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National Investment Framework for Revitalizing the R&D Collaborative Ecosystem of Sustainable Smart Agriculture

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Abstract: Demographic, economic, and environmental issues, including climate change events, aging population, growing urban-rural disparity, and the COVID-19 pandemic, contribute to vulnerabilities in agricultural production and food systems. South Korea has designated smart agriculture as a national strategic investment, expanding investment in research and development (R&D) to develop and commercialize convergence technologies, thus extending sustainable smart agriculture and strengthening global competitiveness. Hence, this study probes the status of smart agricultural R&D investment from the perspectives of public funds, research areas, technologies, regions, organizations, and stakeholders. It examines 5646 public R&D projects worth USD 1408.5 million on smart agriculture in 17 regions and eight technology clusters from 2015 to 2021. Further, it proposes a pool of potential collaborative networks via a case study of strawberry, a representative veritable crop inspiring smart agriculture, to demonstrate the study framework's usefulness in promoting smart agriculture and establishing a sustainable R&D collaboration ecosystem. The proposed framework, accordingly, allows stakeholders to understand and monitor the status of R&D investment from various perspectives. Moreover, given the insight into the tasks belonging to technical areas and regions that require sustainable cooperation in smart agriculture, central and local governments develop policies to reinforce sustainable smart-farming models.

Keywords: smart agriculture; collaboration; national R&D project; government investment; framework; ecosystem; strawberry

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1. Introduction

Short and long-term environmental challenges—including climate change events, high energy costs, limited water and arable land, the continuing outflow of farmers, and the COVID-19 pandemic—have contributed to disproportionate vulnerability in agricultural production and food systems, thereby increasing the risk to global and national food security [1–3]. In response to such multifaceted challenges, multiple governments, such as the EU, the US, Japan, and South Korea (Korea hereafter), have established national policies to digitally transform the agricultural sector through better alignment of financial investment and institutional arrangements for long-term resilience and sustainability [2]. This concept, expressed through different terms, including smart farming, precision agriculture, precision farming, digital agriculture, and agriculture 4.0, aims to strengthen the efficiency of agricultural activities by adopting smart systems that provide operational solutions based on data from agricultural production [4].

First, in the EU, the European Commission presented legislative proposals in June 2018 for a new common agricultural policy (CAP) to outline a more efficient policy that supports the digital transformation/shift to precision and smart farming, thereby ensuring more economic competitiveness and simultaneously safeguarding the environment [5].

The new CAP can be implemented by investing massively in ambitious EU programs for research and development (R&D) projects that boost photosynthesis for food and energy, make precision farming techniques available to small farmers, encourage the sustainable use of land to improve soil health and consider sustainable aquaculture approaches [6].

Second, in the US, the private industry and universities or state cooperative extension specialists are the main drivers of advancing agricultural technologies and information systems for precision agriculture or smart farming. Therefore, a national policy for smart-farming solutions does not exist [1]. However, a current national agricultural and food policy worth USD 428 billion, commonly known as the "2018 Farm Bill" [7], has been made applicable from 2018 to 2023. This policy focuses on the investment in infrastructure to expand broadband Internet access to rural areas; it facilitates precision agriculture technologies, thereby improving productivity and profitability for small farmers [8].

Third, in June 2016, the government of Japan targeted agriculture as a key area for structural reform under the "Japan Revitalization Strategy" to transform the farm sector into a profitable industry by promoting smart agriculture and digital transformation [9]. Further, the government has made concrete efforts to implement the plan by investing in national programs and projects for innovation to assemble various key players to achieve interdisciplinary cooperation in data acquisition systems and analysis and agricultural robot solutions. Moreover, support for several projects across Japan, including paddy rice production, field and greenhouse cultivation, fruits, tea, and livestock, demonstrates the practical use of the latest smart-farming technology and solutions [10,11].

Fourth, the Korean government also addressed the national agricultural and food policy under two five-year comprehensive plans to develop science and technology for agriculture, forestry, and food for 2014 (second plan for the 2015–2019 period) [12] and 2019 (third plan for the 2020–2024 period) [13]. In 2018, the new president emphasized the need to cultivate smart farming as one of eight national strategic industries [14] and proposed a series of national smart-farm strategies, such as the Smart Farm Expansion Plan [15], comprehensive measures to extend smart agriculture based on big data and artificial intelligence (AI) [16], and the 2050 Agri-food Carbon Neutral Promotion Strategy [17].

These governments have a vested interest in pursuing sustainable agriculture as a facet of sustaining national security and natural resources. They emphasize productivity-enhancing technologies, such as mechanization and digitized farming and food systems, as essential in protecting against environmental degradation and supporting agricultural and climate-smart technologies [2,8,18]. However, Korea differs from industrialized countries and regions such as the US, EU, and Japan [8], as it has less cultivated land for agriculture, a high proportion of small-sized subsistence farming [19], and a horticulture facility and livestock-centered smart-farming policy [20]. Korean research stresses the normative argument that policies to strengthen national smart farming should focus on a comprehensive public fund strategy during decision-making [21,22]. Thus, it is necessary to understand the current public investment situation to establish a better Korean smart-farming policy or strategy, specifically from a technological perspective.

Most studies on applications of smart-farming solutions primarily focus on the technical aspects of applying relevant technologies to improve agricultural practices and productivity and post-farmgate processes, such as postharvest quality monitoring in the logistic process and real-time traceability [4]. Meanwhile, recent conceptual and empirical studies on smart farming within social science and policy probe and provide important research streams, including the adoption of smart farming-related technologies on farms, their impacts on farming methods, impacts of digitalized supply chains, and changes in the rules and institutions of the agricultural production systems [4]. However, studies on systematic public investment and the collaboration-related information framework for smart farming in policymaking remain absent. Thus, it is essential to reduce conflicts among different stakeholder types, such as advisors, policymakers, and researchers, contributing to the sustainable development of agriculture, food systems, and rural areas [23].

Therefore, this study investigates the status of smart farming in Korea regarding public funding, organizations, and regions. It (1) reviews the Korean national agricultural policies and describes the challenges therein; (2) reviews the literature on the information framework for smart farming; (3) suggests the development of an information framework using a relevant data-based machine learning technique, and identifies research areas on smart farming that can be foundational to providing insights for better funding allocation and regional collaboration of smart farming; and (4) provides insights and examples to support better smart farming policies.

1.1. Background and Literature Review

1.1.1. Background of Smart-Farming Policies in Korea

The demographic changes in Korea have significantly influenced Korean agriculture. Amid the slowdown of economic growth since the 2010s, rural communities have faced serious challenges given insufficient human resources caused by population aging, reduction in youth influx, and growing disparity between urban and rural areas. For example, almost 60% of farmers are over 65 years old, and their average age is expected to increase [24]. Given such challenges, the agricultural policy focuses on directions to technologically improve the productivity and competitiveness of agriculture [1]. In 2015, the government unified the smart-farm implementation system previously operated by several divisions of the Ministry of Agriculture, Food and Rural Affairs (MAFRA); it then formulated a national plan to develop information and communications technology (ICT)-based high-tech farming.

In December 2014, the MAFRA announced the 2nd Comprehensive Plan to develop science and technology for agriculture, forestry, and food (2015–2019) to reinforce public investment in 50 core strategic technologies in four key research areas. These areas include (1) advanced agricultural and forestry machinery technology, (2) intelligent precision agriculture production realization technology, (3) profitable plant factory business model development, and (4) intelligent agricultural water integrated control systems. The Plan aims to gain global agricultural competitiveness [12]. Under this plan, the goals of smart farming in its three advanced stages are as follows:

- First stage (2015–2018): Convenience improvement (more convenient and remote control)
- Second stage (2019–2020): Productivity improvement (less input and more automatic control of water supply and temperature according to the set environment)
- Third stage (2021–): Sustainability improvement (anyone can operate a farm with AI-based on high production and high-quality accumulated data)

In April 2016, the MAFRA showed the direction of measures to broaden the scope and accelerate the extension of the smart farming concept. Accordingly, the scope of smart farming expanded from greenhouses and livestock to orchards, open fields, and plant factories [25]. In November 2017, the new cabinet selected smart farming as one of eight strategic investment sectors for innovative growth. In April 2018, the MAFRA ambitiously announced the Smart Farm Expansion Plan [15] and proposed the Smart Farm Innovation Valley as a base to ensure synergy between farmers, companies, universities, and research institutes by combining technological innovation, market developments, and youth start-ups [26]. The areas for Phases 1 (Gimje and Sangju) and 2 (Miryang and Goheung) were selected in August 2018 and March 2019, respectively (see Figure 1) [27].

In December 2019, MAFRA announced the 3rd Comprehensive Plan to develop science and technology for agriculture, forestry, and food (2020–2024). It selected five key research areas and 12 core strategic technology areas. This plan emphasized strengthening R&D activities to improve productivity and promote the agri-food value chain [13]. Moreover, in December 2021, the Korean government announced comprehensive measures to extend smart agriculture based on big data and artificial intelligence (AI) [16].

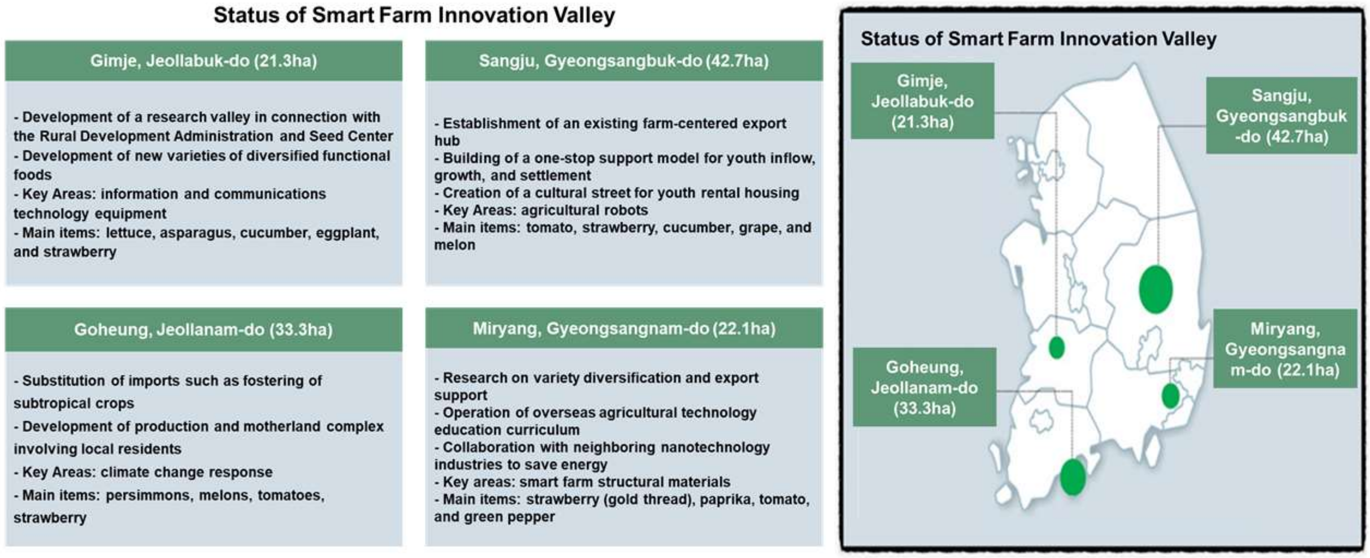


Figure 1. Smart Farm Innovation Valley projects in South Korea [27].

Jang and Kim [28] suggest the following directions for better smart-farm policies: (1) From the technological perspective, smart-farm device technologies should be localized to enhance compatibility by focusing on developing complex environment controller technology, which is the core of smart-farming equipment. Governments should further establish a platform for the market linkage of smart-farming equipment, development of strategic alliance and localization technologies, and development of strategic alliances between domestic companies. (2) From the organizational perspective, there should be collaborative governance between farmers, universities, research institutions, and central and local governments to develop advanced technology in the agricultural sector and strengthen the capacity and role of participants that meet market demands. Thus, Smart Farm Innovation Valley projects will have a significant ripple effect on the agricultural sector and local economy.

