designed to evaluate the effectiveness of specific interventions and requires quality appraisal of included studies, the present study does not seek to assess which technologies work best, but rather to chart what exists across a heterogeneous, multi-disciplinary field. Unlike bibliometric mapping, which analyzes publication patterns and citation networks quantitatively, the present review performs thematic content analysis to identify types of technological applications and their contribution to rural development outcomes—an objective that requires qualitative interpretation of study content.

2.2. Study Selection

The Preferred Reporting Items for Systematic reviews and Meta-Analyses extension for Scoping Reviews (PRISMA-ScR) protocol, proposed by Tricco et al. (2018), was used as a methodological guide for structuring and reporting the review process, to ensure methodological transparency and rigor [50]. The PRISMA-ScR checklist is presented in the Supplementary Materials.

A formal review protocol was not registered in a public registry prior to study commencement. However, the steps for identifying, selecting, and analyzing the literature were defined a priori and applied consistently, in accordance with the PRISMA-ScR recommendations for scoping reviews.

The literature selection process followed four distinct steps: identification, screening, eligibility, and inclusion, described below. The article selection, eligibility assessment, and data extraction stages were conducted in duplicate, with all decisions validated through team consensus.

Phase 1: Identification

Bibliographic searches were conducted between 2–5 January 2026, using the Clarivate Web of Science platform, with the Search in: All Databases option, with a primary focus on the Web of Science Core Collection.

In order to capture recent and relevant developments in the field of emerging technologies applied to rural development, searches were restricted to papers published between 2015 and 2025.

In selected instances, the full texts of articles were accessed through authors' profiles or complementary academic platforms, such as ResearchGate, when they were not fully available through Web of Science.

The search strategy was built on three conceptual blocks: (i) rural context, (ii) emerging technologies, and (iii) terms specific to one of the four pillars of sustainable rural development (economic, social, environmental, governance). Terms were searched within the keywords field.

Block 1—Rural context: rural, rural development, rural areas, village.

Block 2—Emerging technologies: emerging technology, advanced technology, artificial intelligence, machine learning, deep learning, internet of things, IoT, sensor, drone, UAV, remote sensing, satellite, GIS, blockchain, distributed ledger, big data, data analytics, predictive model, cloud computing, edge computing.

Block 3—Terms specific to the pillars:

- **Economic:** econom*, livelihood*, productivit*, efficien*, market access, value chain, supply chain, SME*, entrepreneur*, agricultur*, irrigation, tourism, agritourism, farm*, commercialization, industry, industrial development, infrastructure, rural infrastructure, energy access, renewable energy, employment, job creation, decent work, labor market, fisher, fisheries, aquaculture*, forest, forestry*, livestock, animal husbandry, dairy, poultry, trade, rural markets, finance, financial inclusion, digital economy, orchards, fruit.
- **Social:** quality of life, wellbeing, well-being, rural health, health care, healthcare, access to health, services, telemedicine, mHealth, remote patient monitoring, wearable*, education, quality education, e-learning, gender equality, gender, women empowerment, equity, equal access, social inclusion, inclusion, social cohesion, community cohesion, food security, nutrition, zero hunger, poverty, no poverty, poverty reduction, cultural identity, cultural heritage, traditions, traditional knowledge, community wellbeing, social assistance, community service*, social protection.
- **Environment:** environment*, environmental monitoring, climate change, climate risk, adaptation, mitigation, resilien*, biodiversity, ecosystem*, conservation, soil, soil quality, water, water quality, land use, land cover, drought, flood*, early warning, disaster risk, clean water, safe drinking water, sustainable consumption, responsible consumption, sustainable production, waste management, landscape*, environmental planning, agroecosystem*, soil degradation, land degradation, nature-based solution*, ecosystem service*.
- **Governance:** governance, rural governance, local governance, digital governance, e-governance, public administration, public service*, transparency, accountability, participation, citizen engagement, land registry, cadastre, land tenure, property rights, funding mechanisms, administrative law, rural law, regulation, public budgeting, fiscal decentralization, legislation, infrastructure planning, planning, administrative services, administrative services, open government, smart governance, community development.

Bibliographic searches were conducted separately for each of the four pillars of sustainable rural development, using distinct sets of terms specific to each pillar. Articles identified in a particular search block were not excluded if they predominantly addressed another pillar, but were subsequently reclassified and analyzed within the pillar corresponding to their main content.

The decision to restrict searches to the keywords field was made to enhance thematic precision, as terms related to emerging technologies may appear in titles and abstracts in a generic or contextual sense without representing the primary focus of the study. This approach prioritizes the identification of studies in which the relevant concepts are explicitly designated as central by the original authors. Despite maintaining methodological rigor, the exact number of results may vary when the search is repeated, due to the technical characteristics of search engines.

Phase 2: Screening

The titles, keywords, and abstracts of the identified publications were analyzed to assess their relevance to the study objectives. At this stage, only scientific articles published in indexed academic journals were considered, excluding other types of documents such as proceedings, editorials, and technical notes.

Studies that explicitly or substantially address applications of emerging technologies in rural contexts were included, regardless of sector, provided that they fell within one of the four pillars of sustainable rural development (economic, social, environmental, or governance).

Works in which the relevant terms appear only marginally or without a clear connection to rural development and the use of technologies for data collection, processing, or interpretation were excluded. Similarly, publications that mention rural development or emerging technologies only in their titles but deal exclusively with other topics were not included.

Retracted articles were excluded from the screening process to ensure the quality and validity of the final analysis corpus.

Following this stage, the selected articles formed the basis for the eligibility assessment phase.

Phase 3: Eligibility

The inclusion criteria targeted peer-reviewed articles published in English between 2015 and 2025 that referred to emerging technologies in rural areas in any region of the world that contributed to one of the four pillars of sustainable rural development.

Articles that focused exclusively on urban development were excluded, as were those that mentioned rural development or emerging technologies only incidentally. No restrictions were imposed on the discipline of origin of the studies.

In line with the specific nature of a scoping review, the study does not seek to evaluate the methodological quality of the included papers, but rather to map the types of applications, models, methodological frameworks, and emerging technological solutions proposed in the literature for rural development. This approach allows for the identification of trends, research gaps, and areas with potential for intervention, without imposing restrictive filters on the methodological design of the studies analyzed.

Phase 4: Inclusion

Following the rigorous completion of all methodological stages described above, a total of 129 publications fully met the inclusion criteria and were retained for final analysis, presented in Section 3. Results, within Tables 1–4. These studies underwent an in-depth examination encompassing both a descriptive analysis—addressing the general characteristics of the publications, temporal distribution, predominant pillar, and alignment with the sustainable development goals—and a detailed thematic analysis aimed at identifying the types of emerging technologies used, their domains of application, and their specific contributions to Sustainable Rural Development. The PRISMA selection flow diagram (see Figure 3) illustrates the entire process of identification, screening, eligibility assessment, and inclusion of studies in the corpus.

Table 1. List of publications included under the economic pillar of the scoping review (n = 41). (Notes: Publications shown in *italics* indicate abstract-only access.)

No.	Authors	Publication Year	Title	Category	Sustainable Development Goal
1	Xi Ma [51]	2023	Smart Agriculture and Rural Revitalization and Development Based on the Internet of Things under the Background of Big Data	Precision farming	SDG 8, SDG 9
2	Noor et al. [52]	2024	Deep Image Processing Based Periodically Leaves Diseases Detection and Classification through Wireless Visual Sensors Network (WVSN)	Precision farming	SDG 9, SDG 2

Table 1. *Cont.*

No.	Authors	Publication Year	Title	Category	Sustainable Development Goal
3	Alatawi et al. [53]	2022	Plant Disease Detection using AI based VGG-16 Model	Precision farming	SDG 9, SDG 2
4	Barman et al. [54]	2024	ViT-SmartAgri: Vision Transformer and Smartphone-Based Plant Disease Detection for Smart Agriculture	Precision farming	SDG 9, SDG 2
5	Mujumdar et al. [55]	2025	*Leveraging Satellite Imagery for Comprehensive Agro-Economic Health Assessment in Indian Villages: A Case Study of Karnataka's Diverse Agro-Climatic Zones*	Precision farming	SDG 9, SDG 2
6	Chen et al. [56]	2019	In-Season Diagnosis of Winter Wheat Nitrogen Status in Smallholder Farmer Fields Across a Village Using Unmanned Aerial Vehicle-Based Remote Sensing	Precision farming	SDG 9, SDG 2
7	López Rivero et al. [57]	2020	Network Traffic Modeling in a Wi-Fi System with Intelligent Soil Moisture Sensors (WSN) Using IoT Applications for Potato Crops and ARIMA and SARIMA Time Series	Precision farming	SDG 9, SDG 2
8	Oliveira-Jr et al. [58]	2020	IoT Sensing Platform as a Driver for Digital Farming in Rural Africa	Precision farming	SDG 9, SDG 2
9	Taşkin et al. [59]	2020	A Long-Range Context-Aware Platform Design For Rural Monitoring With IoT In Precision Agriculture	Precision farming	SDG 9, SDG 2
10	Vieira et al. [60]	2023	Detection of Non-Technical Losses in Irrigant Consumers through Artificial Intelligence: A Pilot Study	Energy and rural transport	SDG 7, SDG 9
11	Li et al. [61]	2023	Deep Learning Method for Evaluating Photovoltaic Potential of Rural Land Use Types	Energy and rural transport	SDG 7, SDG 9
12	Li et al. [62]	2024	Consumption as the Catalyst: Analyzing Rural Power Infrastructure and Agricultural Growth through Panel Threshold Regression and Data-Driven Prediction	Energy and rural transport	SDG 7, SDG 9
13	Lin et al. [63]	2025	*Energy Management for Rural Microgrid With Inaccurate Equipment Parameters: A KAN-Based Deep Reinforcement Learning Method*	Energy and rural transport	SDG 7, SDG 9
14	Lu et al. [64]	2024	AI-Enabled Sports-System Peer-to-Peer Energy Exchange Network for Remote Areas in the Digital Economy	Energy and rural transport	SDG 7, SDG 9

