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Smart Farming's Contribution to Sustainable Agriculture: Analyzing Linkages between South Korean Smart Farming Policy and Korean Sustainable Development Goals (K-SDGs)

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Abstract Smart farming (SF) receives significant attention not only as a maximizer of agricultural productivity, but also as a strategy to achieve United Nation's Sustainable Development Goals (SDGs), yet the actual state of its contribution to the environmental SDGs remains uncertain. This paper presents a methodological approach for policy analysis by identifying linkages between South Korean SF policies and Korean Sustainable Goals (K-SDGs) targets addressing six main South Korean agriculture-related environmental issues. Linkage is defined as an explicit measure that acts as a solution to prevent or minimize a specific issue. First, an overview of K-SDGs and six environmental issues (yield productivity, greenhouse gas emission, pest and weeds, water resources, soil quality and biodiversity) reveals that 17 K-SDGs targets address the issues. The analysis reveals significant shortcomings, particularly in the low integration of pesticide use and soil quality concerns into the K-SDGs. Out of a possible 68 linkages between four SF policies and 17 K-SDGs, only 17 were identified, with 10 linking to food production and consumption-related SDGs. This indicates that current smart farming policies put a secondary focus on smart farm technology's potential to minimize environmental challenges. To bridge the gap between SF and sustainable agriculture, SF policies should incorporate climate-smart agriculture, with a specific focus on reducing greenhouse gas emissions, and promote greater collaboration among policymaking institutions.

Keywords Smart Farming, K-SDGs, South Korea, Sustainable Agriculture, Linkages, Policy Analysis

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I. Introduction

Understood from its narrow definition, smart farming (SF) is defined as the maximization of yield quantity and quality through the Internet of Things (IoT) and Information and Communication Technology (ICT) solutions. However, when considering the perspective of multi-sectoral changes it can bring, SF potentially leads the way towards achieving the environmental, social and economic aspects of sustainable development. To realize the ambitious goal of sustainable development, the United Nations (UN) created a blueprint consisting of 17 Sustainable Development Goals (UN-SDGs) adopted in 2015 by all UN member states. Each SDG includes a number of corresponding targets which are adapted by individual country's governmental institutions to reflect the national-specific needs and urgencies centered around climate change, biodiversity preservation, poverty, inequality, health, and education while spurring economic growth (Sachs et al., 2024). SF is increasingly receiving attention as a possible strategy to achieve or improve SDGs and, by extension, ensure more sustainable agriculture. SF is crucial for ensuring food security amid climate change-induced conditions for agriculture (Musa & Basir, 2021) because it offers an undisrupted production of crops in the same regions despite fluctuations in temperature, unpredictable changes in precipitation and extreme weather events that are predicted to increasingly harm or destroy agricultural production (Ortiz-Bobea, 2021).

SF's potentials for contribution to achieving the SDGs and advancements in sustainable agriculture implementation are recognized not only in academia (Balafoutis et al., 2017; Ashir et al., 2022; Fragkou et al., 2023; Musa et al., 2022), but also in developed countries, which are implementing the necessary policies to support and lead their farmers towards adopting new farming practices and investing in SF technology (EU SCAR, 2013; EIP Agri, 2017; O' Shaughnessy et al., 2021; Kim et al., 2016; DAFF, 2023).

SDG theoretical framework perusing a balanced development of the three sustainability pillars (economic, social and environmental) is a concept difficult to achieve in practice (Campbell et al., 2018). Market-driven large agro-food corporations are known to prioritize economic benefits over social and environmental issues, while smallholders lack the knowledge and financial capabilities to practice farming conscious of their impact on the environment (Pagliacci et al., 2020). Developed countries are just as guilty of sacrificing sustainability's environmental pillar. According to the sustainable development goals report (Sachs et al., 2022), the top ten globally leading countries all underperform in achieving the main environmental SDGs (SDG 13, 14, 15). Therefore, an investigation into whether such an environmental disregard applies to SF policymaking and leads to a missed opportunity to utilize SF policymaking to address environmental challenges and a transition towards sustainable agriculture (Walter et al., 2017) is necessary. This paper chose South Korea as its case study and performed SDG and SF policy analysis.