As noted, the concept of smart farming is expressed via multiple terms, a mixture of which is found in several national plans in Korea. Particularly, given that the government expanded smart farming from facility horticulture and livestock industry to open-field agriculture in 2019 [20], the Korea Institute of Science & Technology Evaluation and Planning [25] defines smart agriculture as including precision agriculture, smart farming, and digital agriculture from the Korean agriculture perspective. Even so, it does not cover the digitalization of the agri-food supply chain. Therefore, this study redefines the concept of smart agriculture in Korea as follows:

1. Smart agriculture aims to prepare a sustainability strategy for agriculture in response to factors such as climate change crises, food crises caused by population growth, limited resource utilization, and carbon emission. It employs advanced ICT (AI and big data) to improve agricultural productivity and quality, remotely or automatically manage the cultivation environment of crops and livestock and reduce the labor force via a national innovative growth strategy for sustainable future agriculture.
2. Precision agriculture is the oldest agricultural concept and includes technology for detailed monitoring of farmland and water supply and nutrients in the right place. The core technology of precision agriculture is open-field farming, which involves the cultivation of food crops, vegetables, and fruit trees.
3. Smart farming is a core technology of facility farming, including plant gardening facilities, such as greenhouses and plastic houses, livestock facilities for mass breeding of livestock, and plant factories that are closed plant cultivation facilities using artificial light. Smart-farm technology includes technologies to monitor the growth

and breeding environment of crops and livestock in facility farms using the Internet of things (IoT), big data, and AI and make optimal farming decisions.

4. Digital agriculture includes technology that collects, analyzes, and shares data on the agriculture and livestock industry and traces the entire process of production, processing, logistics, distribution, and consumption. Digital agriculture can be largely divided into fields such as digital agriculture data platform; digital agriculture distribution, logistics, and consumption; and data solutions and service technologies. For distribution and logistics in the agricultural and livestock industry, various ICTs such as big data, IoT, AI, and cloud computing are combined to implement a smart production and logistics system and smart shops. Figure 2 depicts these concepts.

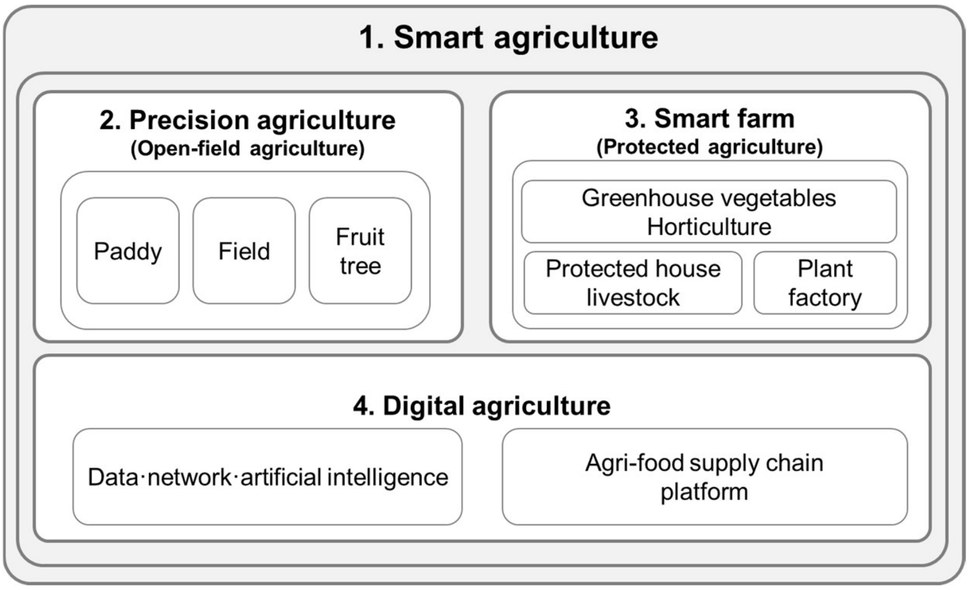


Figure 2. Concept of smart agriculture in South Korea [25].

1.1.2. Theoretical and Empirical Literature Review

In policymaking, decision-makers must adopt approaches to reduce uncertainty by gathering information to achieve analytic comprehensiveness of the targeted domain [29]. Thus, policy scholars focus on building a more comprehensive framework to understand the situation wherein stakeholders face uncertainty related to the content of a decision or policy issue [30]. Apparently, uncertainty in decision-making is associated with three knowledge attributes: incompleteness of knowledge, unpredictability from the complex interaction, and diverging frames of knowledge. Arguably, in principle, epistemic uncertainty from the incompleteness of knowledge can be reduced by collecting more information. Therefore, studies on uncertainty focus on bridging the lack of knowledge by developing a systematic framework [30]. Given the increasingly complex networks of public and private actors who influence the decision-making process, general approaches that allow for bridging the gap between the goals and reality are considered. Here, the assumption is that a shared consensus about the situation and its implications harmonizes the different stakeholder perspectives and enhances public confidence by increasing communication [31]. Further, in the policy development process, situational analysis is recognized as an important phase that defines the noted gaps between the goals-needs and the capacity to reliably deliver quality services and products by providing information and implications about the historical evolution and current status of a topic or issue [32]. Moreover, Cash et al. [33] emphasized that information should have three attributes—salience, credibility, and legitimacy—if it is to be used in decision-making.

Several scholars on environmental sustainability [34–38] and healthcare and wellness sustainability [39–45] suggest the need for an information framework for decision-making in funding or policy development. In general, these studies provide an evidence-informed decision-making framework. They explore the implications or value of a comprehensive and multiple-perspectives approach to share understanding among stakeholders, thereby identifying the required and appropriate information and criteria and bringing various challenges and collaboration opportunities to benefit sustainable development. The framework allows stakeholders to understand the current situation, monitor progress, and confront challenges belonging to different domains and technological areas, indicating the need for collaborative governance (sustainable view) for ecosystems [35,39]. Meadmore et al. [45] found that, though funders of health research generally participate in similar decision-making, they focus on innovative practices that reduce bias and burden by fostering more collaboration and flexible thinking to uphold their core values.

Meanwhile, in sustainable agriculture study streams, several science and technology studies primarily focus on topics such as smart farming, big data analysis, drones, AI and robotics, IoT, and transformative agri-food supply chain systems [4,46,47]. Within policy circles, however, there is a growing demand for studies on smart agriculture that support actors and stakeholders, including farmers, advisors, policymakers, and researchers, by providing useful information, thus contributing to developing smart agriculture [4,48].

One research approach involves focusing on directions or recommendations to develop better smart agricultural policies [49–55]. MacRae et al. [49] proposed a framework to identify a diverse range of short-, medium-, and long-term strategies, including research, diffusion, training, market development, safety programs, and tax provisions to support the transition from conventional to sustainable agriculture. Furthermore, they recommended that the implications of widespread adoption of sustainable practices and management of the food system should be studied. Berthet et al. [50] highlighted that the transition toward sustainable agriculture requires systemic co-innovation approaches that promote central and local collaboration between researchers and stakeholders to realize technological innovation in the farming system, sectors, and value chain, enabling local solutions to contribute to larger-scale solutions. Similarly, Dale and Marshall [52] argue that policy frameworks should be developed to facilitate cooperation at the local scale among governments, the private sector, and rural communities to ensure agricultural development. Accordingly, Adamashvili et al. [54] proposed a framework to establish a successful ecosystem in the agriculture sector, which may be accomplished by a scheme where governments encourage collaborative research among key stakeholders to adopt emerging technologies. Building a digital supply chain in the agriculture sector can, for instance, accelerate a successful evolution of the ecosystem via exchanging information and knowledge among suppliers, farmers, producers, retailers, and governments [55]. Meanwhile, Noor et al. [51] emphasized the essential role of public research institutes in agriculture to provide agricultural expansion services that improve farmers' productivity, income, and employment and generate knowledge for future sustainable growth. Thus, policies that enable public research institutes to motivate researchers with research grants, job promotions, and media publicity to grow in their careers warrants development.

The other approach focuses on investment or funding for scientific and technological research in agriculture [56–59] because, in practice, stakeholders participating in the policy process must obtain information about historical investment in the targeted research domain to discuss future funding directions. Barnes et al. [58] proposed a framework that elaborated on the research stage (e.g., basic, applied, and developmental), category (e.g., livestock and crop), and type (e.g., biological, mechanical, and chemical technologies) to determine where the public funds should be channeled appropriately. Similarly, Mogues et al. [56] argued that it is necessary to provide a framework for agriculture by analyzing information about public investments and expenditures because such information has implications for stakeholders on where to invest in agriculture. Moreover, the European Commission has emphasized the transformation of agriculture and rural areas in the EU by supporting knowledge exchange, collaboration, and research-into-practice linkages. To especially ensure more investment, collaboration programs are needed as vehicles to foster cross-sectoral linkages for knowledge exchange. Thus, it is necessary to develop an overarching and flexible policy framework to improve the situation of agriculture and rural areas where local conditions favor new research [57]. Accordingly, from survey data from project partners from six EU member states and the literature review, Stojanova et al. [59] presented seven recommendations for future smart village projects that bridge the rural-urban gap for policymakers at the local, regional, national, and EU levels. Of these recommendations, the importance of implementing specific funding schemes is stressed to communicate the attractiveness of mountainous and rural areas, thus allowing for connection and networking with stakeholders (e.g., universities and small and medium-sized establishments) and providing opportunities for new employment. However, the normative arguments must be supported via an evidence-based empirical framework.

Hence, to address the limitations of prior studies, this study proposes an information framework for public research funding in smart agriculture to identify the comprehensive investment situation, investigate the allocation of research funding from the perspective of regions and research areas, and present collaboration opportunities at the regional scale. It aims to reduce the epistemic uncertainty from the lack of knowledge of a phenomenon [30], decrease ambiguity given multiple frames (methods) about a phenomenon [30], and ensure a shared understanding of policy or strategic implications among stakeholders in decision-making [31]. Additionally, this study improves information quality through the example of strawberry, which accounts for the biggest share of smart-farming items, to facilitate the collaboration of the private sector with universities and R&D institutes at the transregional scale.

1.1.3. Research Purpose and Questions

The target research area should be divided into small areas, and the status and trends of the sub-research areas must be examined to establish a collaboration ecosystem and R&D investment framework for smart agriculture in Korea. As noted in prior studies [60–62], this procedure is fundamental to ensuring enhanced stakeholder collaboration by reducing information uncertainty on the knowledge status in various target fields, thereby improving the quality of decision-making on national R&D. Therefore, this study presents timely, comprehensive, and useful information on the state of R&D activities in the smart agricultural sector in 17 regions of Korea using the proposed framework. The main research questions (RQs) are as follows:

RQ1: *What information is required to establish the direction of investment in the agricultural R&D sector of the Korean government that this proposed framework can provide?*
RQ2: *Has the Korean government's investment trend been consistently implemented since the government announced key agricultural R&D policies, such as the announcement of the 2018 Smart Farm Expansion Plan, and does such government R&D investment implementation differ per the perspective of individual regions and various innovation-performing organizations?*
RQ3: *Can the proposed framework generate knowledge and strategies for various stakeholders to identify the role of the R&D cooperative ecosystem for sustainable smart farming and potential collaborators, and can it be demonstrated via the case of strawberries, a representative crop item at the forefront of smart agriculture in Korea?*

Eight subcategory RQs to be examined in-depth to solve the three main RQs follows:

RQ1-1: *How much has the Korean government invested in smart agriculture between 2015 and 2021?*
RQ1-2: *How much has the Korean government invested in smart agriculture from a regional perspective?*
RQ1-3: *What investment trend has the Korean government shown in the R&D areas of smart agriculture?*

Beyond analyzing the direction of the Korean government's investment in the smart agricultural industry, the following RQs were further examined:

RQ2-1: *How has the Korean government's investment trend changed since the announcement of the Smart Farm Expansion Plan, a key smart-agriculture strategy in Korea, in 2018?*
RQ2-2: *How does the investment status of Korean smart agriculture differ from the perspective of regions and stakeholders?*

Finally, the following RQs exemplify the role and potential partners of the R&D collaborative ecosystem to share knowledge with other stakeholders by comprehensively analyzing detailed research activities for a smart-agriculture-related item (e.g., fruit):

RQ3-1: *Are there regional differences in R&D collaborative ecosystems and network capabilities for a specific item (e.g., strawberry) in Korean smart agriculture?*
RQ3-2: *From a regional perspective, what is the difference in the competitiveness of innovative organizations (academic, industry, and research institutes) regarding, for instance, strawberries?*
RQ3-3: *Regarding, for instance, strawberries, which innovative organizations in the smart agricultural industry can become potential partners for strengthening the local R&D collaboration ecosystem?*

2. Materials and Methods

2.1. Data Collection and Preprocessing

The study employed the national R&D portal (i.e., National Science & Technology Information Service), which provides information including programs, projects, and human resources of national R&D programs in Korea to identify smart-agriculture-related R&D projects. Titles and abstracts in the national R&D projects were translated into English. The study then extracted keywords and variants related to smart agriculture with experts from universities and research institutes to determine the search terms. Table 1 presents the dataset. Initially, 6961 nationally-funded smart-agriculture R&D projects were collected during the 2015–2021 time. Experts then thoroughly verified the relevance of smart agriculture from the collected data, bringing the data sample to 5796 projects. Finally, after removing projects with missing investment information, the final dataset comprised 5646 projects with a value of USD 1408.5 million (Tables 2 and 3).