Table 1. *Cont.*

No.	Authors	Publication Year	Title	Category	Sustainable Development Goal
15	Pitakaso et al. [65]	2025	Fuzzy Logic-Enhanced Sustainable and Resilient EV Public Transit Systems for Rural Tourism	Energy and rural transport	SDG 9, SDG 11
16	Zhang [66]	2019	Application of Blockchain Technology in Incentivizing Efficient Use of Rural Wastes: A Case Study on Yitong System	Energy and rural transport	SDG 7, SDG 12, SDG 9
17	Galán-Jiménez et al. [67]	2021	Energy-Efficient and Solar Powered Mission Planning of UAV Swarms to Reduce the Coverage Gap in Rural Areas: The 3D Case	Rural digital infrastructure	SDG 10, SDG 9
18	Bartolín-Arnau et al. [68]	2023	LoRaWAN Networks for Smart Applications in Rural Settings	Rural digital infrastructure	SDG 9
19	Yascaribay et al. [69]	2022	Performance Evaluation of Communication Systems Used for Internet of Things in Agriculture	Rural digital infrastructure	SDG 9, SDG 2
20	Patros et al. [70]	2023	Rural AI: Serverless-Powered Federated Learning for Remote Applications	Rural digital infrastructure	SDG 9, SDG 2
21	Perumal et al. [71]	2022	*Enhanced Disruption Tolerant Network (DTN) Framework for Improving Network Efficiency in Rural Areas*	Rural digital infrastructure	SDG 9, SDG 10
22	Enayati et al. [72]	2024	A Qualitative Analysis of Rural Fishermen: Potential for Blockchain-Enabled Framework for Livelihood Sustainability	Rural supply chains	SDG 8, SDG 14
23	Prause et al. [73]	2019	Smart Contracts for Smart Rural Supply Chains	Rural supply chains	SDG 8, SDG 9
24	Liu [74]	2025	*The Optimization of Rural Employment Resources and Services Based on Edge Computing and Blockchain Technology*	Rural digital services	SDG 8, SDG 9
25	Huang [75]	2022	Evaluation and Measurement of the Development Level of Rural Inclusive Finance Using Deep Learning Technology for Supply Chain Intelligence	Rural financial services	SDG 8, SDG 1
26	Shao [76]	2022	New Energy Industry Financial Technology Based on Machine Learning to Help Rural Revitalization	Rural financial services	SDG 8, SDG 9
27	Chen [77]	2023	The GSO-Deep Learning-Based Financial Risk Management System for Rural Economic Development Organization	Rural financial services	SDG 8, SDG 9

Table 1. *Cont.*

No.	Authors	Publication Year	Title	Category	Sustainable Development Goal
28	Chen et al. [78]	2024	Cloud-Based Configurable Data Stream Processing Architecture in Rural Economic Development	Rural financial services	SDG 9
29	Shen et al. [79]	2024	From Text to Insights: Leveraging NLP to Assess How Landscape Features Shape Tourist Perceptions and Emotions toward Traditional Villages	Rural tourism	SDG 8, SDG 11
30	Yuan [80]	2024	Evaluation of Rural Tourism Development Level Using BERT-Enhanced Deep Learning Model and BP Algorithm	Rural tourism	SDG 8, SDG 9
31	Liu [81]	2019	Cognitive Diagnosis of Cultural and Rural Tourism Convergence	Rural tourism	SDG 8, SDG 9
32	Zhao et al. [82]	2022	*Research on the coordinated development model of agricultural economy and rural tourism under the background of big data*	Rural tourism	SDG 8, SDG 2
33	Yang et al. [83]	2024	Design and Development of a Rural Tourism Marketing System Using Deep Learning	Rural tourism	SDG 8, SDG 9
34	Wang [84]	2024	The Analysis of Rural Tourism Image Optimization under the Internet of Things and Deep Learning	Rural tourism	SDG 8, SDG 9
35	Chen et al. [85]	2024	Distribution Characteristics and Development Layout of Rural Tourism Resources Based on LSTM In-Depth Learning in the Context of Common Prosperity	Rural tourism	SDG 8, SDG 9
36	Qiu et al. [86]	2023	Rural Homestay Spatial Planning and Design Based on Bert BiLSTM EIC Algorithm in the Background of Digital Ecology	Rural tourism	SDG 8, SDG 11
37	Wang et al. [87]	2023	*Uncertainty Models in the Integration Path of Rural Tourism Information Construction and Smart Tourism Based on Big Data Technology*	Rural tourism	SDG 8, SDG 9
38	Li [88]	2023	*The Integration of Cultural Tourism and Rural Revitalization in Big Data and the Internet of Things*	Rural tourism	SDG 8, SDG 11
39	Liu et al. [89]	2024	Rural Landscape Design Strategy Based on Deep Learning Model	Rural tourism	SDG 8, SDG 11, SDG 15

Table 1. *Cont.*

No.	Authors	Publication Year	Title	Category	Sustainable Development Goal
40	Huang et al. [90]	2023	Clustering Analysis of Integrated Rural Land for Three Industries Using Deep Learning and Artificial Intelligence	Land management	SDG 8, SDG 9
41	Gupta et al. [91]	2025	Assessing the Impact of Farm Ponds on Agricultural Resilience and Economic Outcomes: A Drone-Based Analysis in Bandlapalle, Andhra Pradesh, India	Resource management	SDG 9, SDG 12

Table 2. List of publications included under the social pillar of the scoping review (n = 30). (Notes: Publications shown in *italics* indicate abstract-only access.).

No.	Authors	Publication Year	Title	Category	Sustainable Development Goal
1	Sharma et al. [92]	2019	Combining Multi-Modal Statistics for Welfare Prediction Using Deep Learning	Social welfare	SDG 1, SDG 6
2	Kang [93]	2022	Artificial Intelligence Network Embedding, Entrepreneurial Intention, and Behavior Analysis for College Students' Rural Tourism Entrepreneurship	Education and entrepreneurship	SDG 4, SDG 8
3	Rutherford et al. [94]	2025	Promoting Rural Entrepreneurship Through Technology: A Case Study Using Productivity Enhancing Technology Experience Kits (PETE-Kits)	Education and entrepreneurship	SDG 4, SDG 8
4	Wei [95]	2022	Decreasing Land Use and Increasing Information Infrastructure: Big Data Analytics Driven Integrated Online Learning Framework in Rural Education	Rural education	SDG 4, SDG 10
5	Darda et al. [96]	2024	*Metamorphosing Traditional Pedagogy: Examining the Transcendent Influence of Alexa in Catalyzing Educational Paradigm Shifts within Rural Indian Communities*	Rural education	SDG 4
6	Zhao [97]	2025	Using Deep Learning to Optimize the Allocation of Rural Education Resources Under the Background of Rural Revitalization	Rural education	SDG 4, SDG 10

Table 2. *Cont.*

No.	Authors	Publication Year	Title	Category	Sustainable Development Goal
7	Tao et al. [98]	2023	An Approach for Identifying Historic Village Using Deep Learning	Cultural heritage	SDG 4, SDG 11
8	Gang et al. [99]	2020	The Impact of COVID-19 on the Protection of Rural Traditional Village	Cultural heritage	SDG 4, SDG 11
9	Cao et al. [100]	2025	Employing Machine Learning for Early Detection of Poly-Victimization in Rural Children: A Survey Study in China's Chaoshan Region	Social protection	SDG 1, SDG 3, SDG 16
10	Bingxu [101]	2020	Design and Analysis of a Rural Accurate Poverty Alleviation Platform Based on Big Data	Social protection	SDG 1, SDG 10
11	Herrador et al. [102]	2025	RE-HAK: A Novel Refurbish-to-Host Solution Using AI-Driven Blockchain to Advance Circular Economy and Revitalize Japan's Akiyas	Community revitalization	SDG 3, SDG 10
12	Bouchrit et al. [103]	2025	*Enhancing Road Safety: UAV-Enabled Warning Message Dissemination in Urban and Rural Environments for VANETS*	Community safety	SDG 3, SDG 11
13	Koech et al. [104]	2022	The PRECISE Network. Acceptability and Feasibility of a Low-Cost Device for Gestational Age Assessment in a Low-Resource Setting: Qualitative Study	Maternal health	SDG 3, SDG 5
14	Shen et al. [105]	2020	An Innovative Artificial Intelligence–Based App for the Diagnosis of Gestational Diabetes Mellitus (GDM-AI): Development Study	Maternal health	SDG 3, SDG 5
15	Li et al. [106]	2025	Artificial Intelligence-Driven Framework for Improving Prenatal Screening for Congenital Heart Disease in Rural Nebraska	Maternal health	SDG 3, SDG 10
16	Ali et al. [107]	2021	An IoT Assisted Real-Time High CMRR Wireless Ambulatory ECG Monitoring System with Arrhythmia Detection	Rural health	SDG 3
17	Beltrán et al. [108]	2025	A Teledentistry Care Model for Older Populations in Remote Settings in Chile Using Satellite Communication Technology	Rural health	SDG 3, SDG 10
18	Tolentino et al. [109]	2020	CAREdio: Health Screening and Heart Disease Prediction System for Rural Communities in the Philippines	Rural health	SDG 3

Table 2. *Cont.*

No.	Authors	Publication Year	Title	Category	Sustainable Development Goal
19	Drinkwater et al. [110]	2025	A Real-World Comparison of Three Deep Learning Systems for Diabetic Retinopathy in Remote Australia	Rural health	SDG 3, SDG 10
20	Kim et al. [111]	2017	Drone-Aided Healthcare Services for Patients with Chronic Diseases in Rural Areas	Rural health	SDG 3
21	Bhuiyan et al. [112]	2022	Design and Implementation of a Feasible Model for the IoT Based Ubiquitous Healthcare Monitoring System for Rural and Urban Areas	Rural health	SDG 3
22	Chadwick et al. [113]	2025	Artificial Intelligence-Enabled Mobile Health Intervention (mDiabetes) to Reduce Diabetes Risk Behaviors in Rural India: Quasi-Experimental Pre-Post Study	Rural health	SDG 3
23	Miah et al. [114]	2017	On-Cloud Healthcare Clinic: An e-Health Consultancy Approach for Remote Communities in a Developing Country	Rural health	SDG 3, SDG 10
24	Wroblewski et al. [115]	2025	Diabetic Retinopathy Screening Using Smartphone-Based Fundus Photography and Deep-Learning Artificial Intelligence in the Yucatan Peninsula: A Field Study	Rural health	SDG 3
25	Kerrison et al. [116]	2023	Blockchain-Enabled IoT for Rural Healthcare: Hybrid-Channel Communication with Digital Twinning	Rural health	SDG 3, SDG 9
26	Auster-Gussman et al. [117]	2022	Reach of a Fully Digital Diabetes Prevention Program in Health Professional Shortage Areas	Rural health	SDG 3, SDG 10
27	Garbhapu et al. [118]	2017	IoT Based Low Cost Single Sensor Node Remote Health Monitoring System	Rural health	SDG 3, SDG 10
28	Du et al. [119]	2025	A Study on Search and Rescue of Mountain Traditional Village Landscapes Using Geographic Information System	Community safety	SDG 3, SDG 13
29	Caminiti et al. [120]	2025	Project TERESA: A GIS-Based Multifactorial Framework Utilizing Supervised Machine Learning for Nation-Scale Electrification Planning	Rural infrastructure	SDG 1, SDG 10, SDG 7
30	Moreno-Ponce et al. [121]	2025	Predictive Models and GIS for Road Safety: Application to a Segment of the Chone–Flavio Alfaro Road	Community safety	SDG 3, SDG 11

Table 3. List of publications included under the environmental pillar of the scoping review (n = 36). (Notes: Publications shown in *italics* indicate abstract-only access.).