As one of the world's leading technology innovators, pioneering the fields of electronics and telecommunications, South Korea (WIPO, 2023) became an important player in smart farm technology innovation, placing second amongst Asian countries with high growth opportunities in the Asia Pacific region (Markets and Markets, 2023). The size of Korean smart farms has increased from 405ha in 2014 to an estimated 7000ha in 2022, and the market share is expected to experience fast growth of 15.5% until 2025 and reach 4,9 billion USD in 2025 (Noh, 2023; MAFRA, 2020). According to Smart Farm Korea's open data platform, there are currently 134 smart farms in South Korea (Figure 1). Such an expansion comes because of a 20-year-long legacy of national policies promoting the digitalization of agriculture and rural areas (Kim et al., 2013; Jeong & Hong, 2019; Nam, 2020), which have eventually evolved into elaborate three 10-year steps (2020-2040) of SF implementation (MAFRA, 2019).

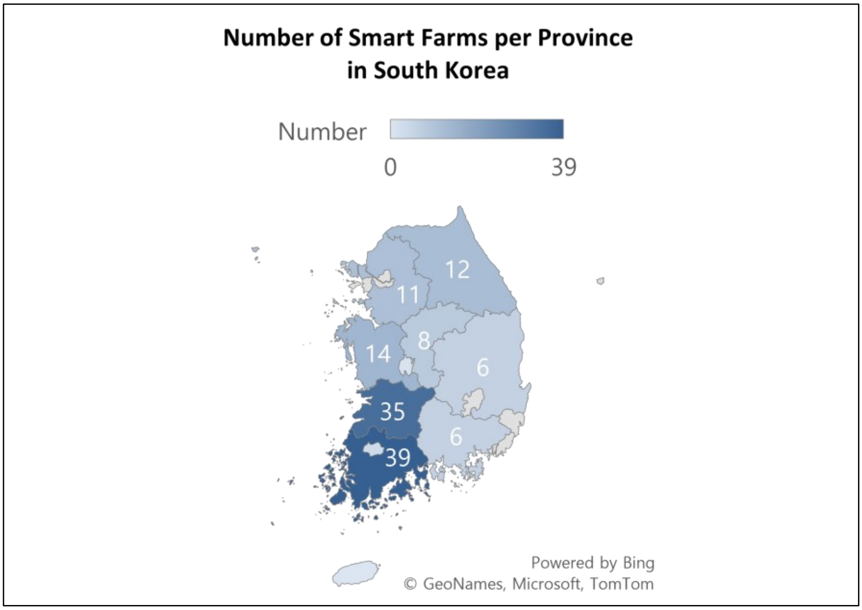

Figure 1. Number of Smart Farms per Province in South Korea
Source: Smartfarm Datamart, November 2023

Meanwhile, the Korean government pledges to the international agenda of sustainable development and the fight against climate change. Korea declared to reduce 40% of greenhouse gas (GHG) emissions until 2030 compared to its 2018 levels (Bureau of Climate, Environment and Science 2021) in its Nationally Determined Contribution 2030 (NDC) submitted in December 2021 (Bureau of Climate, Environment and Science 2021). Moreover, the Korean government actively supports the SDG agenda by creating a Commission on Sustainable Development and designing Korea-specific SDGs (K-SDGs), elaborating on 17 sustainable goals, 122 targets and 128 target indicators first featured in Korea's 3rd Sustainable Development Master plan in 2018 (Ministry of Environment, 2019) (Figure 2).

Figure 2. Korean Sustainable Development Goals (K-SDGs)

Source: Korea Sustainable Development Portal (https://ncsd.go.kr/). Translated by the author.

Nonetheless, none of the current Korean SF policies explicitly interconnect SF with concepts such as sustainable agriculture, which is as of now still limited to eco-friendly and organic food production practices (Kim et al., 2015). Moreover, while a more recently developed and adopted approach of climate-smart agriculture (FAO, 2019) and carbon-smart agriculture (Parameswaran, 2020) have been researched and suggested as a future development path by Korean national research centers, they are yet to be formulated into policies and related to existing SF policies.