Further, to understand the characteristics of studies that correspond to the nationally funded research projects, this study adopted the All Science Journal Classification (ASJC) four digits of Scopus to develop the classification model that used the author keywords of approximately 1 million articles (i.e., features) and the ASJC codes assigned to each paper (i.e., labels). Thereafter, three ASJC codes and their probabilities were assigned to each nationally-funded research project calculated by the ASJC classification model [60–62]. The probability was determined based on the titles and abstracts of the projects. Further, a 25% threshold probability was set to identify more similar projects (clusters). Figure 3 presents a conceptual diagram of this process [60–62].

2.2. Clustering Process

The study identified smart-agriculture research areas via the co-occurrence matrix and investigated the relationship between ASJC codes by understanding the network structure visualized by the VOSViewer (Version 1.6.18, Leiden University, Leiden, The Netherlands) [60–65]. The number of clusters ranged from 1 (γ = 0.1) to 9 (γ = 2.0) by adjusting a resolution parameter (γ). Given the items (ASJC codes) and titles and abstracts of research projects in each cluster, eight clusters were selected.

Table 1. Examples of public research and development projects data in the Korean National Science & Technology Information Service database.

Region	Unique Identification Number (ID)	Organization	Type of Organization	Funding (Thousand USD)	Project Period		Project Content	
					Start Date	End Date	Title	Abstract
Jeollanam-do	1415176355	ELSYS Co., Ltd. Naju, South Korea	Industry	2300,000,000	1 May 2019	31 December 2022	Development and demonstration of renewable energy convergence system for crops	LoRaWAN multi-channel gateway hardware design and production, LoRaWAN multi-channel gateway software development or implementation, low-power Internet of Things hardware and software requirements analysis, energy convergence brokerage service design and development, analysis and design of energy, convergence brokerage platform requirements, energy convergence brokerage trading platform mobile application development
Jeollabuk-do	1395069779	National Academy of Agricultural Sciences	Research institute	130,000,000	1 January 2021	31 December 2023	Field application and advancement of smart insect pollination on a strawberry and tomato smart farm	Existing (prototype) customized smart beehive sensing system design, smart beehive entry-level and high-end smart system design, improvement and advancement of image processing for bee activity measurement (maintaining algorithm, improving platform, and camera), development of modularization technology for both low-level (simple) and advanced types of beehive internal environment sensing technology, simple modularization (beehive internal temperature, humidity, hive weight, and activity recorder), advanced modularization (e.g., beehive internal temperature, humidity, carbon dioxide, food quantity, weight, activity recorder, and fan system for ventilation), and development of low-power sensing technology for field application of fruit trees (e.g., kiwis) for digital agriculture

Table 2. Data of nationally funded projects and search terms related to smart agriculture.

Search Terms	Time Period	Number of Raw Data Items	Number of Data Items Utilized
(“smart farm *” OR “smart agriculture *” OR “precision farm *” OR “precision agriculture *” OR ”precision livestock *” OR “livestock farm *” OR ”digital farm *” OR “digital agriculture *” OR “smart management information system” OR “plant factory” OR “vertical farm *” OR ((“big data” OR digital OR “internet of thing *” OR “IoT” OR “artificial intelligence” OR precision OR vertical OR urban) AND (agriculture * OR crop * OR farm * OR greenhouse * OR fruit * OR vegetable * OR plant * OR livestock * OR husbandry OR animal OR cultiva * OR culture * OR harvest * OR breed *)))	2015–2021	6961	5646 (strawberry: 157)

Asterisks (*) in search terms were employed to broaden the search by finding words that begin with the same letters.

Table 3. Amount of funding and number of projects during 2015–2021 by 17 regions in South Korea.

Region	Funding (Thousand USD)	No. of Projects	Funding Per Project	Funding (%)
Gangwon-do	20,125	217	93	3.0%
Gyeonggi-do	85,700	666	129	12.7%
Gyeongsangnam-do	39,826	437	91	5.9%
Gyeongsangbuk-do	33,652	371	91	5.0%
Gwangju	32,061	239	134	4.8%
Daegu	32,497	234	139	4.8%
Daejeon	57,554	338	170	8.5%
Busan	17,319	130	133	2.6%
Seoul	115,042	768	150	17.1%
Sejong	1794	26	69	0.3%
Ulsan	2275	12	190	0.3%
Incheon	10,757	78	138	1.6%
Jeollanam-do	44,363	332	134	6.6%
Jeollabuk-do	100,289	1125	89	14.9%
Jeju	19,341	136	142	2.9%
Chungcheongnam-do	35,661	260	137	5.3%
Chungcheongbuk-do	26,365	277	95	3.9%
Total	674,622	5646	119	100.0%

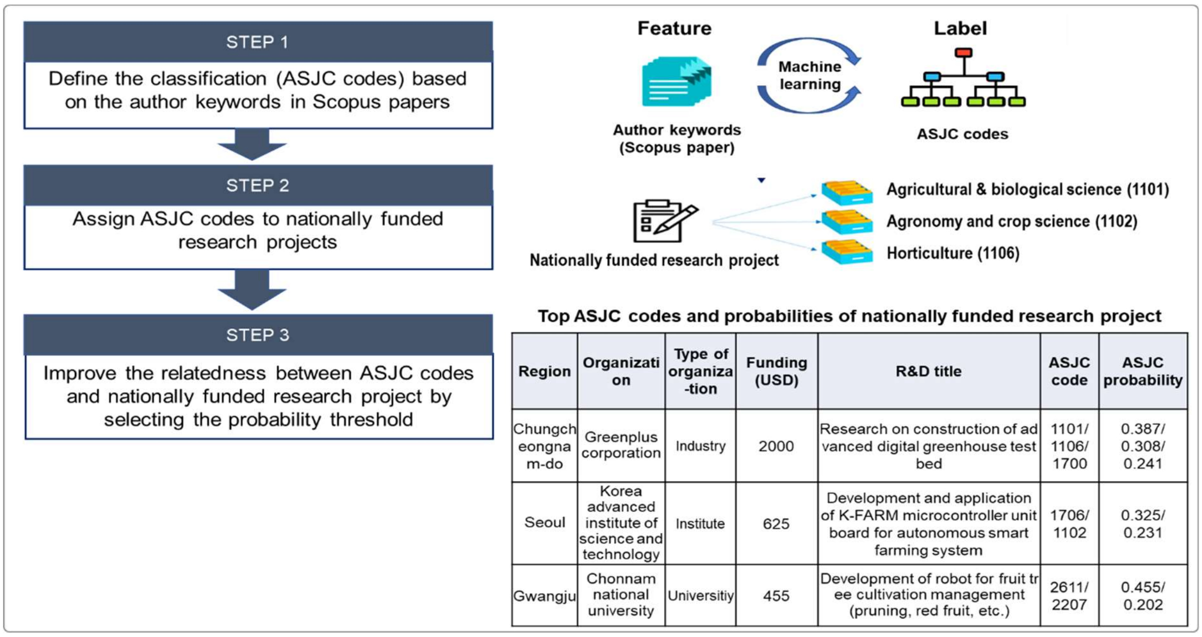


Figure 3. Process of assigning All Science Journal Classification (ASJC) codes to nationally funded research projects and improving the correlation between the ASJC codes and projects.

2.3. Definition of Research Areas Related to Smart Agriculture

Smart-agriculture research areas were labeled after reviewing the content of the R&D projects and the list of the ASJC codes in each area. The labels for research areas were determined via discussions among experts in smart agriculture and relevant research areas. In the discussion, the distribution of ASJC codes comprising each cluster and titles and abstracts of the R&D projects in the clusters were provided to the experts.

2.4. Targeted Collaborative Research Area: Strawberries

Furthermore, to provide strategic implications, the study targeted strawberries as a collaborative research area. Strawberry production in Korea accounted for 10.9% (1023 million) of the total vegetable production, ranking as the largest among vegetable crops in 2021. The penetration rate of domestic strawberry varieties exceeded 96.3% relative to 9% in 2005, and the export number of strawberries reached 53.7 million dollars relative to 4.4 million dollars in 2005. From the regional perspective, Gyeongsangnam-do, Jeollanam-do, and Jeollabuk-do were ranked as the largest strawberry cultivation area [66]. The 157 projects that contained the keyword, strawberries, were reselected from the final dataset. Figure 4 presents the entire process.