No.	Authors	Publication Year	Title	Category	Sustainable Development Goal
1	Sarti et al. [122]	2021	Trees Outside Forest in Italian Agroforestry Landscapes: Detection and Mapping Using Sentinel-2 Imagery	Biodiversity	SDG 13, SDG 15
2	Sepuru et al. [123]	2018	*Understanding the Spatial Distribution of Eroded Areas in the Former Rural Homelands of South Africa: Comparative Evidence from Two New Non-Commercial Multispectral Sensors*	Environmental quality	SDG 15
3	Bahi et al. [124]	2025	A New Thermal Fusion Method to Downscale Land Surface Temperature to Finer Spatial Resolution Using Sentinel-MSI and Landsat-OLI/TIRS Imagery	Environmental quality	SDG 13, SDG 11
4	Luo et al. [125]	2025	Urban–Rural Inequality in Soil Heavy Metal Health Risks: Insights from Baoding, China	Environmental quality	SDG 15, SDG 3
5	Karahan et al. [126]	2025	Integrating UAV Photogrammetry and GIS to Assess Terrace Landscapes in Mountainous Northeastern Türkiye for Sustainable Land Management	Landscape conservation	SDG 15
6	Zheng et al. [127]	2024	UAV Imagery-Based Classification Model for Atypical Traditional Village Landscapes and Their Spatial Distribution Pattern	Landscape conservation	SDG 11, SDG 15
7	Zhu et al. [128]	2024	Research on Evaluating the Characteristics of the Rural Landscape of Zhanqi Village, Chengdu, China, Based on Oblique Aerial Photography by Unmanned Aerial Vehicles	Landscape conservation	SDG 11, SDG 15
8	Liu et al. [129] *	2023	*Visualization System of Hlai Ethnic Village Landscape Design Based on Machine Learning*	Landscape conservation	SDG 11, SDG 15
9	Zhang et al. [130]	2023	Multi-Resolution Feature Extraction and Fusion for Traditional Village Landscape Analysis in Remote Sensing Imagery	Landscape conservation	SDG 11, SDG 15
10	Gong et al. [131]	2025	Rural Local Landscape Perception Evaluation: Integrating Street View Images and Machine Learning	Landscape conservation	SDG 11, SDG 15

Table 3. *Cont.*

No.	Authors	Publication Year	Title	Category	Sustainable Development Goal
11	Shanghao et al. [132]	2025	Study on Rural Landscape Design Strategies Integrating Computer Vision and Deep Learning: An Analysis Based on Human Perception and Visual Aesthetics	Landscape conservation	SDG 11, SDG 15
12	Wescoat et al. [133]	2022	A Sustainability Planning Framework and Methods for Rural Drinking Water in Satara District, Maharashtra, India	Water management	SDG 6, SDG 3
13	Liu et al. [134]	2015	*Application and Study of Internet of Things Used in Rural Water Conservancy Project*	Water management	SDG 6
14	Ingram et al. [135]	2020	Robustness of IoT-Connected e-Taps for Sustainable Service Delivery of Rural Water Supply	Water management	SDG 6
15	Tashman et al. [136]	2020	Anomaly Detection System for Water Networks in Northern Ethiopia Using Bayesian Inference	Water management	SDG 6, SDG 3
16	Cao et al. [137]	2024	*Prediction of Rural Domestic Water and Sewage Production Based on Automated Machine Learning in Northern China*	Water management	SDG 6
17	Bogdan et al. [138]	2023	Low-Cost Internet-of-Things Water-Quality Monitoring System for Rural Areas	Water management	SDG 6, SDG 3
18	Wang et al. [139]	2025	Inversion of Water Quality Parameters from UAV Hyperspectral Data Based on Intelligent Algorithm Optimized Backpropagation Neural Networks of a Small Rural River	Water management	SDG 6, SDG 15
19	Raghavendra Kumar et al. [140]	2022	Assessment of Sustainability Index for Rural Water Management Using ANN	Water management	SDG 6, SDG 13
20	Zhao et al. [141]	2025	Land-Unet: A Deep Learning Network for Precise Segmentation and Identification of Non-Structured Land Use Types in Rural Areas for Green Urban Space Analysis	Territorial monitoring	SDG 15, SDG 11
21	Yan et al. [142]	2021	*Rural Land Information Extraction Based on Improved Deeplabv3+ Network in High Resolution Remote Sensing Image*	Territorial monitoring	SDG 15

Table 3. *Cont.*

No.	Authors	Publication Year	Title	Category	Sustainable Development Goal
22	Deng et al. [143]	2025	*Research on the Construction and Application of Urban and Rural Landscape Feature Recognition Model Based on Deep Learning and Generative Adversarial Network*	Territorial monitoring	SDG 11, SDG 15
23	Li et al. [144]	2024	Land-Use Composition, Distribution Patterns, and Influencing Factors of Villages in the Hehuang Valley, Qinghai, China, Based on UAV Photogrammetry	Territorial monitoring	SDG 15, SDG 11
24	Maciąg et al. [145]	2024	Algorithm for Evaluating the Difficulty of Land Consolidation Using Cadastral Data	Territorial monitoring	SDG 2, SDG 15
25	Sun et al. [146]	2024	Automatic Identification and Evaluation of Rural Landscape Features Based on U-Net	Territorial monitoring	SDG 15, SDG 11
26	Onsay et al. [147]	2024	*Combining Machine Learning (ML) and Participatory Rural Appraisal (PRA) for Disaster Risk Preparedness (DRP): Evidence from the Poorest Region of Luzon, Philippines*	Risk and disasters	SDG 13
27	Li et al. [148]	2025	Multisource SAR-Based Rural Flood and Partially Submerged Vegetation Mapping Using Fuzzy Logic and Machine Learning	Risk and disasters	SDG 13, SDG 15
28	Tang et al. [149]	2025	DroneRiver: An Aerial Semantic Segmentation Dataset for Analysis of River Leakage	Risk and disasters	SDG 13, SDG 6
29	Macharia et al. [150]	2023	Streamflow and Flood Prediction in Rwanda Using Machine Learning and Remote Sensing in Support of Rural First-Mile Transport Connectivity	Risk and disasters	SDG 13, SDG 9
30	Zhang et al. [151]	2025	Predicting the Spatial Distribution of Geological Hazards in Southern Sichuan, China, Using Machine Learning and ArcGIS	Risk and disasters	SDG 13, SDG 11
31	Fayaz et al. [152]	2022	Management of Landslides in a Rural–Urban Transition Zone Using Machine Learning Algorithms—A Case Study of a National Highway (NH-44), India, in the Rugged Himalayan Terrains	Risk and disasters	SDG 13, SDG 11

Table 3. *Cont.*

No.	Authors	Publication Year	Title	Category	Sustainable Development Goal
32	Baldwin et al. [153]	2022	Geospatial Analysis and Land Suitability for "FloodWise" Practices: Nature-Based Solutions for Flood Mitigation in Eastern, Rural North Carolina	Risk and disasters	SDG 13, SDG 15
33	Hill et al. [154]	2024	Monitoring Solutions for Remote Locations: A Data Gathering Approach for Remote Nature-Based Solution Sites	Risk and disasters	SDG 13, SDG 15
34	Makudza et al. [155]	2025	Leveraging Climate Resilience through AI Chatbot Farming Adoption among Rural Zimbabwean Women	Climate change	SDG 13, SDG 2
35	Jiang et al. [156]	2023	Geographic Information Visualization and Sustainable Development of Low-Carbon Rural Slow Tourism under Artificial Intelligence	Sustainable tourism	SDG 13, SDG 12
36	Chen et al. [157]	2024	Exploring the Association between the Built Environment and Positive Sentiments of Tourists in Traditional Villages in Fuzhou, China	Sustainable tourism	SDG 11, SDG 12

* *Retracted on 19 January 2026, after the completion of the literature search (2–5 January 2026); excluded from the analytical discussion.*

Table 4. List of publications included under the governance pillar of the scoping review (n = 22). (Notes: Publications shown in *italics* indicate abstract-only access.).

No.	Authors	Publication Year	Title	Category	Sustainable Development Goal
1	Ye et al. [158]	2025	Transforming Real Estate Mapping Through UAV-Enabled 3D Model Creation	Land administration	SDG 16, SDG 11
2	Hua et al. [159]	2023	A Blockchain-Based Framework for Rural Property Rights Transactions	Land administration	SDG 16, SDG 8
3	Leń et al. [160]	2023	Design of an Automated Algorithm for Delimiting Land Use/Soil Valuation Classes as a Tool Supporting Data Processing in the Land Consolidation Procedure	Land administration	SDG 16, SDG 15
4	Semenets et al. [161]	2018	Family homesteads settlements as the subjects of the public management in rural territories	E-Government	SDG 16, SDG 11

Table 4. *Cont.*

No.	Authors	Publication Year	Title	Category	Sustainable Development Goal
5	Wójcik et al. [162]	2021	Boosting the Potential for GeoDesign: Digitalisation of the System of Spatial Planning as a Trigger for Smart Rural Development	E-Government	SDG 16, SDG 11
6	Merrell [163]	2022	Blockchain for Decentralised Rural Development and Governance	E-Government	SDG 16, SDG 10
7	Wei et al. [164]	2022	Evaluation of Rural Financial Ecological Environment Based on Machine Learning and Improved Neural Network	Rural finance	SDG 16, SDG 8
8	Hou et al. [165]	2021	Application of Artificial Intelligence Technology Optimized by Deep Learning to Rural Financial Development and Rural Governance	Rural finance	SDG 16, SDG 8
9	Buchwald et al. [166]	2025	Possibilities of Improving the Energy Security and Efficiency of Sustainable Smart Village Management through the Use of Blockchain Technologies and Decentralised Autonomous Organisations on the Example of the Pałecznica Commune	Energy governance	SDG 16, SDG 7
10	Iban et al. [167]	2020	A Model for Big Spatial Rural Data Infrastructure in Turkey: Sensor-Driven and Integrative Approach	Data infrastructure	SDG 16, SDG 9
11	Zhao et al. [168]	2025	Integrating Time-Series Nighttime Light Data With Static Remote Sensing and Village View Images for Hollow Villages Identification	Territorial monitoring	SDG 16, SDG 11
12	Ha et al. [169]	2020	Monitoring and Mapping Rural Urbanization and Land Use Changes Using Landsat Data in the Northeast Subtropical Region of Vietnam	Territorial monitoring	SDG 16, SDG 11, SDG 15
13	Yao [170]	2025	DenseNet-Based High-Resolution Remote Sensing Image Surface Feature Recognition for Urban and Rural Planning Design	Territorial monitoring	SDG 16, SDG 11, SDG 15
14	Wang et al. [171]	2020	Road Network Design in a Developing Country Using Mobile Phone Data: An Application to Senegal	Infrastructure planning	SDG 16, SDG 9, SDG 11
15	Dimovski et al. [172]	2024	GIS-Facilitated Procedure for Optimal Rural Electrification Planning: A Case Study in Naeder, Ethiopia	Infrastructure planning	SDG 16, SDG 7, SDG 1

Table 4. *Cont.*

No.	Authors	Publication Year	Title	Category	Sustainable Development Goal
16	Wang et al. [173]	2023	Mountainous Village Relocation Planning with 3D GIS Virtual Imaging Space Model and Neural Network	Territorial planning	SDG 16, SDG 11
17	Liu et al. [174]	2025	The Study of High-Performance Generation Methods for Rural Plan Based on Generative Adversarial Network	Territorial planning	SDG 16, SDG 11
18	Onitsuka et al. [175]	2018	Potential of 3D Visualization for Collaborative Rural Landscape Planning with Remote Participants	Territorial planning	SDG 16, SDG 11, SDG 15
19	Yang et al. [176]	2025	A Machine Learning Approach to Understanding the Road and Traffic Environments of Crashes Involving Driver Distraction and Inattention (DDI) on Rural Multilane Highways	Road safety	SDG 16, SDG 3, SDG 11
20	He et al. [177]	2023	An Interpretable Prediction Model of Illegal Running into the Opposite Lane on Curve Sections of Two-Lane Rural Roads from Drivers' Visual Perceptions	Road safety	SDG 16, SDG 3, SDG 11
21	Rovai et al. [178]	2016	A DSS Model for the Governance of Sustainable Rural Landscape: A First Application to the Cultural Landscape of Orcia Valley (Tuscany, Italy)	Decision support systems	SDG 16, SDG 11
22	Jin et al. [179]	2021	Analysis of the Policy Guarantee Mechanism of Rural Infrastructure Based on Deep Learning	Rural infrastructure	SDG 16, SDG 9

The selected studies explicitly address the relationship between emerging technologies and rural development in the abstract or main text.