This paper first identifies K-SDGs that address Korea's agricultural environmental issues, which are then used in policy analysis of four SF policies to identify linkages (FAO, 2019; Su et al., 2022) between SF policy and the K-SDGs. Linkage is defined as an SF policy measure or strategy that explicitly acts as a solution to prevent or minimize a specific issue formulated as a target through the K-SDG framework. The research is guided by two questions: first, which K-SDG targets address the current agriculture-related environmental issues in Korea? And second, which of these K-SDG targets do Korean SF policies explicitly support and which are overlooked? Results are discussed by dividing them into three topics, on track, shortcomings and policy improvements for a transition towards a more sustainable model of SF.

II. Literature Review

1. Conceptualization of Smart Farming within Sustainable Agriculture

SF is a way of managing agricultural crops and livestock that uses large sets of data to maximize the quantity and quality of production while minimizing the input of human labor. This entails monitoring of soil, water, waste, light, humidity, and temperature with the help of sensors, GPS and satellites, software that helps utilize, analyze, and visualize the data for solutions, as well as using robotics for mechanization (Iotforall, 2023). SF techniques include new approaches like precision farming, controlled environment agriculture (CEA) system and livestock monitoring (Grand View Research, 2022). Through the concept of SF, traditional farming practices can be transformed, not only producing food in a more effective and efficient way, but also considering the protection of the environment and benefits to society. The two examples are climate-SF (Wakweya, 2023; Hellin & Fisher, 2019) and carbon-SF (Parameswaran, 2020), which, alongside SF, make subcategories of sustainable agriculture, defined as a type of agriculture that produces high amounts of quality food by relying on renewable resources and natural processes on the farm to ensure environmental resource protection and longevity (Reganold et al., 1990) (Figure 3). There is a north-south geographical difference between countries adopting climate-SF and carbon-SF on one side, and SF on the other. While climate-SF and carbon-SF remain implemented primarily as an international cooperation project in developing countries led by organizations such as FAO and World Bank, they receive significantly less attention in the global north (EIP Agri, 2021; DAFF, 2023), where SF prevails as a preferred policy approach (Markets and Markets, 2023).

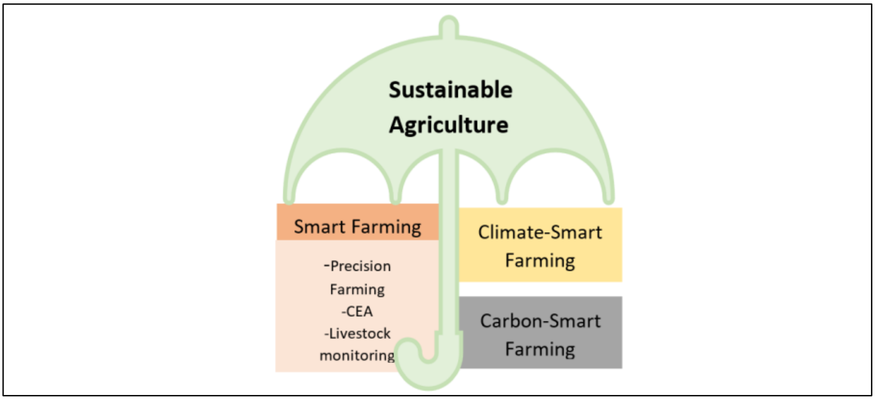

Figure 3. Sustainable Agriculture as an umbrella term for the forms of smart agricultural management and farming practices

SF with its farming technologies mitigating or adapting to climate change clearly indicates the potential to ensure a transition towards a more sustainable agricultural system. Walter et al. (2017) argued that a link between SF and sustainable agriculture could not be established unless SF includes four key aspects: technology, diversity in crops and livestock, market networks and policy-building institutions. Existing literature on SF shows academia's interest in SF technology (Tripicchio et al., 2015; Balafoutis et al., 2017; Verdouw et al., 2021; Ashir et al., 2022; Navarro et al., 2022), changes in crop and livestock (Grogan, 2012; Richard et al., 2021) and opening of new markets (Pivoto et al., 2018; Maraseni et al., 2021) aspect. However, despite most developed country's governments creating and pursuing SF since the 2010s, less attention has so far been paid to Walter et al. (2017)'s fourth key aspect - the way policies have been formulated and which policy strategies have been given priority (Koutridi & Christopolou, 2023; Nurhad et al., 2024).