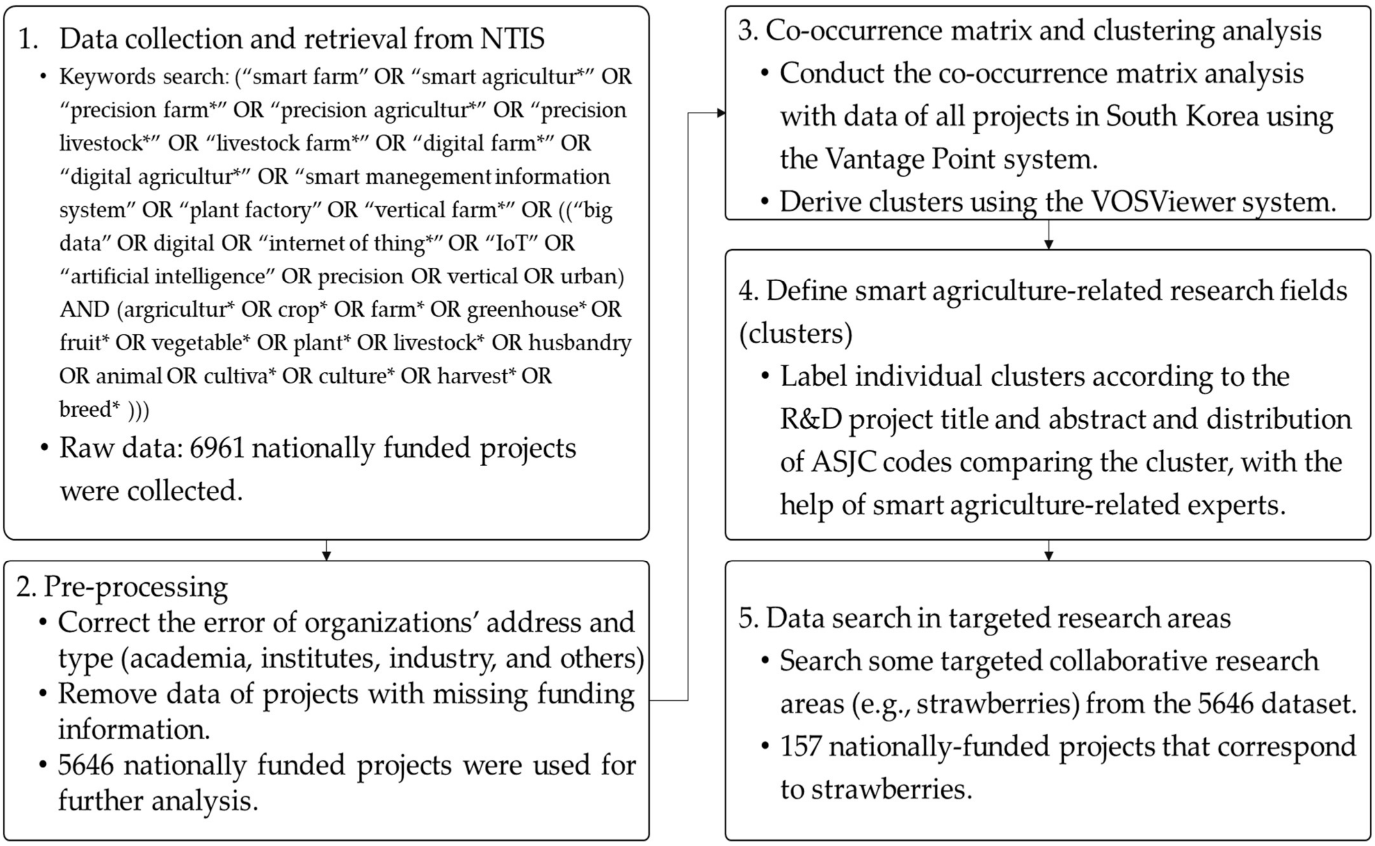
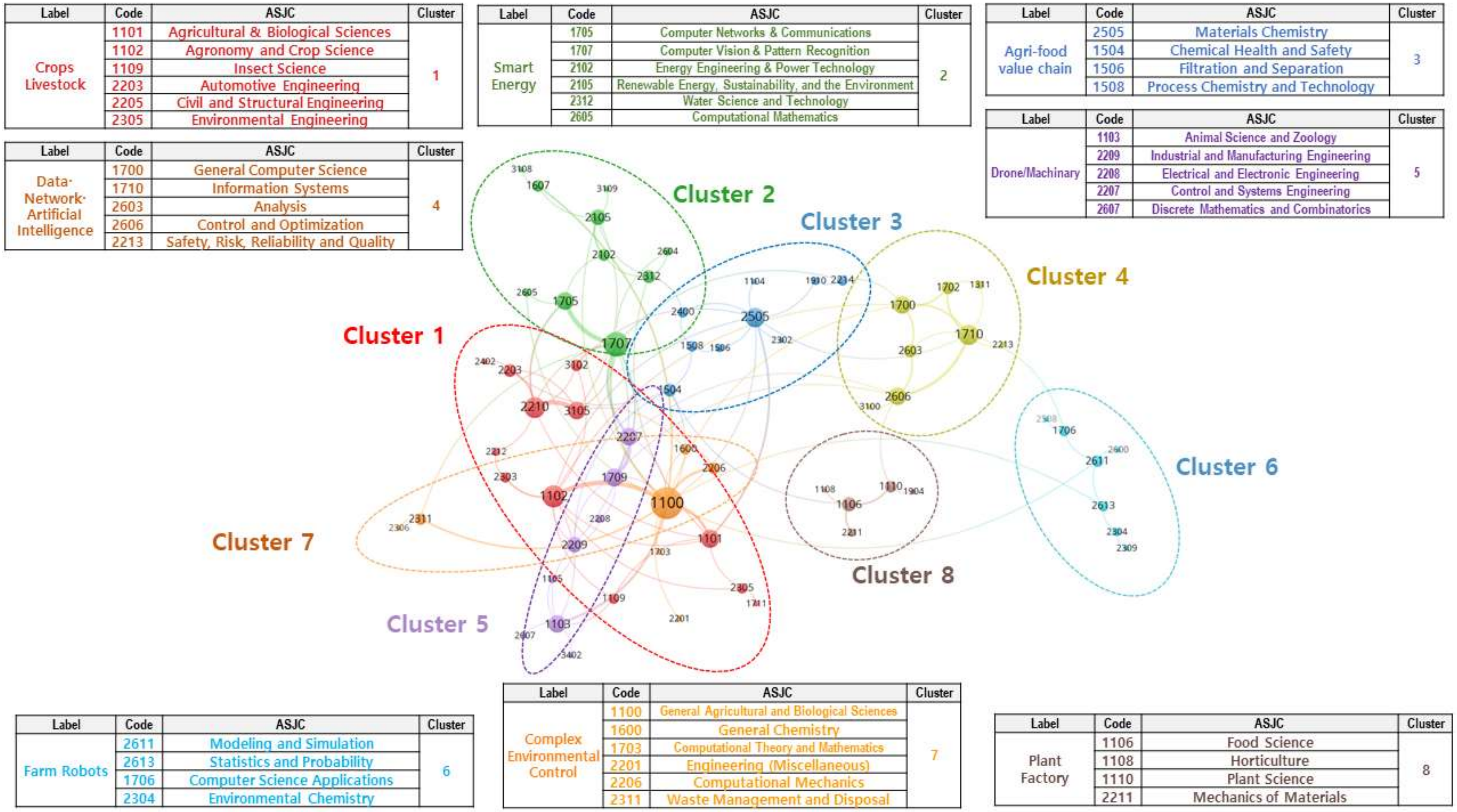


Figure 4. Data collection process and analyses of nationally funded global research projects on smart agriculture. Asterisks (*) in search terms were employed to broaden the search by finding words that begin with the same letters.

3. Results

3.1. Nationally-Funded Projects Regarding Smart Agriculture

Figure 5 shows the network visualization of smart-agriculture research areas. The item or node was considered the ASJC code in the subject of study. Refer to the link of co-occurrence between the research areas of study for links indicating the relationship between the two items. The strength or weight of the link represents the number of projects in the research areas. The size of the labels and circles in each area of study was determined by the weight of the areas. Thus, the larger the weight of the research area, the larger the label and circle. The characteristics of each research area were determined by the cluster to which it belonged.



Label	Code	ASJC	Cluster
Crops Livestock	1101	Agricultural & Biological Sciences	1
	1102	Agronomy and Crop Science	
	1109	Insect Science	
	2203	Automotive Engineering	
	2205	Civil and Structural Engineering	
	2305	Environmental Engineering	

Label	Code	ASJC	Cluster
Smart Energy	1705	Computer Networks & Communications	2
	1707	Computer Vision & Pattern Recognition	
	2102	Energy Engineering & Power Technology	
	2105	Renewable Energy, Sustainability, and the Environment	
	2312	Water Science and Technology	
	2605	Computational Mathematics	

Label	Code	ASJC	Cluster
Agri-food value chain	2505	Materials Chemistry	3
	1504	Chemical Health and Safety	
	1506	Filtration and Separation	
	1508	Process Chemistry and Technology	

Label	Code	ASJC	Cluster
Data-Network-Artificial Intelligence	1700	General Computer Science	4
	1710	Information Systems	
	2603	Analysis	
	2606	Control and Optimization	
	2213	Safety, Risk, Reliability and Quality	

Label	Code	ASJC	Cluster
Drone/Machinary	1103	Animal Science and Zoology	5
	2209	Industrial and Manufacturing Engineering	
	2208	Electrical and Electronic Engineering	
	2207	Control and Systems Engineering	
	2607	Discrete Mathematics and Combinatorics	

Label	Code	ASJC	Cluster
Farm Robots	2611	Modeling and Simulation	6
	2613	Statistics and Probability	
	1706	Computer Science Applications	
	2304	Environmental Chemistry	

Label	Code	ASJC	Cluster
Complex Environmental Control	1100	General Agricultural and Biological Sciences	7
	1600	General Chemistry	
	1703	Computational Theory and Mathematics	
	2201	Engineering (Miscellaneous)	
	2206	Computational Mechanics	
	2311	Waste Management and Disposal	

Label	Code	ASJC	Cluster
Plant Factory	1106	Food Science	8
	1108	Horticulture	
	1110	Plant Science	
	2211	Mechanics of Materials	

Figure 5. Research areas on smart agriculture. ASJC: All Science Journal Classification.

The research areas on smart agriculture were divided into eight clusters. After considering the titles and abstracts of the projects, their representative research areas, and the related keywords, the ultimate goals of each area were determined as follows:

- Goals of Cluster 1 (Crops and Livestock): Crop Production, Growth, Livestock Growth, and Health Management Technology for Smart Agriculture. It included technologies for measuring crop growth and physiology and detecting the presence of pathogens, identifying pests and diseases.
- Goals of Cluster 2 (Smart Energy): Renewable Energy Utilization Technology for Agricultural Power Generation for Smart Agriculture. It covered technologies to maintain and manage homeostasis in optimal conditions using minimal (renewable) energy.
- Goals of Cluster 3 (Agri-Food and Supply Platform): Integrated Management Platform (Distribution, Logistics, and Consumption) for Digital Agriculture. It implied a platform that optimizes efficient management and marketing by sharing information about producers, consumers, and logistics companies.
- Goals of Cluster 4 (Data·Network·AI): AI for Digital Agriculture. It contained technologies that collect real-time big data in facility horticulture or livestock and optimize environmental conditions in the AI algorithms.
- Goals of Cluster 5 (Agricultural Machinery): Smart Agricultural Machinery and Agricultural Drone for Precision Agriculture. It included technologies that utilize agricultural machinery and robots and collect data from agricultural sites with imaging equipment and sensors mounted on unmanned aerial vehicles.
- Goals of Cluster 6 (Farm Robots): AI Farmbots for Smart Farms. It covered technologies that can autonomously perform optimal agricultural work, as per the situation, by analyzing the status of crops and livestock.
- Goals of Cluster 7 (Environmental Information): Complex Environmental Information Measurement and Control Technology for Smart Agriculture. It included technologies to measure external factors such as temperature, humidity, and air quality.
- Goals of Cluster 8 (Plant Factory): Urban Agriculture Technology, including Indoor Vertical Farming System or Plant Factory for Smart Farms. It included technology to design, control, and utilize complex facilities and equipment to realize the prelude for crop and livestock production activities in a completely closed space.

3.2. Status of Government Investment in Smart Agriculture

3.2.1. Investment Status of Korean Government-Funded Projects in Smart Agriculture

Korea invested USD 674.6 million in smart agriculture from 2015 to 2021 (Table 4). Figure 6 shows the status of the government's R&D investment in smart agriculture in 17 regions. From Table 3 and Figure 6, the regions of Seoul and Jeollabuk-do receive the most funding, accounting for 17.1% (USD 115 million) and 14.9% (USD 100 million) of government investment, respectively, followed by the Gyeonggi province (USD 8.57 million; 12.7%), Daejeon (USD 57 million; 8.5%), Jeollanam-do (USD 44 million; 6.6%), Gyeongsangnam-do (USD 39 million; 5.9%), and Chungcheongnam-do (USD 35 million; 5.3%). Information on the ratio of local investment in smart-agriculture R&D shows that the government has invested in R&D in all regions nationwide.

Table 4. Trends of the time-series scale of the nationally funded projects by clusters.

Smart Agriculture	Technology Cluster	2015	2016	2017	2018	2019	2020	2021	Total	%
Protected Agriculture	Crops and livestock (CLS_1)	20.4	26.0	27.9	25.4	27.8	26.7	37.3	191.4	28.4%
	Smart energy (CLS_2)	7.8	10.1	9.6	9.2	10.4	23.7	17.3	88.1	13.1%
	Farm robots (CLS_6)	0.7	1.6	3.8	5.7	9.5	11.5	7.6	40.7	6.0%
	Environmental information (CLS_7)	5.4	4.4	6.0	10.8	11.6	11.1	12.7	62.0	9.2%

Table 4. *Cont.*

Smart Agriculture	Technology Cluster	2015	2016	2017	2018	2019	2020	2021	Total	%
Protected Agriculture	Plant factory (CLS_8)	8.4	4.2	1.5	2.2	4.4	4.8	6.6	32.1	4.8%
Open-Field Agriculture	Agricultural machinery (CLS_5)	6.9	10.3	8.8	14.4	16.1	21.9	38.9	117.2	17.4%
Digital Agriculture	Data·network·artificial intelligence (CLS_4)	9.2	14.3	14.0	11.9	18.9	18.5	14.5	101.5	15.0%
	Agri-food platform (CLS_3)	6.4	7.7	7.3	6.8	5.0	4.4	4.2	41.8	6.2%
Total Sum (Unit: million USD)		65.2	78.5	78.9	86.4	103.7	122.7	139.1	674.6	100.0%

3.2.2. Status and Trend of Public R&D Projects by Technology Cluster of Smart Agriculture

It is important to determine the status of and comparatively analyze the investment differences in the R&D area to evaluate the R&D project portfolio adequacy. Therefore, the first step is to classify processes that can be prioritized and their projects accordingly [67]. Figure 7 shows the results of the comparative analysis of the total national R&D funds regarding technology clusters and sub-clusters in smart agriculture. First, when Korea's smart agriculture was divided into protected agriculture (smart-farm facility), open-field agriculture (precision agriculture), and digital agriculture, the ratio of R&D investment to the amount invested was the highest for protected agriculture (61.4%). This proportion was 17.4% (21.2%) for open-field (digital) agriculture. Thus, they are in an early stage relative to protected agriculture, such as a smart farm.