The reduction from 799 identified records to 129 included studies reflects a multi-stage filtering process. Following the application of document type exclusion filters directly in Web of Science—removing review articles, conference papers, editorials, books, abstracts, clinical trials, and non-English publications—558 records were excluded, leaving 241 records for content-based screening. Of these, 96 were excluded following verification of three inclusion criteria: explicit application of emerging technologies, clear relevance to rural development, and alignment with at least one sustainability pillar. The remaining 145 records underwent eligibility assessment, resulting in the exclusion of 16 articles for the following reasons: 3 lacked any application of emerging technologies; 4 applied emerging technologies outside the defined study scope; and 9 were of a document type not relevant to the analysis. A total of 129 studies were retained for final inclusion, of which 16 were analyzed based on abstract only due to restricted full-text access, as indicated by italic formatting in Tables 1–4.

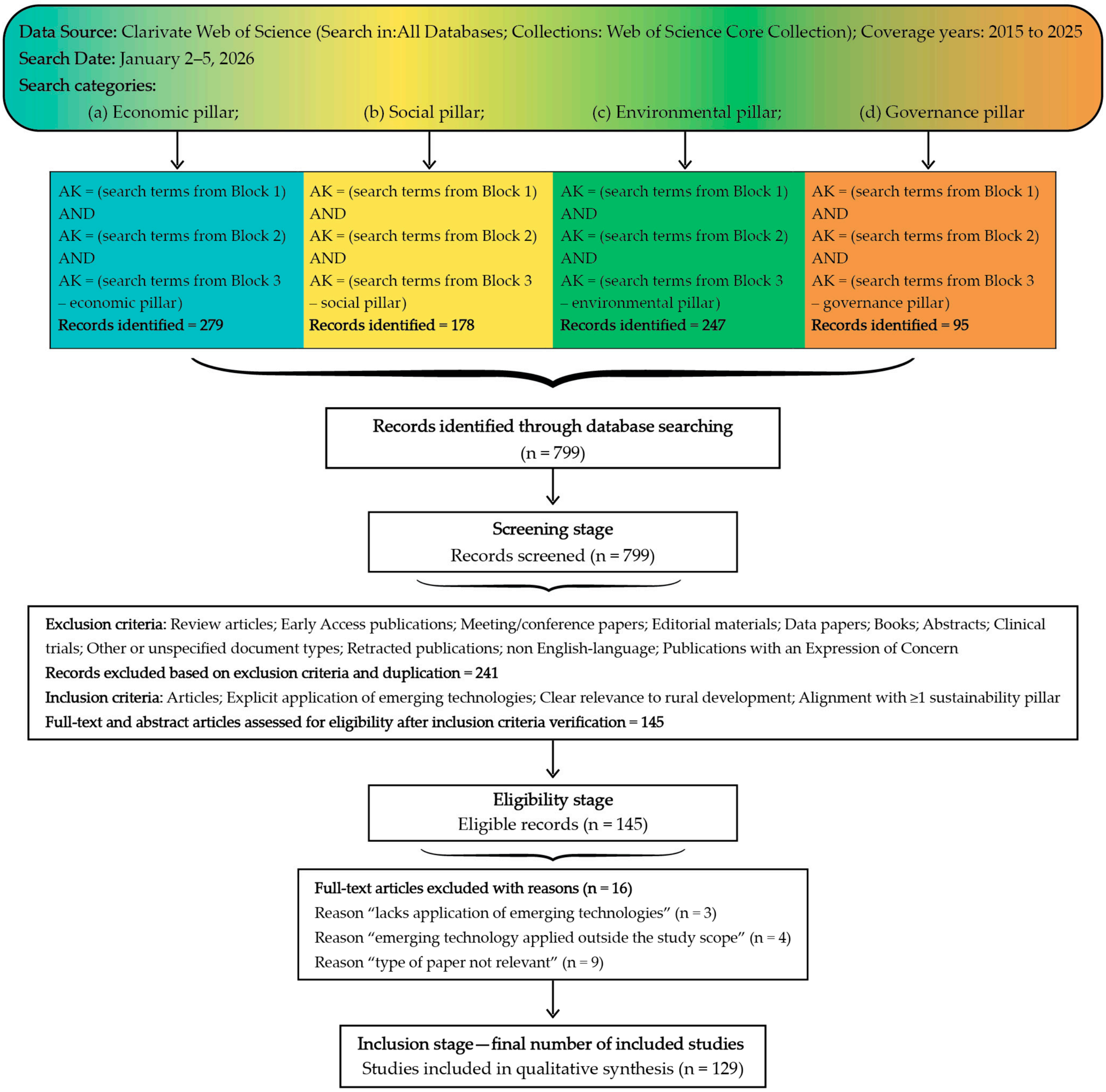

Figure 3. PRISMA flow diagram.

2.3. Data Extraction and Analysis

The full texts of the included studies were analyzed where available; for articles with restricted access, the analysis was based on the information provided in the abstract. A total of 129 academic papers were processed during January 2026.

For each article included in the final analysis, relevant information was extracted and recorded in systematic tables. The data extracted included: authors and year of publication, pillar-specific intervention category, and alignment with the SDGs.

The articles were classified according to the main pillar of sustainable rural development to which the analyzed technological application contributes (economic, social, environmental, or governance), based on the dominant objective of the study. In cases where a paper addressed more than one pillar, it was classified under the pillar considered central to its contribution.

Data analysis was performed using descriptive and comparative methods, with the aim of mapping the types of emerging technologies, their areas of application, and their distribution in relation to the four pillars of sustainable rural development. The results are presented in the form of tables and thematic analyses, organized by pillar, in order to highlight trends, recurring patterns, and gaps in the existing literature.

The classification of each study into a development pillar and the alignment with the SDGs followed a structured decision protocol applied consistently across all included studies. For studies available in full text, classification was based on a comprehensive reading of the objectives, theoretical framework, methodology, results, and discussion sections.

For studies accessible only through the abstract, classification was based on the explicit objectives, intervention domain, reported outcomes, and keywords as stated in the abstract. In both cases, pillar assignment was determined by the dominant objective of the study—defined as the primary rural development outcome explicitly targeted by the technological application. SDG alignment was determined based on the SDG dimensions explicitly addressed or clearly implied by the study's objectives and findings, as stated by the original authors, and should be interpreted as indicative rather than evaluative.

Potential trade-offs between SDG targets—for instance, AI-driven rural tourism may advance SDG 8 (Decent Work and Economic Growth) while simultaneously generating pressures relevant to SDG 13 (Climate Action) or SDG 10 (Reduced Inequalities)—were beyond the scope of the present scoping review. In cases of ambiguity, classification decisions were discussed among the research team until consensus was reached.

Generative artificial intelligence tools were used to assist specific stages of the research process. Claude Sonnet 4.5 (Anthropic PBC, San Francisco, CA, USA) was used for structuring and summarizing data from the included studies. ChatGPT-4o (OpenAI, San Francisco, CA, USA) was used for language improvement. SciSpace (https://scispace.com, accessed on 2 January 2026) was used for data extraction from the included documents. Bibliographic searches were conducted using the Clarivate Web of Science Core Collection (Clarivate Analytics, Philadelphia, PA, USA). Full texts not available through Web of Science were accessed via ResearchGate (ResearchGate GmbH, Berlin, Germany). All AI-generated outputs were carefully reviewed and edited by the authors, who assume full responsibility for the content of this publication.

3. Results

Following the selection process described (see Section 2), a total of 129 studies were included in the final analysis, distributed across the four pillars of sustainable rural development (see Figure 4): the economic pillar (n = 41), the environmental pillar (n = 36), the social pillar (n = 30), and the governance pillar (n = 22).

The analysis of the temporal distribution of publications reveals a significant upward trend in scientific interest in the application of emerging technologies in rural development. Between 2015 and 2019, the number of publications was relatively low, with values ranging from 0 to 4 articles per year for each pillar. From 2020 onwards, an accelerated increase was observed in the volume of research, reflecting the growing recognition of the potential of emerging technologies to address the specific challenges facing rural areas.

The period 2023–2025 witnessed a substantial intensification of research in all four dimensions. The economic pillar records the highest number of publications in 2024 (n = 11), the environmental pillar peaks at 12 publications in 2025, the social pillar peaks at 13 publications in 2025, and the governance pillar, albeit with a comparatively lower volume, also records the highest value in 2025 (n = 6).