Research on SF policy-building institutions in South Korea includes Suh and Kim (2016) who analyzed policy priorities of SF and found that the policy's focus lies in increasing farmer's income, lessening the managing costs and integrating smart farms into the local system, while Jeong & Hong (2019) analyzed Korean SF from a three-stream perspective, problem, policy and political stream and found the government to be the key factor that introduced SF as a policy alternative to improve Korea's agricultural competitiveness and employment of young people. Similarly, shedding light on the government's role in SF formulation, O'Shaughnessy et al. (2021) perform a comparative study of USA in South Korean SF policy and discover a number of cultural and political differences that distinctively divide the process of growth and promotion of smart farms. Moreover, they suggest the failures and successes of both country's approaches be evaluated and compared to find new solutions to faster achievement of the sustainable development indicators, SDGs.

While such a 'bottom-up' evaluation is a valuable and meaningful approach for checking the progress of implemented policies and benchmarking successful policy strategies, another approach is to evaluate the policies from a more 'top-down' approach. That is to perform a policy analysis of already formulated government's SF strategies and measures and to evaluate the extent to which they explicitly address, in other words, link to a specific SDG target. The described policy evaluation approach brings insight into contributions as well as shortcomings clearly indicating the areas for improvement.

2. Contribution of Smart Farming Policy towards Achieving the SDGs

The topic of SF's potential to contribute to or disrupt the SDGs is relatively well represented in academia. According to Musa et al. (2022), SF can create new jobs, especially for the highly skilled youth (SDG 8), and strengthen and secure the sustainable food system (SDGs 2, 12). Similarly, Ashir et al. (2022) find that smart agriculture supports the achievement of SDGs 6, 7, 8, 9, 11 and 12, while Balafoutis et al. (2017), Fragkou et al. (2023) and Bartkowiak (2021) mention significant reductions in pollutants and greenhouse gasses on farms which adopted SF (SDGs 9, 14, 15). Pereira et al. (2022) emphasize low energy efficiency amongst many rural farms and develop a solar energy control system pilot project to increase energy consumption efficiency on a large livestock and crop production rural farm. A regular farm implementing such a system was converted into a smart farm and found to contribute to achieving SDG 7 (affordable and cleaner energy) with an 83.2% reduction in energy from the grid and 5527 kg CO_2 savings, as well as SDGs 6, 9 and 10. Likewise, Lin et al. (2021) merge the idea of smart farm and wind renewable energy and propose an application method which is efficient, reliable and consumes less energy.

Although application methods such as those proposed by Pereira et al. (2022) and Lin et al. (2021) are a positive step forward, significant environmental concerns about smart farm's role in exacerbating climate change remain. Smart farm's operation is known to consume larger amounts of electricity, difficulties in renewable energy sources integration, land use, CO_2 emissions and socio-economic issues. Lieder & Schroter-Schlaack (2021), for example, identify several rebound effects affecting the environment negatively that could diminish the positive effects of SF technologies. They discuss how the core idea of SF, 'more yield for a lower input', might incentivize farmers to expand the intensive use of farmland and adjust to monocultural production of bioenergy crops, which would result in increased intensity of fertilizer use especially on a heterogeneous field, risk of biodiversity loss and long-term damage to soil health.

Moreover, they point out that despite an improvement in energy efficiency brought by the SF technology, the increase in consumed energy is significant. Nevertheless, they conclude that compared to regular commercial farm, SF technologies ultimately enhance the protection of the environment during food production while improving food security, which overall outweighs the increase in energy use. Focusing on SF's CO_2 emission levels, Lee (2023) finds that a popular smart farm technology called the hydroponic cultivation technique leads to higher emissions compared to traditional farming due to the lack of soil soaking up the carbon dioxide. Taking a sociological approach, some research discusses obstacles to SF implementation such as the inability or unwillingness to accept or reject the technologies by farmers (O'Shaughnessy et al., 2021; Marescotti et al., 2021), concerns regarding data privacy (Regan, 2019), and endangered equity of small farmers due to government's prioritization of funding the multinational agro-food corporations (Bronson, 2018).