Meanwhile, in protected agriculture, the largest amount of government R&D funds were invested in crop and livestock advancement (cluster [CLS] 1; 28.4%), followed by smart energy (CLS 2; 13.1%), complex environmental information advancement (CLS 7; 9.2%), farm robots (CLS 6; 6.0%), and plant factories (CLS 8; 4.8%). In digital agriculture, the funds were invested in the data·network·AI (CLS 4; 15.0%) and agri-food (CLS 3; 6.2%) platforms.

Table 4 shows the combined annual growth rate (CAGR) of smart-agriculture R&D areas from 2015 to 2021. The crop and livestock area (CLS 1) grows the fastest every year among all smart-agriculture sectors. From the perspective of R&D technology clusters, crop and livestock (CLS 1) is the fastest-growing cluster area, with investment showing 28.4% of CAGR: from USD 20.4 million in 2015 to USD 37.3 million in 2021. The second fastest-growing cluster area is open-field agriculture (CLS 5), with investment increasing from USD 6.9 million in 2015 to USD 38.9 million (CAGR: 17.4%) in 2021. For digital agriculture, the data·network·AI platform cluster (CLS 4) grew by 15.0% to USD 14.5 million in 2021, and the smart energy cluster (CLS 2) grew from USD 7.8 million in 2015 to USD 17.3 million in 2021. Thus, the government intends to strengthen R&D capabilities in related technologies such as crop and livestock advancement, open-field agriculture, digital agriculture, and smart energy.

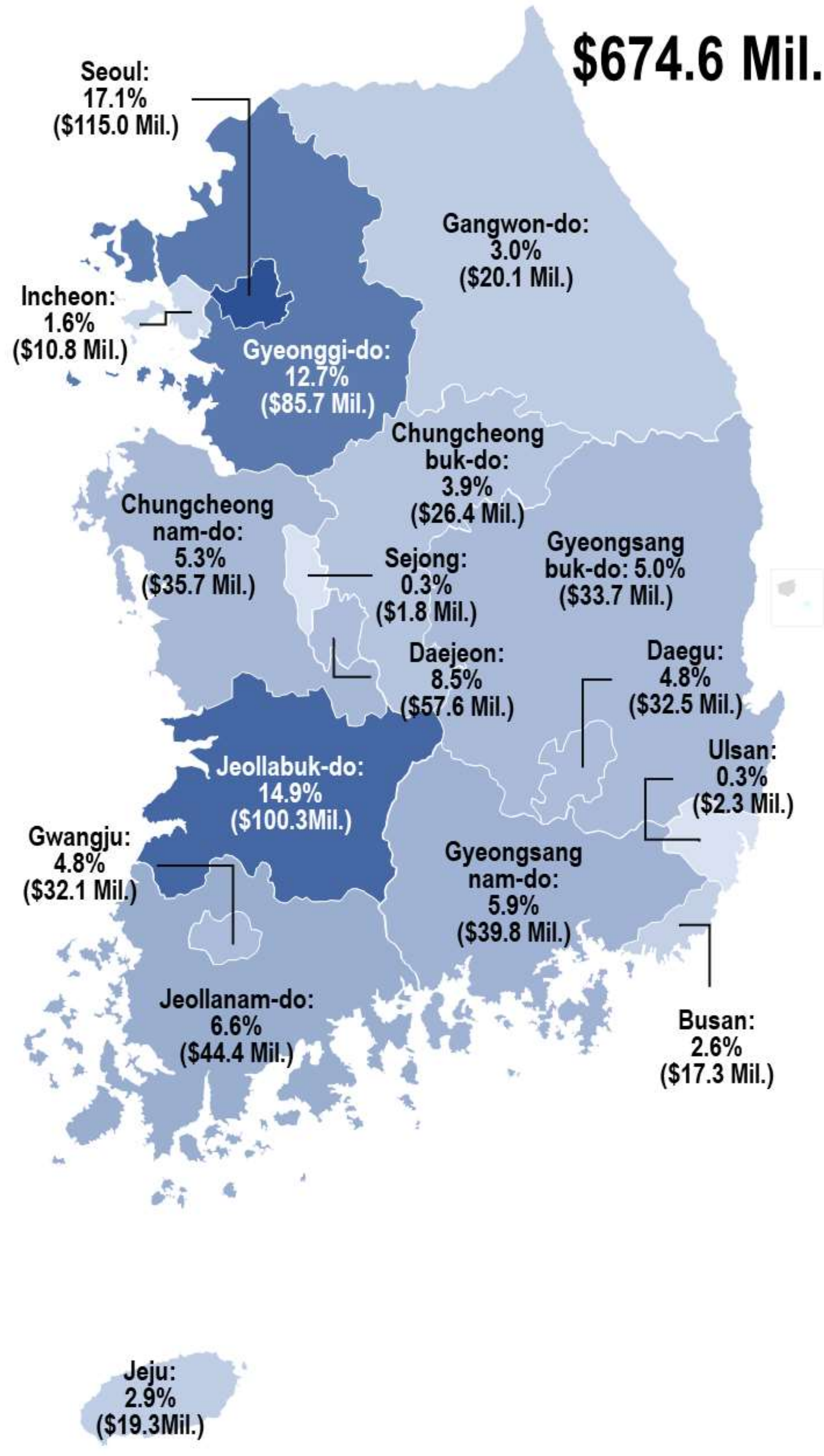


Figure 6. Proportion of government research and development investment in smart agriculture in the 17 regions.

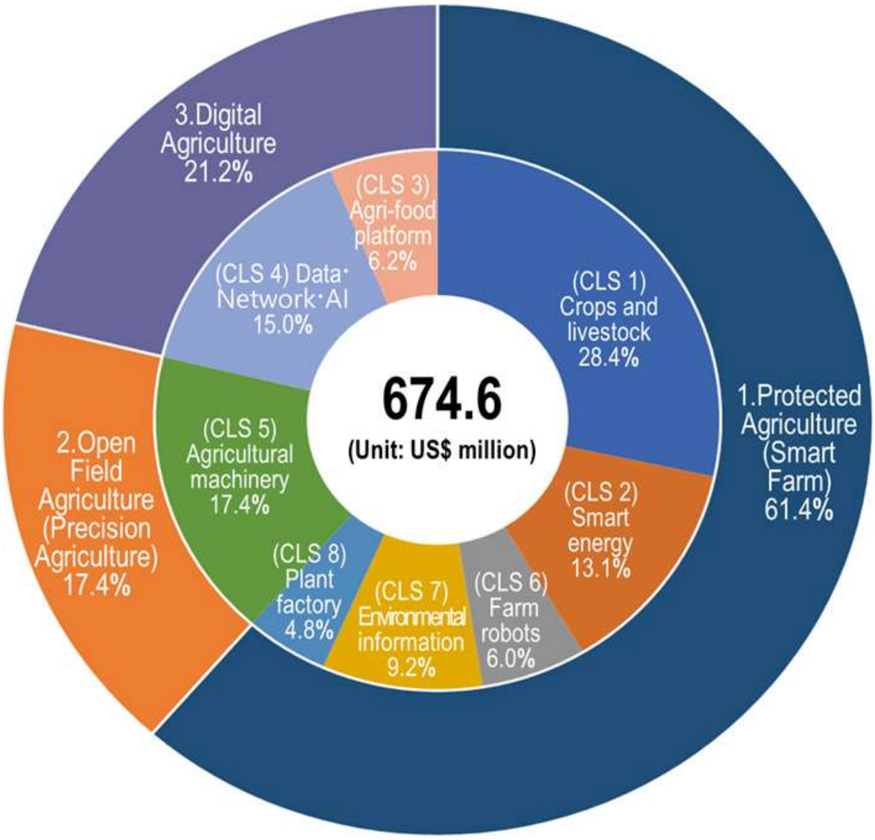


Figure 7. Status of research and development investment by technology cluster and sector in smart agriculture.

3.2.3. Status and Trend of Government R&D Investment in Smart Agriculture from the Perspective of the Time Phase

Table 5 demonstrates how the government's R&D investment amount and CAGR have changed since the announcement of the Smart Farm Expansion Plan in 2018. The total amount of R&D investment and the CAGR were analyzed by dividing the 2015–2021 period into Phase 1 (2015–2018) and Phase 2 (2019–2021) relative to 2018. Relative to Phase 1, the area where the CAGR increased significantly in Phase 2 was open-field agriculture (CLS 5; referred to as agricultural machinery), which grew steeply from USD 40.3 million (CAGR 27.9%) in Phase 1 to USD 76.9 million (CAGR 55.5%) in Phase 2. The area of smart energy (CLS 2) also increased in investment from USD 36.7 million (CAGR 5.6%) during Phase 1 to USD 51.4 million (CAGR 29%) during Phase 2. Moreover, the areas of crop and livestock (CLS 1; CAGR 10.6%) and environmental information (CLS 7; CAGR 15.2%) increased in investment with high growth rates in Phase 2. However, the farm robot area (CLS 2) grew at a CAGR of 101.3% in Phase 1, but in Phase 2, the growth rate of investment decreased, indicating a slowdown. Hence, R&D investment has increased in the overall technology cluster area of smart agriculture since MAFRA announced its Smart Farm Expansion Plan policy in 2018. Further, the direction of R&D investment is shifting from existing protected agriculture, such as smart farming, to open-field agriculture and energy-saving smart energy R&D from the government's policy perspective.

Table 5. Comparison of investment size and trend by time phase of government research and development funding projects for smart agriculture.

Smart Agriculture	Technology Cluster	Phase 1 Total (2015–2018)	Phase 2 Total (2019–2021)	Phase 1 CAGR (2015–2018)	Phase 2 CAGR (2019–2021)	Total CAGR (2015–2021)
Protected Agriculture (Smart Farm)	Crops and livestock (CLS_1)	99.6	91.8	7.6%	15.9%	10.6%
	Smart energy (CLS_2)	36.7	51.4	5.6%	29.0%	14.1%
	Farm robots (CLS_6)	11.9	28.7	101.3%	−10.5%	48.8%
	Environmental information (CLS_7)	26.6	35.4	25.8%	4.5%	15.2%
	Plant factory (CLS_8)	16.3	15.8	-36.2%	22.6%	−3.9%
Open-Field Agriculture (Precision Agriculture)	Agricultural machinery (CLS_5)	40.3	76.9	27.9%	55.5%	33.5%
Digital Agriculture	Data·network·artificial intelligence (CLS_4)	49.5	52.0	8.9%	−12.4%	7.9%
	Agri-food platform (CLS_3)	28.2	13.6	2.1%	−8.6%	−6.8%
Total Sum (Unit: million USD)		280.8	352.0	9.8%	15.8%	13.5%

3.2.4. Status and Trend of Government R&D Investment in Smart Agriculture from the Perspectives of the Region and Stakeholders

From the technology clusters and regions' perspectives, competitiveness in regional technology was estimated by examining the status of government R&D projects. From Table 6, Korea invested in smart-agriculture research capabilities in all regions in the order of Seoul, Jeollabuk-do, Gyeonggi-do, Daejeon, Jeollanam-do, and Gyeongsangnam-do. Considering the status of R&D investment by region and R&D technology cluster, Seoul received the most investment in the areas of crop and livestock (CLS 1; USD 37.6 million), data·network·AI (CLS 4; USD 29.4 million), agricultural machinery (CLS 5, open-field agriculture; USD 11.5 million), and plant factories (CLS 8; USD 10.2 million). Jeollabuk-do, having the second-largest R&D investment, showed a similar tendency, with the most investment in crop and livestock (CLS 1; USD 29.6 million), followed by agricultural machinery (CLS 5, open-field agriculture; USD 20.6 million), data·network·AI (CLS 4; USD 16.1 million), environmental information (CLS 7; USD 8.6 million), and agri-food platform (CLS 3; USD 8.3 million). There is an even distribution of investment across the technology clusters. Jeollanam-do received the most investment in smart energy (CLS 2: USD 13.8 million) in the country, thus securing an advantage in technology competitiveness. Gyeonggi-do secured a relative advantage in environmental information technology (CLS 7; USD 7.1 million), and Gyeongsangnam-do, Gyeongsangbuk-do, and Daegu showed excellent technological competitiveness in agricultural machinery (CLS 5, open-field agriculture; USD 8.1 million, USD 8.8 million, and USD 14.3 million, respectively). Figure 8 presents a map of the investment status of the 17 regions in Korea for the eight smart-agriculture R&D technology clusters.

Table 6. Status of smart-agriculture research areas in the 17 regions of Korea.