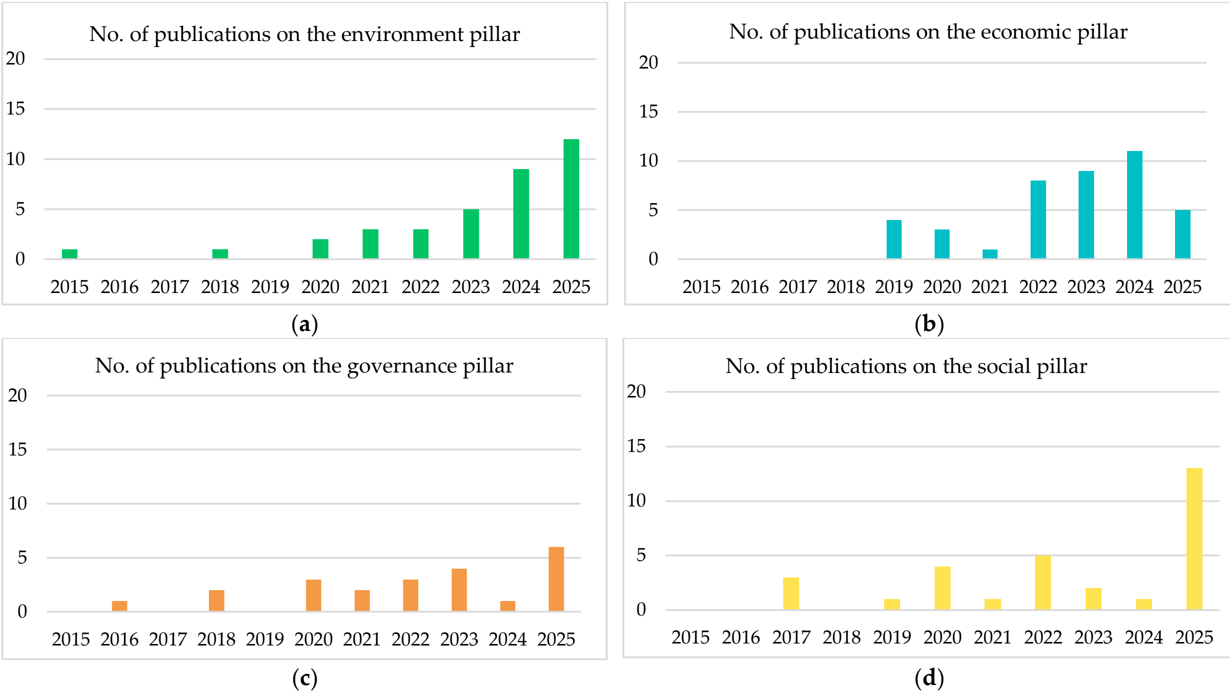

Figure 4. Temporal distribution of publications on emerging technologies in rural development (2015–2025): (**a**) Number of publications on the environment pillar; (**b**) Number of publications on the economic pillar; (**c**) Number of publications on the governance pillar; (**d**) Number of publications on the social pillar.

These findings confirm that emerging technologies have become an established field of research with cross-cutting applicability in all dimensions of sustainable rural development. The following sections present detailed results for each pillar, highlighting the types of emerging technologies identified, their thematic categories, and their contributions to rural development.

3.1. The Economic Pillar

Through the analysis of the literature, 41 studies were identified (see Table 1) that propose models, predictive systems, or applications of emerging technologies with an impact on the economic dimension of rural development. Studies were assigned to this pillar based on their contribution to productivity and income growth, innovations in economic services, as well as connectivity and energy infrastructure. The studies were grouped into nine thematic categories, reflecting the breadth of domains in which emerging technologies contribute to rural economic development.

Rural tourism constitutes the category with the highest representation within the economic pillar, concentrating nine studies that demonstrate how artificial intelligence (AI) and Big Data can transform rural areas into competitive tourism destinations. Natural language processing (NLP) techniques applied to large volumes of online reviews enable the systematic analysis of tourist perceptions and satisfaction [79,80,86], providing rural communities and local administrators with actionable intelligence for improving visitor experience and landscape management—a dimension directly linked to SDG 8 (Decent Work and Economic Growth) and SDG 11 (Sustainable Cities and Communities). Intelligent marketing and spatial planning systems further support the optimization of tourism resource distribution and destination promotion [83–85], while studies addressing the convergence of cultural tourism with rural revitalization [81,87–89] highlight the potential of emerging technologies to preserve cultural identity while generating economic opportunities, consistent with endogenous development perspectives that emphasize local assets as drivers of rural growth.

Nine studies address precision agriculture as a primary vector for increasing productivity and reducing economic losses in rural smallholder systems. Automated crop disease detection through computer vision and Deep Learning [52–54] enables early intervention that reduces yield losses—a critical contribution to food security and farmer income in contexts where agricultural losses can have severe livelihood consequences. Internet of Things (IoT)-based soil and environmental monitoring platforms [51,57–59] support data-driven irrigation and resource management decisions, with particular relevance for smallholder farmers in Sub-Saharan Africa and South Asia who lack access to traditional agricultural advisory services. Remote sensing and Unmanned Aerial Vehicle (UAV)-based approaches [55,56] extend these capabilities to village-scale agro-economic assessment, supporting SDG 2 (Zero Hunger) and SDG 9 (Industry, Innovation and Infrastructure).

Energy access and rural transport represent a third significant domain, directly addressing one of the most persistent barriers to rural economic development. Studies on solar energy potential assessment [61], microgrid optimization [63], and peer-to-peer energy exchange networks [64] collectively demonstrate how emerging technologies can support community-level energy independence—a prerequisite for productive economic activity in off-grid rural areas. Blockchain-based waste-to-energy systems [66] and AI-optimized electric transport [65] extend these contributions toward circular economy models, while energy loss detection systems [60] and infrastructure impact analyses [62] improve the efficiency and planning of existing rural energy networks, contributing to SDG 7 (Affordable and Clean Energy).

Rural digital and financial infrastructure emerges as a cross-cutting enabler across all economic categories. Connectivity solutions—including Low-Power Wide-Area Network (LPWAN) protocols [68,69], UAV-based network architectures [67], and Edge Computing platforms with Federated Learning [70,71]—address the fundamental digital divide that constrains rural economic participation. In the financial domain, blockchain and Machine Learning (ML) applications demonstrate measurable contributions to rural financial inclusion [75–78], reducing information asymmetries and improving access to credit and market intelligence for rural producers. Supply chain applications [72,73] address power imbalances between rural producers and intermediaries through blockchain-enabled transparency, while digital employment services [74] broaden economic opportunity for rural populations through data-driven job matching.

Land management and natural resource applications complete the economic pillar. The integration of Deep Learning with clustering algorithms supports rural land suitability assessment for multi-industry development [90], providing decision support for local administrators. Drone-based photogrammetry enables the quantification of economic benefits derived from agricultural water management infrastructure [91], demonstrating the potential of precision monitoring to inform resource allocation decisions at the village level.

Collectively, the 41 studies in the economic pillar suggest that emerging technologies are reshaping rural economic development across nine distinct domains—from precision agriculture and rural tourism to energy access, financial inclusion, and digital connectivity—contributing directly to SDG 2 (Zero Hunger), SDG 7 (Affordable and Clean Energy), SDG 8 (Decent Work and Economic Growth), SDG 9 (Industry, Innovation and Infrastructure), SDG 10 (Reduced Inequalities), SDG 11 (Sustainable Cities and Communities), SDG 12 (Responsible Consumption and Production), and SDG 14 (Life Below Water).

3.2. The Social Pillar

The literature analysis identified 30 studies (see Table 2) that propose models, systems, or applications of emerging technologies with an impact on the social dimension of rural development. Inclusion in this pillar was based on the contribution to improving access to health and education services, protecting vulnerable groups, and preserving cultural heritage. The studies were grouped into ten thematic categories, reflecting the diversity of areas in which emerging technologies contribute to the well-being of rural communities.

Rural health concentrates the largest share of studies within the social pillar, proposing telemedicine and remote monitoring solutions for communities with limited or no access to specialized medical services. IoT-based vital sign monitoring systems [107,112,118] enable continuous patient surveillance in areas where hospital infrastructure is absent, reducing the burden of travel for vulnerable populations. Chronic disease screening—particularly for cardiovascular conditions and diabetic retinopathy—is addressed through Deep Learning and ML applications deployed in the Philippines, Australia, and Mayan communities in the Yucatan Peninsula [109,110,115], demonstrating that AI-powered diagnostic tools can substantially reduce geographic disparities in access to specialist care. Telemedicine platforms integrating IoT with blockchain [116], cloud-based consultation systems [114], and satellite-enabled dental care for elderly populations in rural Chile [108] extend the reach of health services to communities previously excluded from formal healthcare networks. Diabetes prevention programs using conversational AI and Reinforcement Learning [113,117] demonstrate the potential of mobile health interventions to address chronic disease burden in rural populations with limited healthcare literacy. Drone-based drug delivery systems [111] further extend the technological toolkit for last-mile healthcare access, contributing to SDG 3 (Good Health and Well-being) and SDG 10 (Reduced Inequalities).

Maternal health proposes AI-driven solutions for prenatal care in resource-constrained settings. Low-cost wireless ultrasound devices with embedded AI software enable gestational age assessment in rural Kenya, improving prenatal consultation attendance [104]. AI algorithms requiring minimal clinical inputs enable gestational diabetes diagnosis without laboratory infrastructure [105], while cloud-based AI frameworks address geographic disparities in congenital heart disease screening in rural Nebraska [106]. These studies collectively demonstrate that emerging technologies can meaningfully reduce maternal health inequities in both low- and high-income rural contexts.

Rural education applies Big Data and AI to address the persistent gap in access to quality educational resources. Predictive analytics integrated into online learning frameworks [95] personalize learning pathways for students in geographically isolated areas, while voice assistant technologies deployed in underfunded primary schools in rural India [96] broaden access to interactive educational content. Deep Learning models for educational resource allocation [97] support more equitable distribution of learning opportunities across rural school networks, contributing to SDG 4 (Quality Education) and SDG 10.

Community safety leverages UAV, GIS, and ML technologies to protect rural populations from road accidents and natural hazards. UAV-based real-time warning systems reduce road accident risk [103], while GIS-integrated Reinforcement Learning supports search and rescue operations in complex mountain village terrain [119]. Predictive traffic accident models applied to rural roads in Ecuador [121] further demonstrate the potential of data-driven approaches to reduce rural safety disparities, contributing to SDG 3 and SDG 11 (Sustainable Cities and Communities).

Education and entrepreneurship are addressed through AI-driven predictive models that analyze entrepreneurial intentions among rural students [93] and IoT-based experiential learning kits that develop technological competencies in rural communities [94].

Cultural heritage benefits from Deep Learning applications for the automatic identification of historic villages from satellite imagery [98] and Big Data systems for the digital preservation of traditional cultural resources [99], supporting SDG 4 and SDG 11. Social protection integrates ML for the early detection of child victimization risk in rural migrant families [100] and Big Data algorithms to improve the targeting accuracy of poverty alleviation programs [101], contributing to SDG 1 (No Poverty), SDG 3, and SDG 16 (Peace, Justice and Strong Institutions).

Complementary categories include social welfare, where Deep Learning models improve the targeting of social policies by estimating household welfare from multimodal data [92]; community revitalization, where the blockchain-based Refurbish to Host in Akiyas (RE-HAK) framework addresses rural depopulation in Japan through smart contract-enabled property renovation [102]; and rural infrastructure, where the GiSele framework integrates supervised ML and meta-heuristic algorithms to plan energy access for 1292 communities in Mozambique [120], contributing directly to SDG 1, SDG 7 (Affordable and Clean Energy), and SDG 10.

Collectively, the 30 studies in the social pillar suggest that emerging technologies are making measurable contributions to reducing rural inequalities in access to healthcare, education, social protection, and community services, contributing to SDG 1, SDG 3, SDG 4, SDG 5 (Gender Equality), SDG 7, SDG 10, SDG 11, SDG 13 (Climate Action), and SDG 16.