III. Analytical Framework and Policy Analysis Methods

The schematic diagram (Figure 4) graphically demonstrates the methodological approach for analyzing the consideration of K-SDG targets addressing agriculture-related environmental issues in SF policies. First, a literature survey and review are done to identify the K-SDG targets used to review and identify linkages between SF policies. Twelve academic papers conducting case studies across the world were found via a word search combining terms related to sustainable agriculture ('climate-smart agriculture,' 'climate-sustainable farming (climate-SF),' 'carbon-smart agriculture,' and 'carbon-sustainable farming (carbon-SF)') with the word 'SDG' on Google scholar, Science direct and Taylor and Francis online academic journal search engine. Pagliacci et al. (2020) offer a perspective that some smart farms possessing the technology, environmental social awareness, and knowledge and are financially supported by policies can be characterized as implementors of climate-SF, despite not being directly associated with the term. This indicates the blurred lines between definitions and the scope between SF, climate-SF and carbon-SF as types of smart sustainable agriculture. Therefore, focusing the literature review solely on SF and SDG-related research would result in limited conclusions that place SF into a box and unfairly narrow the scope of SF's potential for sustainability. Table A1 and Table A2 (Appendix) display results of the literature survey, showing that out of the 17 UN-SDGs, 11 SDGs (1, 2, 6, 7, 8, 9, 11, 12, 13, 14, 15) were found as improvable through sustainable agriculture. SDG 2 (Zero Hunger) is the most frequently referenced, which aligns with agriculture's central role in ensuring food security. Subsequently, SDG 9 (Industry, Innovation, and Infrastructure), 13 (Climate Action), and 15 (Life on Land) also feature prominently, reinforcing the interconnectedness between climate change, environmental protection, and sustainable agriculture.

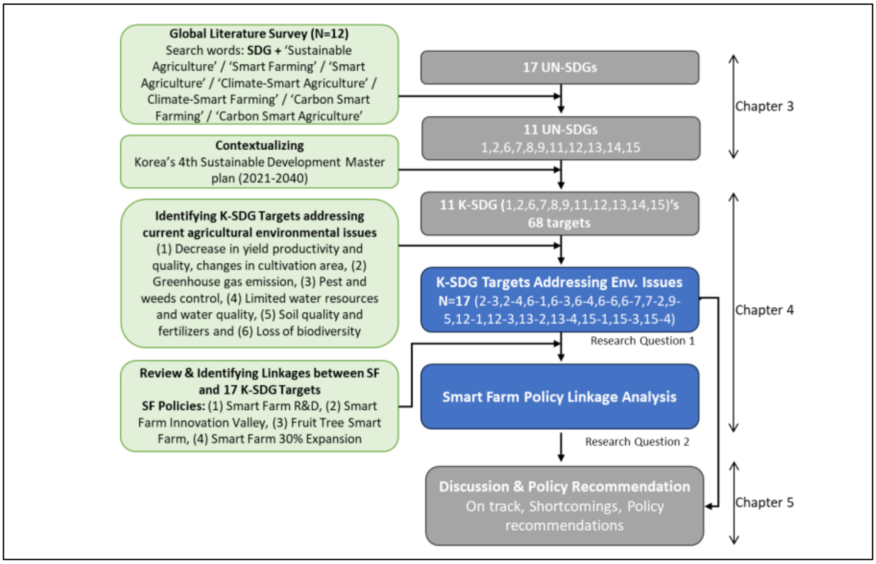

Figure 4. Schematic diagram of a methodological approach for analysis of links between K-SDGs and agricultural environmental issues and smart farming policies

Chapter 4 first contextualizes the 11 UN-SDGs within the case study by extracting the 11 corresponding K-SDGs. Based on Korea's 4th Sustainable Development Master Plan (2021-2040), the 11 K-SDGs include a total of 68 targets, which were carefully and thoroughly reviewed to identify specific targets that address at least one of the six main agricultural environmental issues in South Korea. Six environmental issues were extracted from South Korea Climate Change Assessment Report, 2020 (KMA, 2020) as (1) Decrease in yield productivity and quality, cultivation area changes (Chae, 2022; RDA, 2022), (2) Greenhouse gas emission (FAO, 2020; Lee, 2020), (3) Pest and weeds control (Kwon et al., 2012; Hong et al., 2021) (4) Limited water resources and water quality (Nam et al., 2015; O'Shaughnessy et al., 2021), (5) Soil quality and fertilizers (OECD, 2020; Jeon et al., 2022) and (6) Loss of biodiversity (SNU News, 2020; Rho, 2007). The review process revealed 17 K-SDG targets as directly targeting the improvement of sustainable farming and farming land use.