Regions (Unit: Million USD)	Protected Agriculture					Open-field Agriculture	Digital Agriculture		Total
	Crops and Livestock (CLS_1)	Smart Energy (CLS_2)	Farm Robots (CLS_6)	Environmental Information (CLS_7)	Plant Factory (CLS_8)	Agricultural Machinery (CLS_5)	Data·Network·Artificial Intelligence (CLS_4)	Agri-Food Platform (CLS_3)	
Gangwon-do	5.4	3.0	-	3.2	1.0	3.0	2.7	1.9	20.1
Gyeonggi-do	28.6	11.5	3.0	7.1	3.0	10.9	16.2	5.3	85.7
Gyeongsangnam-do	12.4	6.4	0.9	5.5	1.1	8.1	4.5	0.9	39.8
Gyeongsangbuk-do	8.6	1.3	3.2	3.3	6.2	8.8	1.8	0.6	33.7
Gwangju	4.6	8.1	4.9	2.8	0.5	5.2	4.4	1.7	32.1
Daegu	5.4	1.2	4.5	1.3	0.2	14.3	4.7	0.7	32.5
Daejeon	13.9	11.3	4.5	5.3	0.8	6.7	6.6	8.3	57.6
Busan	6.6	1.6	3.2	1.4	0.2	1.3	0.4	2.5	17.3
Seoul	37.6	6.3	5.7	8.2	10.2	11.5	29.4	6.1	115.0
Sejong	0.7	0.6	-	0.1	-	-	0.2	0.1	1.8
Ulsan	1.3	-	-	0.4	-	0.3	0.3	-	2.3
Incheon	3.4	1.6	1.2	1.2	-	2.5	0.8	-	10.8
Jeollanam-do	10.5	13.8	0.5	3.3	0.3	5.4	7.1	3.5	44.4
Jeollabuk-do	29.6	5.4	4.5	8.6	7.1	20.6	16.1	8.3	100.3
Jeju	3.4	7.0	0.3	6.3	-	0.6	1.1	0.7	19.3
Chungcheongnam-do	11.6	6.5	2.7	2.3	0.2	8.7	3.2	0.4	35.7
Chungcheongbuk-do	7.8	2.5	1.5	1.5	1.1	9.2	1.9	0.9	26.4
Total	191.4	88.1	40.7	62.0	32.1	117.2	101.5	41.8	674.6

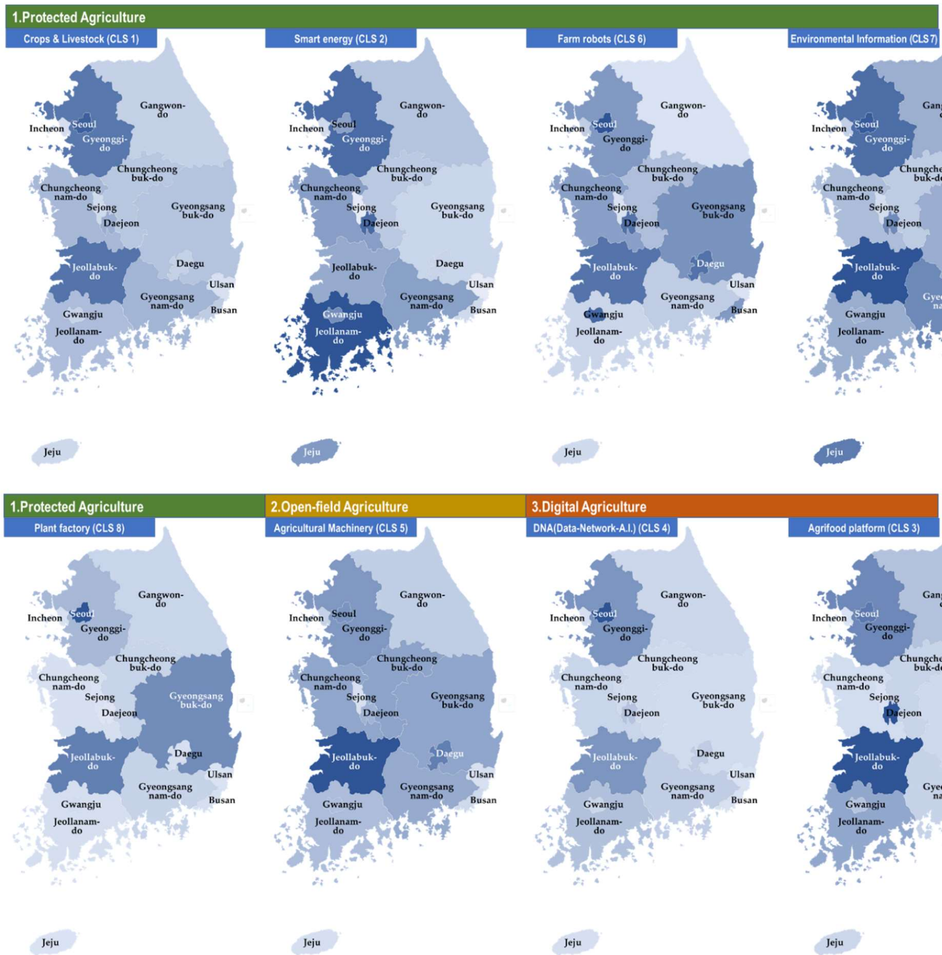


Figure 8. Status maps of the 17 regions of Korea for the eight smart-agriculture research areas. AI: artificial intelligence.

Regarding the status and role sharing in the industry-university-institute R&D collaboration ecosystem in the smart agricultural industry, the study reviewed the status of public R&D investment by substituting technology cluster and regional perspectives. This result shows the competitiveness of innovative organizations (industry-university-institutes) for each technology cluster of smart agriculture R&D in each region.

From Table 7, Seoul, with an edge in all technology cluster areas, including crops and livestock (CLS 1), data·network·AI (CLS 4), agricultural machinery (CLS 4), open-field agriculture (CLS 5), and plant factories (CLS 8), has balanced competitiveness (university: USD 40,817 thousand; industry: USD 37,962 thousand; institute: USD 34,232 thousand). The proportion of the industry's R&D role in all technology cluster areas was high; thus, there is active technology development and commercialization. The result indicates the investment status by technology cluster area in each region and the competitiveness and role sharing of innovative organizations (industry-university-institute) by technology area. That is, by showing the level of industry-university-institute R&D competitiveness within the region, this result provides basic information on how to construct and support an R&D collaborative ecosystem per each region's technological competitiveness level.

3.3. Strategic Directions of R&D Investment for Smart Agriculture from a Regional Perspective: Strawberry

This study aims to determine whether there is a regional difference in the level of the R&D collaborative ecosystem and network capabilities for specific crops. It examines the status of public R&D projects involving strawberries. Strawberries lead all aspects of Korea's smart agriculture, such as cultivation area, production amount, and export volume, as per the Rural Development Administration and the Ministry of Agriculture, Forestry, and Food.

3.3.1. Status of Government-Funded Project Investment by Region Regarding Strawberries

The study investigates the regional R&D investment status to examine regional differences in R&D capabilities related to strawberries in Korea. The strawberry-related R&D investment is USD 11,333 thousand, and regional strawberry-related R&D capabilities were concentrated in Jeollanam-do, Gyeongsangnam-do, and Jeollabuk-do. The current proportion of R&D investment in the three regions is 67.1% of the nationwide market share. Jeollanam-do received the highest investment of USD 3095 thousand, followed by Gyeongsangnam-do (USD 2502 thousand) and Jeollabuk-do (USD 2004 thousand). Table 8 and Figure 9 show the current status of R&D investment in the 17 regions of Korea.

3.3.2. Status of Government-Funded Projects for Strawberry from the Perspectives of Technology Clusters, Stakeholders, and Regions

The study investigated the three most intensively invested regions by industry-university research subjects, technology cluster, and region to understand the R&D collaboration ecosystem and network capability level for strawberries and suggest implications for future R&D investment directions (Table 9). First, we examined the investment status of each research entity (industry-academic-research) in Jeollanam-do, Gyeongsangnam-do, and Jeollabuk-do, the top three regions with the most government R&D expenditure for strawberry production. Relative to other regions, Jeollanam-do, the region with the greatest R&D investment, saw a balanced investment in all organizations, such as companies, research institutes, and universities, and its industrial R&D capabilities are significantly greater. Gyeongsangnam-do and Jeollabuk-do saw intensive investment in research institutes, and the amount of R&D investment in their industries was small relative to the total investment amount. Thus, the amount of public R&D investment in industries is insufficient even relative to the overall status of the nation by organization. Second, the study examined the R&D investment status by technology cluster in the top three regions. Jeollanam-do saw the most investment in the areas of crop and livestock productivity advancement (CLS 1). Moreover, Jeollanam-do saw higher R&D investments in environmental information (CLS 7) and data·network·AI platform (CLS 4) than the other two regions. Meanwhile, in Gyeongsangnam-do and Jeollabuk-do, crop and livestock productivity advancement (CLS 1) saw much R&D investment.

Table 7. Status of public research and development investment by technology cluster and region.

(Unit: Thousand USD)	Organization	Gangwon-do	Gyeonggi-do	Gyeongsangnam-do	Gyeongsangbuk-do	Gwangju	Daegu	Daejeon	Busan	Seoul	Sejong	Ulsan	Incheon	Jeollanam-do	Jeollabuk-do	Jeju	Chungcheongnam-do	Chungcheongbuk-do
Crops and livestock (CLS_1)	Industry	2555	13,369	696	2195	1675	2004	4545	529	12,476	492	1217	2905	2377	2956	984	6921	2174
	University	1659	2593	4783	1450	2540	3024	3307	5092	17,322	111	42	450	4136	6902	1554	572	3473
	Institute	1061	10,844	6925	1438	383	385	6075	613	6730	-	-	-	2167	15,673	799	4088	2156
	Misc.	127	1828	-	3541	-	-	-	408	1092	121	-	-	1789	4058	21	-	-
Smart energy (CLS_2)	Industry	1197	6367	4550	1241	7930	333	1639	1453	3060	621	-	1209	12,673	665	745	4567	2388
	University	1466	377	358	16	134	823	1128	192	2405	-	-	433	466	817	6217	350	-
	Institute	292	3798	1488	-	-	83	8498	-	821	-	-	-	392	3911	50	1625	83
	Misc.	-	983	-	-	-	-	-	-	-	-	-	-	225	-	-	-	-
Farm robots (CLS_6)	Industry	-	2336	541	468	1229	4528	554	3181	4658	-	-	1200	409	814	333	1433	1362
	University	-	629	83	302	3680	-	3422	-	1080	-	-	-	-	1411	-	83	117
	Institute	-	-	263	2448	-	-	550	-	-	-	-	-	67	1987	-	1175	-
	Misc.	-	-	-	-	-	-	-	-	-	-	-	-	42	267	-	-	-
Environmental information (CLS_7)	Industry	2033	5984	1553	1741	1727	528	2258	346	3735	-	447	989	2413	1208	1027	1024	424
	University	766	1001	443	1133	1058	815	1354	1067	3313	-	-	250	100	922	5208	878	558
	Institute	413	158	3460	283	-	-	1731	-	650	-	-	-	628	6335	42	438	505
	Misc.	-	-	3	98	-	-	-	-	500	100	-	-	168	158	-	-	-
Plant factory (CLS_8)	Industry	775	2833	465	2722	438	158	658	211	1696	-	-	-	-	1682	-	21	729
	University	-	40	556	579	17	83	-	-	2875	-	-	-	292	2951	-	197	358
	Institute	250	142	100	2659	-	-	167	-	5641	-	-	-	25	2501	-	-	17
	Misc.	-	-	-	217	-	-	-	-	-	-	-	-	-	-	-	-	-
Agricultural machinery (CLS_5)	Industry	1860	6392	4706	6182	1955	11,506	1250	728	3057	-	287	1709	3863	6531	49	7644	7269
	University	732	1223	1959	754	3247	2420	3282	592	5586	-	-	648	260	2816	278	151	1833
	Institute	371	2341	1446	1820	-	257	2043	-	2465	-	-	117	283	10,268	247	946	119
	Misc.	-	954	-	33	-	144	167	-	366	-	-	-	1042	1013	-	-	-
Data·network·artificial intelligence (CLS_4)	Industry	951	13,796	200	1381	409	3281	3293	368	6398	3	283	848	3547	4653	993	639	995
	University	538	529	2700	340	3951	339	717	3	4994	-	-	-	992	1210	-	262	492
	Institute	1192	1559	1633	50	-	1078	2318	33	17,925	-	-	-	1930	7305	100	2277	425
	Misc.	-	350	-	-	-	-	283	-	74	229	-	-	630	2959	-	-	-
Agri-food platform (CLS_3)	Industry	713	4525	410	-	675	458	688	263	2882	-	-	-	1625	1173	353	291	490
	University	468	106	200	200	478	250	6677	1403	3241	117	-	-	377	144	153	-	167
	Institute	629	550	231	166	533	-	950	838	-	-	-	-	1305	6556	189	79	233
	Misc.	76	92	75	192	-	-	-	-	-	-	-	-	144	446	-	-	-
Total	Industry	10,084	55,602	13,121	15,931	16,039	22,796	14,886	7078	37,962	1116	2234	8859	26,906	19,683	4484	22,540	15,831
	University	5630	6498	11,083	4774	15,105	7754	19,886	8349	40,817	228	42	1781	6622	17,172	13,409	2493	6996
	Institute	4208	19,393	15,545	8865	917	1803	22,332	1483	34,232	-	-	117	6795	54,533	1427	10,628	3538
	Misc.	203	4207	78	4082	-	144	450	408	2032	450	-	-	4040	8901	21	-	-

Table 8. Status of public research and development projects for strawberries in Korea.