3.3. The Environmental Pillar

Through the analysis of the literature, 36 studies were identified (see Table 3) that propose models, systems, or applications of emerging technologies with an impact on the environmental dimension of rural development. Inclusion in this pillar was based on the contribution to ecosystem monitoring, natural resource conservation, climate change adaptation, and disaster risk reduction.

The studies were grouped into eight thematic categories, reflecting the diversity of areas in which emerging technologies contribute to the protection of the rural environment.

Water management integrates IoT and ML technologies to monitor and conserve water resources in rural communities—a critical dimension of sustainable rural development given that access to clean water remains one of the most persistent challenges in low-income rural areas, directly linked to SDG 6 (Clean Water and Sanitation). Low-cost IoT monitoring systems deployed in Romania [138], Sub-Saharan Africa [135], and Ethiopia [136] demonstrate that affordable sensor networks can support real-time water quality surveillance and proactive infrastructure maintenance in contexts where centralized water management systems are absent. Integrated GIS-based sustainability frameworks [133] and multi-layer IoT architectures [134] extend water governance capabilities to rural administrations with limited technical capacity, while ML-based consumption prediction models [137] support evidence-based water resource planning. UAV-based hyperspectral monitoring [139] and artificial neural network sustainability indices [140] further advance the precision of water quality assessment in rural river systems, contributing to SDG 6, SDG 3 (Good Health and Well-being), SDG 13 (Climate Action), and SDG 15 (Life on Land).

Risk and disaster management applies ML and remote sensing to predict and mitigate natural hazards that disproportionately affect rural communities with limited emergency response capacity. Flood mapping and prediction systems integrating Synthetic Aperture Radar (SAR) data with fuzzy logic [148], ML-based streamflow models [150], and UAV-derived river datasets [149] provide rural infrastructure planners and emergency managers with decision-support tools for flood preparedness. Geological hazard prediction models for landslide risk in Sichuan [151] and Kashmir [152] address the vulnerability of mountain rural communities to terrain instability. Nature-based solutions are supported by GIS-based suitability analyses identifying areas appropriate for wetland restoration and agroforestry in North Carolina [153], while portable Light Detection and Ranging and UAV systems enable high-resolution monitoring of conservation interventions in remote locations [154]. Community-based disaster preparedness is addressed through hybrid ML and Participatory Rural Appraisal (PRA) approaches in the Philippines [147], contributing to SDG 13, SDG 15, SDG 9 (Industry, Innovation and Infrastructure), and SDG 11 (Sustainable Cities and Communities).

Landscape conservation uses UAV, Deep Learning, and ML to document and protect rural landscape heritage—a dimension of sustainable development with direct implications for cultural identity, tourism potential, and territorial planning. UAV photogrammetry combined with clustering algorithms enables the assessment of agricultural terraces and traditional village structures [126–128], revealing high rates of physical degradation that threaten both heritage and productive land. ML-based classification systems analyze traditional village character at high accuracy [130], while landscape perception evaluation models [131,132] connect environmental quality indicators with residents' well-being—linking physical landscape to social outcomes. These studies collectively contribute to SDG 11 and SDG 15.

Territorial monitoring applies Deep Learning and remote sensing to analyze rural land use dynamics, providing the informational foundation for evidence-based rural planning. Semantic segmentation architectures specifically designed for rural land use [141–143] improve the precision of land cover mapping, while UAV-based classification studies [144] provide village-scale land use inventories. GIS-based land consolidation algorithms [145] and automated landscape feature identification systems [146] support rural land administration processes, contributing to SDG 2 (Zero Hunger), SDG 11, and SDG 15.

Environmental quality monitoring integrates sensors and ML to detect ecosystem degradation in rural areas. Multispectral sensor-based erosion mapping in South Africa [123] supports soil conservation policy, while thermal fusion methods combining Landsat and Sentinel satellite data [124] enable heat island monitoring at enhanced spatial resolution. A spatially explicit risk assessment of heavy metal soil contamination in Baoding, China [125] reveals that rural residents face threefold higher individual health risks than urban residents—a finding with direct implications for environmental justice and SDG 3, SDG 15.

Complementary categories include sustainable tourism, where AI-based systems support low-carbon rural tourism planning [156] and NLP analysis of tourist sentiment identifies environmental elements that generate positive visitor experiences in traditional villages [157], contributing to SDG 11, SDG 12 (Responsible Consumption and Production), and SDG 13. Biodiversity conservation benefits from Deep Learning applied to multi-temporal satellite data for the automatic detection of trees in Italian agroforestry landscapes [122], supporting emissions reporting and SDG 15. Climate change adaptation is addressed through an AI chatbot deployed among female farmers in rural Zimbabwe [155], providing personalized agricultural recommendations and contributing to SDG 2 and SDG 13.

Collectively, the 36 studies in the environmental pillar suggest that emerging technologies are transforming rural ecosystem monitoring, disaster risk management, landscape conservation, and climate change adaptation, contributing to SDG 2, SDG 3, SDG 6, SDG 9, SDG 11, SDG 12, SDG 13, and SDG 15.

3.4. The Governance Pillar

Through literature analysis, 22 studies were identified (see Table 4) that propose models, systems, or applications of emerging technologies with an impact on the governance dimension of rural development. Inclusion in this pillar was based on the contribution to administrative transparency, citizen participation, spatial planning, and the efficiency of public services. The studies were grouped into eleven thematic categories, reflecting the diversity of areas in which emerging technologies contribute to the modernization of rural governance.

Land administration integrates emerging technologies to modernize cadastral systems and streamline rural property transactions—a foundational dimension of rural governance that directly affects land tenure security, investment incentives, and the reduction in rural disputes. UAV oblique photogrammetry combined with AI and ML-driven data analysis enables the creation of accurate Three-Dimensional (3D) property registration models, reducing boundary disputes in rural villages [158]. Blockchain-based frameworks address the transparency and efficiency of rural property rights transactions in China [159], while automated GIS algorithms streamline cadastral data processing for land consolidation in Poland, reducing administrative processing time and eliminating manual errors [160]. These applications collectively contribute to SDG 16 (Peace, Justice and Strong Institutions), SDG 8 (Decent Work and Economic Growth), and SDG 15 (Life on Land).

E-governance explores the potential of distributed and digital technologies for rural public administration. Blockchain applications demonstrate measurable reductions in administrative costs for self-organized rural communities in Ukraine [161], while GeoDesign and geoportal assessments reveal significant disparities in the digital governance capacity of rural municipalities in Poland—with only 20% demonstrating high transformation potential [162]. A theoretical framework combining blockchain with Decentralized Autonomous Organizations (DAO) proposes a distributed governance model for marginalized rural areas, addressing information asymmetries and enabling decentralized community decision-making without central authority [163], contributing to SDG 16 and SDG 10 (Reduced Inequalities).

Territorial monitoring applies remote sensing and ML to analyze rural dynamics and support evidence-based public policy. Multi-source models integrating remote sensing data, nighttime light imagery, and Long Short-Term Memory (LSTM) networks enable the identification of depopulating hollow villages in rapidly urbanizing regions [168]. Random Forest classifiers reveal long-term patterns of urban expansion and agricultural land loss in Vietnam [169], while Deep Learning methods applied to high-resolution satellite imagery support rural-urban transition monitoring for spatial planning purposes [170]. These tools contribute to SDG 16, SDG 11, and SDG 15.

Territorial planning applies AI and 3D visualization technologies to support evidence-based rural spatial planning decisions. Digital survey methods combining 3D GIS, UAV photography, and neural networks for building recognition support mountain village relocation planning [173]. Generative Adversarial Networks (GAN) enable the automatic generation of village layout structures that preserve traditional spatial characteristics [174], while 3D visualization tools derived from drone imagery facilitate collaborative landscape planning with remote participants—including diaspora communities—thereby broadening participatory governance beyond geographic constraints [175], contributing to SDG 16 and SDG 11.

Infrastructure planning leverages Big Data and ML to support investment decisions in contexts where traditional data sources are scarce. Mobile phone Call Detail Records (CDR) enable the derivation of rural mobility models for road network design in Senegal, providing connectivity planning tools for countries with limited survey infrastructure [171]. GIS-based electrification planning tools applying Random Forest algorithms support cost-effective rural energy access strategies in Ethiopia, with direct application to approximately

11,560 households [172], contributing to SDG 16, SDG 1 (No Poverty), SDG 7 (Affordable and Clean Energy), SDG 9, and SDG 11.

Rural finance integrates ML for the evaluation and supervision of rural financial systems. Improved neural network architectures assess rural financial ecological environments [164], while Bidirectional Long Short-Term Memory—Convolutional Neural Network (BLSTM-CNN) models enable customer churn prediction for rural banks with high accuracy [165], supporting the financial resilience of rural communities and contributing to SDG 16 and SDG 8.

Road safety applies ML to improve transport infrastructure governance in rural areas. ML-based analyses of driver distraction factors on rural multilane highways [176] and interpretable prediction models for illegal overtaking behavior on two-lane rural roads [177] provide transparent, evidence-based tools for rural road safety policy, contributing to SDG 16, SDG 3, and SDG 11.

Complementary categories include energy governance, where blockchain, DAO, and smart contracts support sustainable energy management in the municipality of Pałecznica, Poland, targeting reductions of 15–20% in energy consumption and CO_2 emissions [166]; data infrastructure, where IoT and Big Data underpin a Spatial Data Infrastructure (SDI) model for rural geospatial data management in Turkey [167]; decision support systems, where GIS and neural networks support sustainable land use forecasting [178]; and rural infrastructure policy, where Deep Learning approaches analyze policy guarantee mechanisms for rural infrastructure investment in China [179].

Collectively, the 22 studies in the governance pillar suggest that emerging technologies are modernizing rural administration across land administration, e-governance, territorial planning, infrastructure investment, financial supervision, and road safety, contributing to SDG 1, SDG 3, SDG 7, SDG 8, SDG 9, SDG 10, SDG 11, SDG 15, and SDG 16.

4. Discussion

4.1. Distribution and Trends in the Literature on Emerging Technologies in Rural Development

Analysis of the 129 studies included in the review reveals an uneven distribution of literature across the four pillars of sustainable rural development: the economic pillar concentrates the highest number of publications (n = 41, representing 31.8% of the total), followed by the environmental pillar (n = 36, 27.9%), the social pillar (n = 30, 23.3%) and the governance pillar (n = 22, 17.0%). This distribution reflects current research priorities, with a strong focus on applications with direct economic potential (precision agriculture, rural tourism, energy) and environmental monitoring, while the social and governance dimensions remain relatively underrepresented.

The analysis of the technologies used reveals both cross-cutting convergences and specializations per pillar. ML and Deep Learning are the technologies with the widest applicability, appearing across all four pillars: crop disease detection and sentiment analysis in tourism (economic), risk prediction and territorial monitoring (environment), medical screening and social protection (social), cadastral monitoring and territorial planning (governance). IoT and sensors dominate real-time monitoring applications, particularly in agriculture (economic pillar) and water management (environmental pillar), but also in telemedicine (social pillar). Blockchain and distributed technologies are concentrated in the economic (financial services, supply chains) and governance (land administration, e-government) pillars, addressing issues of transparency and trust. UAVs and remote sensing appear across multiple pillars in precision agriculture, ecosystem monitoring, landscape conservation, and spatial planning.