Four recent SF policies were selected for analysis to examine linkages between Korean SF policies and the 17 Korean Sustainable Development Goals (K-SDGs). The chosen policies are "Smart Farm R&D," "Smart Farm Innovation Valley," "Fruit Tree Smart Farm," and "Smart Farm 30% Expansion."

These represent some of the latest and most relevant documents published by the Korean Ministry of Agriculture, Food and Rural Affairs (MAFRA). To triangulate the policy analysis results and gain insight into SF application in South Korea the researcher performed sight observations on two smart farms and informal semi-structured interviews with four smart farm owners. One visit was done in April 2023 on a 'DIY' vegetable smart farm using a so-called 1st generation computer and one in November 2023 on a strawberry farm using the latest 4th generation computer. Chapter 5 presents an analysis of the results and policy discussion which is divided into 3 groups – policy measures on track, shortcomings, and future policy recommendations.

IV. Findings

1. Reflection of South Korean Agricultural Environmental Issues in K-SDG Targets

Seventeen K-SDG targets that directly address six environmental issues are summarized in Table 1. While South Korea categorizes SDGs 7, 12, 13, 14, and 15 as focusing on environmental sustainability (Ministry of Environment, 2019), the most effective targets for addressing current environmental issues are SDGs 2, 9, and 12. The environmental issue of limited water resources and water quality has been addressed six times across the 17 SDG targets, indicating that it is one of the most thoroughly considered and integrated topics. Five of the connections are not a surprising result, as they belong to SDG 6 (clean water and sanitation), while the sixth was identified in SDG 15 (life on land). The issue of decrease in agricultural yield was followed with four, GHG emission, pest and weeds control and biodiversity with three and lastly, soil quality and fertilizers with only two connections between the environmental agricultural issue and the K-SDG targets. Results regarding the high incorporation of water-related issues into targets and poor consideration of soil quality and fertilizer directly reflect the current preparedness and consideration of such issues in South Korea. While Korea established a resilient infrastructure for adaptation and mitigation to potential water scarcity issues with 18,000 agricultural water reservoirs across the country (Nam et al., 2015), it lags in controlling and minimizing the wide use of inorganic fertilizers, making it one of the highest N and P fertilizers users amongst OECD countries (OECD, 2020; Lim et al., 2021). Fertilizer overuse spans back to Korea's rapid industrialization and agricultural productivity increase in the 1980s and 1990s, when chemical fertilizers were the sole source of providing soil with additional nutrients, leading to fertilizer overuse of almost two times above crop requirements (Jeon et al., 2022).

Table 1. K-SDG targets directly addressing the 6-agriculture related environmental issues

K-SDG Target	K-SDG Target Details	Environmental Issue						Total
		1	2	3	4	5	6	
2-3	**Establish a sustainable food production system** (increase self-sufficiency rate above 50%, increase size of agricultural land, improve soil acidity)	■				■		2/6
2-4	**Maintain genetic diversity** (Increase the number of plant genetic resources)			■			■	2/6
6-1	**Supply safe drinking water** (Increase the low water supply in rural areas)				■			1/6
6-3	**Improve water quality and hydro-ecological healthiness** (utilize the rate of sewage treated water and control pollutants				■			1/6
6-4	**Stable water supply and efficient use of water** (decrease the overuse of water for agriculture)				■			1/6
6-6	**Protect and restore hydro-ecosystem** (improve the average (29,8%) and bad (3.2%) evaluated river ecosystems)				■		■	2/6
6-7	**Local community and private sector participation** (joint safe and clean water management)				■			1/6
7-2	**Increase clean energy generation**		■					1/6
9-5	**Eco-friendly industrial activities and technological innovation** (reducing GHG emissions)	■						1/6
12-1	**Sustainable Consumption and Production** (strengthen market competitiveness of green products, resource circulation)	■						1/6
12-3	**Reduce losses from the life cycle of food** (minimize food loss in production, distribution and disposal)	■		■				2/6
13-2	**Reflect climate change action plans in policy**		■					1/6