Regions	(Unit: Thousand USD)	Ratio
Gangwon-do	350.8	3.1%
Gyeonggi-do	477.5	4.2%
Gyeongsangnam-do	2502.4	22.1%
Gyeongsangbuk-do	552.5	4.9%
Daegu	733.3	6.5%
Daejeon	150.0	1.3%
Seoul	750.0	6.6%
Jeollanam-do	3095.8	27.3%
Jeollabuk-do	2004.6	17.7%
Chungcheongnam-do	658.3	5.8%
Chungcheongbuk-do	58.3	0.5%
Total	11,333.6	100.0%

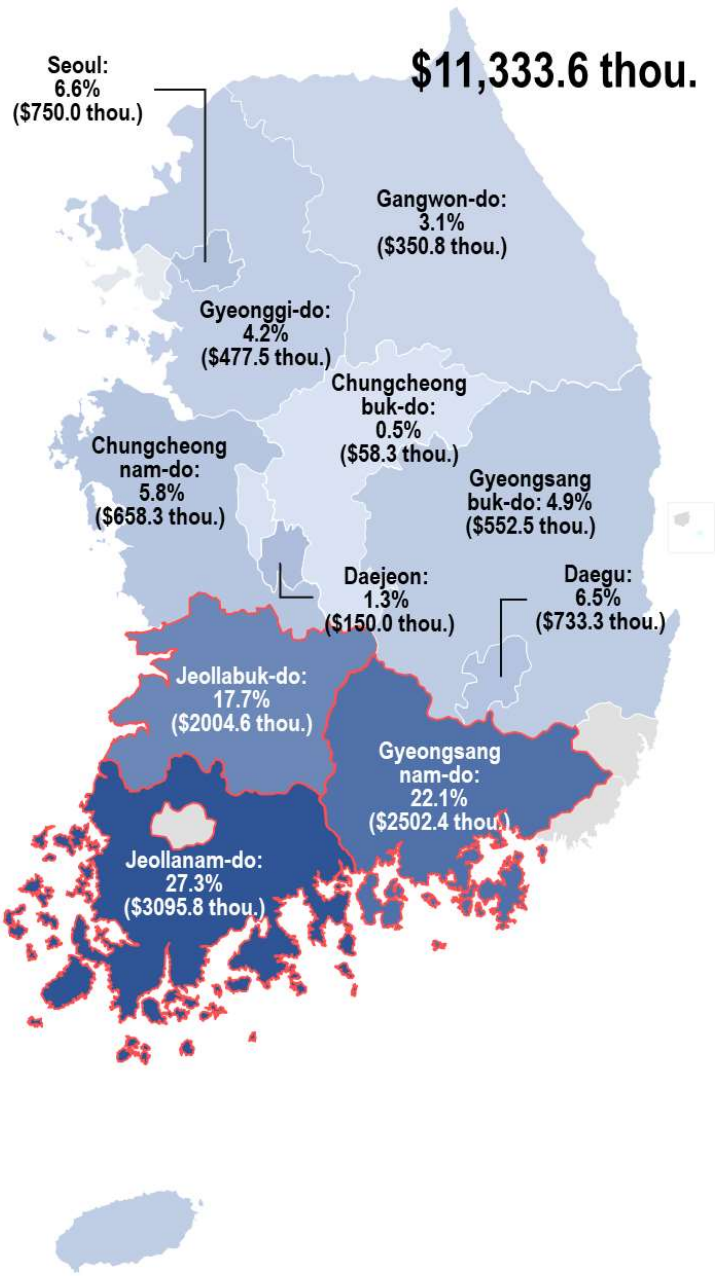


Figure 9. Status maps of public research and development projects for strawberries in South Korea.

Table 9. Status of public research and development investment by technology clusters, regions, and stakeholders.

(Unit: Thousand USD)	Types of Organizations	Protected Agriculture				Open-Field Agriculture	Digital Agriculture		Total
		Crops and Livestock (CLS_1)	Smart Energy (CLS_2)	Environmental Information (CLS_7)	Plant Factory (CLS_8)	Agricultural Machinery (CLS_5)	Data·Network·Artificial Intelligence (CLS_4)	Agri-Food Platform (CLS_3)	
Jeollanam-do	Industry	665	-	-	-	-	167	793	1625
	University	165	-	-	25	-	-	127	317
	Institutes	232	-	183	25	-	108	197	746
	Misc.	189	-	75	-	-	-	144	408
	Sub-total	1251	-	258	50	-	275	1261	3096
Gyeongsangnam-do	Industry	-	-	-	-	283	-	-	283
	University	225	-	-	-	-	-	-	225
	Institutes	1740	-	254	-	-	-	-	1994
	Misc.	-	-	-	-	-	-	-	-
	Sub-total	1965	-	254	-	283	-	-	2502
Jeollabuk-do	Industry	-	-	-	-	-	-	-	-
	University	133	-	-	-	-	-	-	133
	Institutes	892	167	146	-	-	375	-	1580
	Misc.	167	-	125	-	-	-	-	292
	Sub-total	1192	167	271	-	-	375	-	2005
Sub-total of three regions	Industry	665	-	-	-	283	167	793	1908
	University	524	-	-	25	-	-	127	676
	Institutes	2864	167	583	25	-	483	197	4319
	Misc.	356	-	200	-	-	-	144	700
	Sub-total	4409	167	783	50	283	650	1261	7603
Total strawberries by organization	Industry	1473.50	170.83	350.83	708.33	283.33	166.67	792.83	3946
	University	523.75	-	545.83	254.17	-	116.67	126.83	1567
	Institutes	3168.50	306.67	582.88	25.00	-	741.67	197.08	5022
	Misc.	355.50	-	298.33	-	-	-	144.42	798
	Sub-total	5521	478	1778	988	283	1025	1261	11,334
Total strawberries by year	2015	1246	-	83	25	-	-	-	3369
	2016	1307	44	51	33	-	42	108	3601
	2017	912	217	375	33	-	42	160	3755
	2018	443	217	443	33	-	67	382	3603
	2019	338	-	298	158	117	267	382	3578
	2020	668	-	348	242	167	608	230	4282
	2021	608	-	179	463	-	-	-	3271
	Sub-total	5521	478	1778	988	283	1025	1261	11,334

We obtained a detailed status on innovative organization names, R&D project titles, R&D stage level, project managers, and funding size (Table 10) to present the regional R&D investment direction and potential collaboration network list of strawberry-related industries. This collaborative network list can provide information necessary for stakeholders to establish, plan, and budget adjustments to determine the nature and direction of local organization research capabilities. Furthermore, it is possible to provide useful information to make appropriate policies considering the role of each organization and the regional capabilities and realistic environments based on the organization's strengths and weaknesses.

Jeollanam-do is an example of a practical innovation model as its R&D collaboration ecosystem is the most balanced. In a project called the Jeonnam 6th industrialization demonstration model development for strawberries based on ICT convergence, local research institutes oversaw the advanced technologies to improve new varieties for growth, quality, and productivity per the value chain of the strawberry industry. Small and medium-sized enterprises such as ELSYS and One's Berry developed a complex environment integrated support system for optimal growth management and post-procession programs necessary for postharvest distribution and export. Universities played a role in researching growth models or standardizing related data construction and information systems. Therefore, using this collaborative model, this study can present various discussion agendas and policy implications. It enables the promotion of policies to strengthen existing networks and promotes policies to extend sustainable smart agricultural models by fostering innovative organizations with smart energy technology capabilities or technologies not included in existing network pools, such as the strawberry vertical farm factory. Moreover, in

Gyeongsangnam-do and Jeollabuk-do, where R&D capabilities are relatively concentrated in research institutes, policies can be proposed to support technology commercialization promotion programs, such as venture company start-ups and technology transfers.

Table 10. Representative strawberry-related research organizations, project titles, and funding size in three regions.

Region	Type of Organization	Organization	R&D Title	R&D Spectrum	Project Manager	Funding (Thousand USD)
Gyeongsang nam-do	University	Gyeongsang National University	Practical infrastructure development based on information on space movement and mutual exchange of strawberry flower-biome	Applied	Yeon-Sik Kwak	225
	Institutes	National Institute of Horticultural and Herbal Science	Study on the growth characteristics according to the temperature of the cooling, heating, and irrigation water during partial cooling and heating for high-bed strawberry	Experimental	Jong-Pil Moon	150
	Institutes	National Institute of Horticultural and Herbal Science	The development of a hanging-bed culture system in greenhouse strawberry	Experimental	Myung-Hwan Cho	185.83
	Institutes	National Institute of Horticultural and Herbal Science	The development of a hanging-bed culture system in greenhouse strawberry	Experimental	Lee Han-cheol	170
	Industry	Daisys Co., Ltd. Daegu, South Korea	Smart-farm development and demonstration suitable for night and (melons and watermelons) and strawberry cultivation in Dandong greenhouses	Experimental	Kim Ki-hwan	316.67
	Industry	Dongin Co., Ltd. Jinju, South Korea	Development of electric cultivator for strawberry high-rise reclamation	Experimental	Donghoon Kang	283.33
Jeollanam-do	University	Mokpo National University	Closed strawberry seedling demonstration advancement and economic analysis	Basic	Park Kyung-seop	25
	University	Sunchon National University	Development of an empirical model for the 6th industrialization of Jeonnam strawberry based on ICT convergence	Experimental	Chang-Sun Shin	291.67
	Institutes	Gangjingun Agricultural Research & Extension Services	Development of vitality technology to produce excellent strawberry seedlings	Experimental	Young-Jun Choi	183.33
	Institutes	Damyanggun Agricultural Research & Extension Services	Development of an empirical model for the 6th industrialization of Jeonnam strawberry based on ICT convergence	Experimental	Cheol-Gyu Lee	166.67
	Institutes	Jeollabuk-do Agricultural Research & Extension Services	Development of an empirical model for the 6th industrialization of Jeonnam strawberry based on ICT convergence	Experimental	Gil-Ho Shin	90
	Institutes	Jeollabuk-do Agricultural Research & Extension Services	The establishment of a supply system for rapid propagation and early dissemination of new strawberry cultivars	Experimental	Jong-Boon Seo	25
	Institutes	Jeollabuk-do Agricultural Research & Extension Services	Field demonstration and enhancement of optimal growth control model for smart-farm strawberry and tomato in Jeonnam province	Applied	Kyung-Cheol Cho	108.33
	Industry	ELSYS Co., Ltd. Naju, South Korea	Development of an empirical model for the 6th industrialization of Jeonnam strawberry based on ICT convergence	Experimental	Kyung-Woo Oh	750