At the thematic category level, the economic pillar shows the highest concentration in rural tourism and precision agriculture, which together account for approximately half of the studies within this pillar. The environmental pillar is dominated by water management (n = 8) and risk and disaster management (n = 8), reflecting the urgency of adapting to climate change. The social pillar concentrates most of its studies on rural health (n = 12, representing 40% of the pillar), highlighting the priority of access to medical services in isolated communities. The governance pillar is more fragmented, with eleven distinct categories, none exceeding three studies, suggesting a field still in its exploratory phase, lacking consolidated research directions.

The alignment of studies with the SDGs confirms the relevance of research to the global sustainability agenda. SDG 3 (Good Health and Well-being) and SDG 11 (Sustainable Cities and Communities) are most frequently addressed in the social and governance pillars. SDG 7 (Affordable and Clean Energy) and SDG 8 (Decent Work and Economic Growth) predominate in the economic pillar. SDG 13 (Climate Action), SDG 15 (Life on Land), and SDG 6 (Clean Water) characterize the environmental pillar. This distribution demonstrates the potential of emerging technologies to contribute simultaneously to multiple Sustainable Development Goals in rural contexts.

To address the varying degrees to which the reviewed studies engage with social, institutional, and political-economic dimensions, we propose a systematic classification framework based on four levels of social integration, applied to all 129 included studies (Table 5).

The systematic classification of the 129 included studies across four levels of social integration reveals a pronounced concentration at the technical end of the analytical spectrum. Level 1 (technical validation) accounts for 52 studies (40.3%), confirming that a substantial portion of the literature prioritizes demonstrating technological functionality over examining broader social implications. Level 2 (social outcomes) comprises 37 studies (28.7%), while Level 3 (institutional integration) includes 34 studies (26.4%), indicating that approximately half of the corpus engages with social and institutional dimensions to varying degrees. However, only 6 studies (4.7%) reach Level 4, offering a political-economic analysis of power relations, equity implications, or distributional effects of emerging technologies in rural contexts. It should be noted that 16 of the 129 included studies (12.4%) were classified based on title, abstract, and keywords only, due to restricted full-text access. While these sources typically convey the primary objective and main findings in sufficient detail to support level assignment, findings derived from them should be interpreted with appropriate caution.

Analysis by development pillar reveals distinct disciplinary patterns. The Economic pillar exhibits the highest concentration at Level 1 (23 of 41 studies, 56.1%), reflecting a tradition of precision agriculture and rural tourism research oriented toward technical performance metrics. The Social pillar shows the most advanced social integration profile, with equal representation at Level 2 and Level 3—13 studies each (43.3%)—particularly in rural health, education, and social protection domains, where technology is embedded within service delivery systems. The Governance pillar is dominated by Level 3 studies (13 of 22, 59.1%), consistent with its focus on spatial planning, land administration, and infrastructure policy, where institutional context is inherent to the research design. The Environmental pillar follows a bimodal pattern: 20 studies (55.6%) remain at Level 1, focused on remote sensing and landscape mapping, while 9 studies (25.0%) reach Level 2 and 6 studies (16.7%) achieve Level 3 integration through frameworks for water governance, disaster risk reduction, and nature-based solutions.

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Table 5. Classification of the 129 included studies by degree of social integration across development pillars.

Level of Social Integration	Economic Pillar	Social Pillar	Environmental Pillar	Governance Pillar
Level 1 Technical Validation	Xi Ma [51]; Noor et al. [52]; Alatawi et al. [53]; Barman et al. [54]; Mujumdar et al. [55]; Chen et al. [56]; López Rivero et al. [57]; Taşkin et al. [59]; Vieira et al. [60]; Li et al. [61]; Lin et al. [63]; Galán-Jiménez et al. [67]; Bartolín-Arnau et al. [68]; Yascaribay et al. [69]; Perumal et al. [71]; Chen et al. [78]; Yuan [80]; Yang et al. [83]; Wang [84]; Chen et al. [85]; Qiu et al. [86]; Liu et al. [89]; Huang et al. [90].	Ali et al. [107]; Garbhapu et al. [118]; Bouchrit et al. [103]; Tao et al. [98].	Sarti et al. [122]; Sepuru et al. [123]; Bahi et al. [124]; Karahan et al. [126]; Zheng et al. [127]; Zhu et al. [128]; Liu et al. [129] *; Zhang et al. [130]; Liu et al. [134]; Tashman et al. [136]; Cao et al. [137]; Wang et al. [139]; Zhao et al. [141]; Yan et al. [142]; Deng et al. [143]; Li et al. [144]; Sun et al. [146]; Li et al. [148]; Tang et al. [149]; Zhang et al. [151].	Ha et al. [169]; Yao [170]; Liu et al. [174]; Yang et al. [176]; He et al. [177].
Level 2 Social Outcomes	Oliveira-Jr et al. [58]; Li et al. [62]; Lu et al. [64]; Pitakaso et al. [65]; Patros et al. [70]; Huang [75]; Shao [76]; Chen [77]; Shen et al. [79]; Liu [81]; Zhao et al. [82]; Wang et al. [87]; Li [88]; Gupta et al. [91].	Rutherford et al. [94]; Wei [95]; Darda et al. [96]; Gang et al. [99]; Koech et al. [104]; Shen et al. [105]; Tolentino et al. [109]; Drinkwater et al. [110]; Kim et al. [111]; Wroblewski et al. [115]; Du et al. [119]; Moreno-Ponce et al. [121]; Kang [93].	Gong et al. [131]; Shanghao et al. [132]; Bogdan et al. [138]; Macharia et al. [150]; Fayaz et al. [152]; Hill et al. [154]; Jiang et al. [156]; Chen et al. [157]; Makudza et al. [155].	Hou et al. [165].
Level 3 Institutional Integration	Zhang [66]; Liu [74].	Sharma et al. [92]; Zhao [97]; Cao et al. [100]; Bingxu [101]; Herrador et al. [102]; Li et al. [106]; Beltrán et al. [108]; Chadwick et al. [113]; Miah et al. [114]; Kerrison et al. [116]; Auster-Gussman et al. [117]; Caminiti et al. [120]; Bhuiyan et al. [112].	Wescoat et al. [133]; Ingram et al. [135]; Raghavendra Kumar et al. [140]; Maciąg et al. [145]; Onsay et al. [147]; Baldwin et al. [153].	Ye et al. [158]; Leń et al. [160]; Semenets et al. [161]; Wójcik et al. [162]; Wei et al. [164]; Iban et al. [167]; Zhao et al. [168]; Wang et al. [171]; Dimovski et al. [172]; Wang et al. [173]; Onitsuka et al. [175]; Rovai et al. [178]; Jin et al. [179].
Level 4 Political-Economic Analysis	Enayati et al. [72]; Prause et al. [73].	—	Luo et al. [125].	Hua et al. [159]; Merrell [163]; Buchwald et al. [166].

* *Retracted on 19 January 2026, after the completion of the literature search (2–5 January 2026); excluded from the analytical discussion.*

Notably, no social pillar study reaches Level 4, and only one Environmental study explicitly addresses distributional inequities—urban–rural disparities in soil contamination health risks [125]. This gap suggests that while emerging technologies are increasingly deployed in rural contexts with social and environmental objectives, the field has not yet developed robust analytical frameworks for examining who controls these technologies, who bears their costs, and who captures their benefits. Future research should move beyond demonstrating that technologies work and toward interrogating the structural conditions that determine for whom they work.

4.2. Gaps Identified in the Literature

Mapping the literature on the four pillars of sustainable rural development enables the identification of areas that have been insufficiently addressed in relation to the scope of each dimension. Table 6 summarizes thematic categories covered by the the analyzed studies and the gaps identified for each pillar.

In the economic pillar, the literature focuses predominantly on rural tourism and precision agriculture, which together account for more than half of the studies. Although these areas are essential to the rural economy, sustainable economic development also would benefit from the diversification of non-agricultural activities, support for traditional crafts, and facilitating small producers' access to digital markets—aspects that are insufficiently addressed in the analyzed corpus.

The environmental pillar provides solid coverage of water management and natural risks, but areas critical to ecological sustainability remain marginally addressed. Biodiversity and climate change adaptation, although central to the resilience of rural ecosystems, are underrepresented. The rural circular economy, carbon sequestration, and air quality are research areas that require greater attention in the context of the ecological transition.

In the social pillar, the concentration of 40% of studies on rural health reflects the technological maturity of telemedicine, but overlooks pressing social challenges. The aging rural population, youth depopulation and outmigration, social isolation, and mental health represent major challenges for contemporary rural communities. These issues do not yet benefit from dedicated technological solutions in the reviewed literature.

The governance pillar, the least represented in the corpus, highlights an emerging interest in digital land administration and smart territorial planning. However, the participatory dimension of governance—participatory budgeting, transparency of public data, citizen involvement in decision-making—remains largely unexplored. Access to justice in rural areas and the digitalization of local administrative services are priorities for future research.

The cross-pillar analysis reveals structural imbalances that reflect the current orientation of research in emerging technologies for rural development. The dominance of the economic pillar (n = 41, 31.8%)—concentrated in precision agriculture and rural tourism—and the underrepresentation of the governance pillar (n = 22, 17.1%) suggest that research priorities are shaped primarily by domains where technological performance can be measured against clear, short-term metrics. This pattern is further reinforced by the social integration analysis (Table 5), which shows that 54.8% of economic pillar studies remain at Level 1 (technical validation), while the governance pillar is dominated by Level 3 studies (59.1%), indicating that governance research, though less numerous, tends to engage more deeply with institutional dimensions. The underrepresentation of biodiversity monitoring (n = 1), climate change adaptation (n = 1), elderly care, and rural circular economy across pillars suggests that research gaps cluster precisely around challenges that are difficult to quantify, require longer time horizons, or demand interdisciplinary approaches that transcend individual technological applications.

Table 6. Summary of areas covered and gaps identified in the pillars of sustainable rural development.