Table 10. *Cont.*

Region	Type of Organization	Organization	R&D Title	R&D Spectrum	Project Manager	Funding (Thousand USD)
Jeollanam-do	Industry	ELSYS Co., Ltd.	Bear gray room building export energy savings for disease control in strawberry cultivation-type environmental management and disease forecasting/reporting system	Basic	Yo-Han Kim	166.67
	Industry	Green Contro System Co., Ltd. Gwangju, South Korea	Development of fruit vegetable (tomato, paprika, and strawberry) growth management program using a growth model	Applied	Im-Sung Bae	166.67
	Industry	One's berry Co., Ltd. Damyang, South Korea	Development of an empirical model for the 6th industrialization of Jeonnam strawberry based on ICT convergence	Experimental	Doo-Hyun Yoon	541.67
	Miscellaneous	Korea Greenhouse Crop Research Institute	Development of an empirical model for the 6th industrialization of Jeonnam strawberry based on ICT convergence	Experimental	Beom-Seok Seo	333.33
	Miscellaneous	Korea Greenhouse Crop Research Institute	Development and demonstration of environmental control optimization technology for high-productivity strawberry greenhouse	Basic	Beom-Seok Seo	75
Jeollabuk-do	University	Jeonbuk National University	Strawberry disease diagnosis web UI advancement and expert utilization system establishment	Experimental	Jun-Hwan Lee	133.33
	Institutes	National Institute of Agricultural Sciences	Development of smart environment control system for growing strawberry greenhouse	Applied	Han Gil-soo	145.83
	Institutes	National Institute of Agricultural Sciences	Development of an energy-saving system for growing strawberries	Applied	Jong-Pil Moon	83.33
	Institutes	National Institute of Agricultural Sciences	Development of transplanting method and flowering promotion techniques for export strawberry	Applied	Jong-Pil Moon	81.67
	Institutes	National Institute of Agricultural Sciences	Development of control method for a bacterial angular spot of strawberry	Basic	In-Sik Myung	41.67
	Institutes	National Institute of Agricultural Sciences	Developed and demonstrate a responsive web UI for strawberry disease based on a cloud system	Experimental	Jeong-Hyun Baek	41.67
	Institutes	National Institute of Horticultural and Herbal Science	Demonstration of strawberry cultivation using an innovative cooling house that overcomes high temperatures and research on optimal management technology	Applied	Dae-Young Kim	291.67
	Institutes	National Institute of Horticultural and Herbal Science	The study of optimizing the cultivated environment of strawberries on a two-floor bed system	Basic	Seung-Yu Kim	269.17
	Institutes	National Institute of Horticultural and Herbal Science	Image collection and DB upgrade for strawberry disease diagnosis AI training	Experimental	Jong-Han Park	33.33
	Institutes	National Institute of Horticultural and Herbal Science	Development of an energy-saving system for growing strawberries	Applied	Jin-Kyung Kwon	83.33
	Institutes	National Institute of Horticultural and Herbal Science	Development of transplanting method and flowering promotion techniques for strawberry export	Applied	Jin-Kyung Kwon	181.67
	Institutes	National Institute of Horticultural and Herbal Science	The effect of root-cutting time on the growth characteristics of strawberries during in situ seeding production	Applied	Jae-Han Lee	263.33

Table 10. *Cont.*

Region	Type of Organization	Organization	R&D Title	R&D Spectrum	Project Manager	Funding (Thousand USD)
Jeollabuk-do	Institutes	National Institute of Horticultural and Herbal Science	Development of application technology of greenhouse shading agent for stable production in exporting strawberry	Applied	Jae-Han Lee	100
	Institutes	National Institute of Horticultural and Herbal Science	The study of the hanging-bed culture system as a demonstrate culture in greenhouse strawberry	Experimental	Myung-Hwan Cho	183.33
	Institutes	Jeollabuk-do Agricultural Research & Extension Services	The field study of 1st generation smart-farm technology with ICT convergence	Applied	Eun-Ji Kim	83.33
	Miscellaneous	Rural Development Administration	Field demonstration and improvement of growth model of strawberry and tomato for optimal control in a smart greenhouse in Jeonbuk province	Applied	Hye-Jin Lee	125

The study investigated recent research trends of government-funded R&D projects to provide potential R&D collaboration partners in the strawberry-related industry. Table 11 lists recent R&D projects related to strawberry pest control technology. Innovative organizations with technological competitiveness in controlling strawberry-related pests include Chungcheongnam-do Agricultural Technology Institute in Chungcheongnam-do, National Horticultural Research Institute, and Chonbuk National University in Jeollabuk-do. This list can provide information as a tool to find potential collaboration partners for innovative models of R&D collaboration, such as in Jeollanam-do. That is, it is possible to strengthen the R&D innovation model of local smart agriculture by establishing a new cooperation system with innovative organizations that have pest control technologies in other regions not included in the existing R&D collaboration network pool.

Table 11. Representative strawberry pest control-related research organizations, project titles, and funding size.

Region	Type of Organization	Organization	R&D Title	R&D Spectrum	Project Manager	Funding (Thousand USD)
Jeollabuk-do	University	Jeonbuk National University	Strawberry disease diagnosis web UI advancement and expert utilization system establishment	Experimental	Jun-Hwan Lee	133.33
Jeollabuk-do	Institutes	National Institute of Horticultural and Herbal Science	Image collection and DB upgrade for strawberry disease diagnosis AI training	Experimental	Jong-Han Park	33.33
Chungcheong nam-do	Institutes	Chungcheongnam-do Agricultural Research& Extension Services	Development of control technique of disease and insect pest in hydroponic culture	Applied	Myung-Hyun Nam	158.33
Jeollabuk-do	Institutes	National Institute of Agricultural Sciences	Develop and demonstrate a responsive web UI for strawberry disease based on a cloud system	Experimental	Jeong-Hyun Baek	41.67
Chungcheong nam-do	University	Kongju National University	Development of export strawberry dry damage reduction technology	Experimental	Hyo-Gil Choi	154.17

4. Discussion

4.1. R&D Investment Strategy and Collaborative Ecosystem Framework for Sustainable Smart Agriculture in Korea

The proposed framework for sustainable smart agriculture in Korea provides a variety of useful information regarding research areas, regions, and stakeholders. Three RQs (eight subcategory RQs) were raised to demonstrate the usability of the framework. First, regarding RQ1, the study provided useful information to establish the investment direction of the Korean government in the agricultural R&D sector. Specifically, regarding RQ1-1 and RQ1-2, the study revealed the overall and regional status of government R&D investment in smart agriculture during the 2015–2021 period to provide evidence to stakeholders to discuss the appropriateness of R&D investment from the Korean central and local government perspective. Regarding RQ1-3, the study examined the investment situation of government R&D from the perspective of research areas on smart agriculture in Korea to provide information to determine the concentration of research areas, thereby discussing the degree of government R&D investment in each research area.

Second, regarding RQ2, we investigated changes in the government R&D investment trend as of 2018 when the Smart Farm Expansion Plan was announced. Moreover, the implementation of such government R&D investment was analyzed for differences per individual regions and innovative organizations performing R&D. The emergent result showed that the total amount of government R&D investment increased significantly, and the direction of the investment shifted from protected agriculture, such as smart farming, to open-field agriculture. Further, the government focused on smart energy R&D while considering the global environmental issue of carbon neutrality. Thus, stakeholders can use this information to discuss the allocation of government R&D investment for the next national smart agriculture plan. Regarding RQ2-2, the study investigated the status of public R&D investment concerning technology clusters, regions, and organizations. The results showed the degree of R&D capabilities of the industry-university-institutes in the regions and the regional research competitiveness, which can be the starting point to build and support an R&D collaboration ecosystem for a research area. Moreover, for central and local policymakers in charge of developing collaboration programs, these results can be adopted as fundamental information to enhance a strategic R&D collaboration or partnership in a specific research domain.

Third, regarding RQ3, the proposed framework presents the information needed to establish knowledge and strategies for various stakeholders to discover the role of the R&D cooperation ecosystem for sustainable smart farming and potential collaborators. Furthermore, we demonstrated the usefulness of the framework in creating an R&D collaboration ecosystem through the strawberry case. Regarding RQ3-1, the study identified the three regions with the highest R&D investment. This result showed the potentially attractive or benchmarking regions to be investigated. Regarding RQ3-2 and RQ3-3, we examined the level of the R&D collaborative ecosystem and network capabilities for strawberries and suggested future collaboration strategies for government R&D investment. The study provided detailed information, such as organization name, R&D project title, R&D stage level, project manager, and fund size, to present the direction of regional R&D investment and the potential collaboration network list for strawberry-related industries. The collaboration situation and potential network lists may become essential information to ensure coordination, planning, and budget adjustments to determine the nature and direction of R&D in local research organizations. Moreover, it is possible to provide useful information to develop appropriate policies considering the role of each organization, its regional capabilities, and the realistic environment per its strengths and weaknesses.

4.2. Conclusions

The Korean government has continuously announced national plans regarding smart agriculture, including the 2nd Comprehensive Plan (2014) [12], Smart Farm Expansion Plan (2018) [15], 3rd Comprehensive Plan (2019) [13], Smart Farm Innovation Valley projects in four regions (2018–2019) [27], and comprehensive measures to extend smart agriculture based on big data and AI (2021) [16]. Such announcements of national policies on smart agriculture may indicate a lack of a coherent plan, thereby deteriorating the effect of government investment [28] (National Assembly Legislative Research Office, 2019). Thus, there is a need to examine the status of smart agriculture from the perspective of technology and local innovative organizations to narrow the urban-rural gap by developing a practical framework that allows for showing the comprehensive investment situation, identifying the allocation of research funding from the perspective of regions and research areas, and bringing collaboration opportunities at the regional scale.

The proposed framework, stemming from previous works, showed changes in the Korean smart agriculture R&D policy that induced big data and AI-based digital agriculture extended the policy to open-field precision agriculture, and promoted urban factories in protected agriculture, which was previously largely confined to rural areas. That is, the policies have shifted from automation to intelligent automation and rural agriculture to urban agriculture. Furthermore, the case study of strawberry production empirically demonstrated the usability of creating a collaborative research ecosystem at the transregional scale.

This study makes two important contributions. First, it suggested the framework for government R&D investment and collaboration in the smart-agriculture sector. Multiple prior studies [49–53] provided directions or recommendations to develop better smart agricultural policies without considering government R&D investment information. However, it may create a bias in stakeholders during decision-making [45], thereby increasing ambiguity and the number of differing perspectives held by stakeholders [30,31]. This study addressed the limitation in the literature [49–53] by discussing the fundamental functions of a robust framework that enables stakeholders to understand the research investment situation, monitor research investment progress, and identify challenges in different technological areas and regions that need collaboration to ensure sustainability [35,39]. Thus, policymakers and stakeholders of central and local governments can view the investment concentration and regional distribution and set directions to consider the appropriate government investment to enhance regional competitiveness and capabilities.

Second, the study empirically showed how to operate the framework for smart agriculture. Although some previous studies on agriculture policy proposed practical investment frameworks [56,58], their frameworks did not show the systematic analysis process, including a precisely integrated innovation scheme with regional, technical, and organizational dimensions. However, this study provided information on the current situation of government R&D investment and showed various stakeholders (e.g., universities and research institutions) in smart agriculture from the perspective of 17 regions and technology clusters during the 2015–2021 period. Moreover, few prior studies [54,57,59] emphasize the importance of collaboration programs to support research-into-practice linkages in rural areas to accomplish an agricultural transformation. In response to these requests, this study considered the case of a research collaboration ecosystem for strawberries. In this study, the Jeollanam-do region was introduced as having developed the most balanced R&D collaboration ecosystem, and the list and status of potential future collaboration partnerships in this region were presented. Insights from this collaboration case study can help central and local governments develop policies to reinforce sustainable smart-farming models by nurturing innovative organizations with smart energy or strawberry pest control technology that are excluded from the existing network pool. Furthermore, local governments in Gyeongsangnam-do and Jeollabuk-do, where research institutions are relatively concentrated, must develop policies to support technology commercialization promotion programs, such as venture business start-ups and technology transfer, to address the weaknesses of the current research institute-oriented ecosystem.

4.3. Limitations and Further Research

Despite these contributions, this study has some limitations that present challenging questions for future research [60]. The data on public R&D projects were taken from the central government because there was no database on the R&D expenditures of the 17 local governments. Thus, the dataset for local government-funded projects must be assessed. Moreover, this study examined limited information items. Hence, future studies can examine more information (e.g., comparison of ministries' budgets) required by stakeholders (central and local government, research funding agencies, universities, private sectors, and research institutes). Meanwhile, to ensure the legitimacy of policy decision-making, future studies must develop a fair procedure that can reduce conflicts between stakeholders. Thus, for decision-makers, future studies can conduct a qualitative analysis of the degree of fairness in the information production procedure of the proposed framework and whether the information included multiple perspectives and greater transparency and investigated how the legitimacy is affected by participants' perspectives in an extended consideration.

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