Pillar	Areas Covered	Identified Gaps
Economic	• Rural tourism: sentiment analysis, marketing systems, tourism planning • Precision agriculture: disease detection, soil monitoring, UAV remote sensing • Energy and transportation: photovoltaic microgrids, waste-to-energy, transportation • Connectivity infrastructure: LPWAN, 5G, edge computing, federated learning • Financial services: blockchain, fintech, risk management • Supply chains: blockchain traceability, market access • Other categories: land classification, pond monitoring, employment services	• Non-agricultural rural industries and traditional crafts • Rural entrepreneurship and business incubators • Collaborative economy and rural sharing platforms • E-commerce for local agricultural producers • Economic diversification of mono-industrial communities • Market access for small producers (excluding fisheries)
Social	• Rural health: telemedicine, IoT monitoring, AI screening • Maternal health: prenatal diagnosis, wireless AI ultrasound • Rural education: online platforms, voice assistants, resource allocation • Community safety: traffic alerts, search and rescue, accident prediction • Education and entrepreneurship: intent prediction, technological literacy • Cultural heritage: identification of historic villages, digital preservation • Social protection (n = 2): child victimization detection, poverty reduction • Other categories: social welfare, community revitalization, electrification	• Aging population and virtual services for the elderly • Addressing social isolation and loneliness in rural communities • Inclusion of people with disabilities • Rural depopulation and youth retention • Community cohesion and strengthening social capital • Gender equality and women's empowerment (outside of maternal health) • Mental health in rural communities
Environment	• Water management: IoT monitoring, consumption prediction, water quality • Risks and disasters: floods, landslides, early warning systems • Landscape conservation: agricultural terraces, traditional villages, visual comfort • Territorial monitoring: land use, semantic segmentation • Environmental quality: erosion, surface temperature, heavy metals • Sustainable tourism: low carbon emissions, sentiment analysis • Biodiversity: agroforestry tree detection • Climate change: farmer adaptation chatbot	• Rural circular economy (waste management, recycling, industrial symbiosis) • Biodiversity monitoring and conservation (limited coverage, n = 1) • Adaptation to climate change (limited coverage, n = 1) • Carbon sequestration in agricultural soils • Air quality in rural areas • Sustainable forest management and combating deforestation

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Table 6. *Cont.*

Pillar	Areas Covered	Identified Gaps
Governance	• Land administration: 3D UAV cadastre, blockchain-based property rights management, QGIS consolidation • E-government: blockchain cost reduction, GeoDesign geoportals, DAO • Territorial monitoring: LSTM-based identification of depopulated villages, Random Forest land use changes • Territorial planning: village relocation Mask R-CNN, Conditional Generative Adversarial Networks (CGAN) generation, 3D visualization • Infrastructure planning: road networks, VANIA electrification • Rural finance: financial ecosystem assessment, customer churn prediction using BLSTM-CNN • Road safety: accident factor analysis, behavior prediction • Other categories: DAO energy governance, SDI data infrastructure, Decision Support System, policies	• Virtual civic participation and participatory budgeting • Budget transparency and open government data • Integrated public services, without physical presence (certificates, authorizations, civil documents) • Access to justice and virtual mediation in rural areas • AI-assisted local public officials • Inter-municipal cooperation and multi-level governance • Real-time monitoring and evaluation of public policies

4.3. Limitations of the Study

Interpreting the results of this scoping review requires consideration of several methodological limitations. The study used exclusively the Web of Science Core Collection database, which, while recognized for its high academic quality standards [180], may not capture all relevant literature; extending searches to complementary databases such as Scopus or gray literature could identify additional relevant studies. Including only English-language publications may lead to an underrepresentation of research from regions with a tradition of publishing in national languages. The 2015–2025 time frame, while appropriate for the recent nature of emerging technologies, does not capture earlier pioneering contributions. The classification of each study into a single predominant pillar, necessary for structuring the analysis, may simplify the interdisciplinary nature of some research.

A total of 16 out of 129 included studies (12.4%) were analyzed based on abstract only, due to restricted full-text access; these studies are transparently identified through italic formatting in Tables 1–4, and findings derived from them should be interpreted with appropriate caution.

In accordance with the methodological specificity of the scoping review, the study did not evaluate the methodological quality of the included papers and did not perform a quantitative synthesis of the results.

Additionally, the included studies span highly diverse rural contexts—ranging from digitally connected regions in East Asia and Europe to infrastructure-constrained communities in Sub-Saharan Africa and South Asia—yet most do not discuss the conditions required for replicating or transferring their findings to other settings, and the present review does not perform systematic cross-study comparisons regarding technology effectiveness across rural conditions. Both aspects limit the extent to which conclusions can be generalized and represent priority directions for future systematic reviews building on this mapping exercise.

4.4. Guiding Framework for Research and Public Policy Intervention

Based on the gaps identified in the previous section, this study proposes a guiding framework for intervention designed to orient future research, innovation, and public policy initiatives in the field of emerging technologies applied to sustainable rural development.

Within the economic dimension, future research could explore platforms based on emerging technologies for marketing local products and facilitating small producers' access to markets, artificial intelligence and augmented reality solutions for revitalizing traditional crafts and rural creative industries, collaborative economy models supported by smart platforms tailored to low-density communities, as well as ML-based systems for matching supply and demand with a view to occupational diversification. Technologies such as e-commerce platforms with blockchain traceability, augmented reality for promoting craft heritage, or artificial intelligence algorithms for analyzing the rural labor market show potential for advancing these directions.

Research priorities within the environmental dimension include IoT and Deep Learning systems for monitoring and conserving biodiversity at the community level, integrated platforms based on artificial intelligence for modeling climate change adaptation scenarios in rural agriculture, IoT and blockchain architectures for implementing the circular economy in agricultural and household waste management, as well as advanced sensors for monitoring carbon sequestration in agricultural soils. Deep learning applied to satellite images for biodiversity mapping, predictive AI models for local climate scenarios, and sensor networks for measuring carbon stocks are tools with potential for these objectives.

At the social level, the research agenda could focus on IoT devices and conversational AI to assist the elderly and combat social isolation, smart platforms to retain young people and counteract depopulation, AI-based mental telehealth solutions adapted to the rural context, and technological tools to strengthen social capital and community cohesion. Wearable sensors and AI voice assistants for monitoring the elderly, networking platforms with recommendation algorithms for young people in rural areas, chatbots based on natural language processing for psychological support, and community social networks are emerging technologies with applicability in these areas.

In terms of governance, future research could address blockchain platforms for participatory budgeting and citizen engagement, open data systems with AI-based visualizations for local budget transparency, integrated e-governance architectures based on emerging technologies for rural public services, as well as AI-assisted training tools for local government capacity building. Blockchain technology for voting and participatory budgeting, open data portals with automated analytics, one-stop-shop platforms for public services, and adaptive learning systems for training civil servants show potential for contributing to the modernization of rural governance.

This mapping exercise suggests the value of research approaches that transcend isolated technical validations and integrate interdisciplinary perspectives. Future studies would benefit from longitudinal assessments of the impact of emerging technologies on rural communities, looking not only at immediate outcomes but also at medium- and long-term socio-economic effects. Comparative research between diverse rural contexts (geographical, economic, demographic) would allow the identification of transferable success factors and barriers to adoption. Multi-pillar approaches, which explore synergies between economic, social, environmental, and governance dimensions, would contribute to a holistic understanding of the role of emerging technologies in sustainable rural development. Future systematic reviews building on this mapping exercise would also benefit from explicitly classifying included studies by implementation stage—distinguishing between conceptual frameworks, simulations, pilot applications, and fully implemented field deployments—in order to provide more nuanced guidance on the readiness of specific technologies for rural contexts.

The study's findings suggest several directions for public rural development policies. Based on the patterns identified across the analyzed corpus, investments in connectivity infrastructure appear as a key enabling condition for harnessing the potential of emerging technologies, and would benefit from being accompanied by technology training programs tailored to the specific needs of rural communities. Research and innovation funding programs could prioritize projects that address identified gaps—particularly participatory governance, climate adaptation, and services for the elderly. Public–private–academic partnerships appear as a promising mechanism for accelerating the transfer of technology from validated prototypes to large-scale implementation, addressing cost and institutional capacity barriers identified across the reviewed studies.

Rural communities and local organizations can leverage research results by identifying solutions based on emerging technologies that are mature and adaptable to their own context. The analyzed corpus includes promising examples in telemedicine, precision agriculture, and territorial planning that may warrant further investigation for replication or adaptation in different rural contexts. Active community involvement in the co-design of technological solutions is identified in the literature as a factor associated with higher likelihood of adoption and long-term sustainability. Collaboration networks between rural communities can facilitate the exchange of experiences and reduce implementation costs through economies of scale [181].

5. Conclusions

This scoping review systematically mapped the literature on the application of emerging technologies in rural development, integrating 129 studies into a conceptual framework based on the four pillars of sustainability: economic, social, environmental, and governance. The analysis addresses the three proposed objectives and offers a comprehensive perspective on a rapidly expanding field.

In terms of the classification of emerging technology applications, the study highlights a remarkable diversity of proposed solutions: ML and Deep Learning for crop disease detection, sentiment analysis in tourism and medical screening, IoT and sensors for real-time monitoring of water resources, soil parameters, and vital signs, blockchain for supply chain traceability, land administration, and participatory governance, UAV and remote sensing for precision agriculture, landscape conservation, and spatial planning. This diversity suggest the cross-cutting potential of emerging technologies to address the specific challenges facing rural communities.

The analysis reveals an accelerated increase in scientific interest starting in 2020, with peak publication activity during 2023–2025 for all pillars. The uneven distribution of research—with the economic pillar dominating (41 studies) and the governance pillar underrepresented (22 studies)— reflects current research priorities while simultaneously revealing opportunities for future investigation. The gaps identified concern critical areas such as biodiversity, climate change adaptation, services for the elderly, citizen participation, and the rural circular economy.

With regard to the formulation of the indicative intervention framework, the study proposes research priorities for each pillar and recommendations for the scientific community, decision-makers, and rural communities. Longitudinal approaches, comparative research, and multi-pillar perspectives are identified as priority methodological directions. Investments in connectivity, technological training, and public–private–academic partnerships are recommended to accelerate the transfer from research to implementation.

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The reviewed literature suggests that emerging technologies are increasingly moving beyond isolated experimental applications, showing growing potential to contribute to sustainable rural development across multiple dimensions. However, realizing this potential depends on addressing identified gaps, integrating interdisciplinary perspectives, and creating ecosystems conducive to adoption in rural communities. This study provides a map of current knowledge and an agenda for future research, contributing to the advancement of balanced rural development across all four dimensions of sustainability.

Supplementary Materials: The following supporting information can be downloaded at: https://www.mdpi.com/article/10.3390/agriculture16101081/s1, PRISMA-ScR-Fillable-Checklist.

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Abbreviations

The following abbreviations are used in this manuscript:

3D	Three-Dimensional
AI	Artificial Intelligence
BLSTM-CNN	Bidirectional Long Short-Term Memory–Convolutional Neural Network
CGAN	Conditional Generative Adversarial Networks
CNN	Convolutional Neural Network
DAO	Decentralized Autonomous Organization
FAO	Food and Agriculture Organization
GIS	Geographic Information System
IFAD	International Fund for Agricultural Development
IoT	Internet of Things
LPWAN	Low-Power Wide-Area Network
LSTM	Long Short-Term Memory
NLP	Natural Language Processing
PRISMA-ScR	Preferred Reporting Items for Systematic Reviews and Meta-Analyses-Extension for Scoping Reviews
RE-HAK	Refurbish to Host in Akiyas

SAR	Synthetic Aperture Radar
SDG	Sustainable Development Goals
SDI	Spatial Data Infrastructure
UAV	Unmanned Aerial Vehicle
WB	World Bank
WVSN	Wireless visual sensor networks

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