	(increasing renewable energy, increase in adaptation measures, ecofriendly vehicles)		■					
13-4	**Reduce national GHG emissions**		■					1/6
15-1, 15-4*	**Preservation and restoration of land and animal ecosystem** (achieving 17% of protected land, preventing the loss of plant diversity, increasing forest area)						■	1/6
15-3	**Prevent land degradation** (soil conservation measures, vinyl waste polluting farmland soil and groundwater contamination)				■	■		2/6
15-7	**Prevention and control of harmful alien species** (measurement and analysis of 1000 species)			■				1/6
Total		4	3	3	6	2	3	**21/102**

Note: Environmental Issue 1-Decrease in yield productivity and quality, changes in cultivation area, 2-Greenhouse gas emission, 3-Pest and weeds control, 4-Limited water resources and water quality, 5-Soil quality and fertilizer use, 6-Loss of biodiversity.

* K-SDG targets 15-1 and 15-4 are combined into one category under the general term biodiversity as the former target represents flora biodiversity while the latter fauna biodiversity.

2. Linkages between Korean Smart Farming Policies and Sustainable Agriculture Promoting K-SDGs Targets

Four relevant South Korean SF policies were weighted against the 17 K-SDG targets aiming to improve the agriculture-inflicted environmental issues (Table 1). Each of the four SF policies can be connected to the 17 individual SDG targets, resulting in a theoretical maximum of 68 possible linkages. The analysis identified a total of 17 actual linkages among these policies and the SDGs (Table 2).

Although the term “smart farm” has been frequently used in Korean policymaking since 2015, particularly in the 2nd Comprehensive Plan for Agriculture and Food Science and Technology Development (2015-2019), it was not until 2018 that the development and expansion of SF were more rigorously planned. This shift in 2018 was marked by the introduction of specific programs focused on education, research, investment, and public-private partnerships to support the growth of SF in South Korea. 2nd Comprehensive Plan for Agriculture and Food Science and Technology Development (2015-

2019) mentioned 'smart farm' and 'smart greenhouse' for a total of 58 times, while its successor, the 3rd Comprehensive Plan for Agriculture and Food Science and Technology Development (2020-2024) expands the vocabulary to 'smart farm,' 'smart agriculture,' 'smart livestock,' 'smart horticulture,' and 'smart greenhouse' by mentioning such words 146 times. The two comprehensive plans resulted in detailed strategies implemented either by ministries or in funding opportunities for existing or new farmers to purchase and install government-approved equipment. Amongst such strategies, four were recognized as currently the most impactful based on their detailed planning of specific projects and goals and the scale of impact.

First is the 'Smart Farm R&D' policy (MAFRA, 2019), which is one of the initial policies that set the stage for an active proliferation with plans to invest KRW 286.7 billion (USD 212 million) during 2021-2027 to advance the technology for a faster spread of smart farms and secure the source of technology for a smooth transition towards the 3rd phase of SF. The project is supported by three collaborating ministries and agencies: The Ministry of Agriculture, Food and Rural Affairs, the Korea Agricultural Research Service, and the Ministry of Science and ICT. Together, they aim to use the 'K-Farm' brand name and grow Korean agriculture's highly productive digital cultivation (SDGs 2-3, 9-5), global competitiveness and the possibility of technology exporting. The policy thoroughly focuses on economic and technology development, but somewhat neglects the mitigation and adaptation possibilities of such technological advancements. Additionally, the policy emphasizes energy circulation and utilization technology for livestock and greenhouse farming (SDGs 7-2, 12-1) and the development of smart greenhouse pest management technologies (however, no K- SDG target directly mentions pests). Regarding climate adaptation and mitigation, strategies such as consumption of 100% renewable energy, zero-emission with eco-friendly air conditioning technology (7-2, 13-2, 13-4), and energy sources utilizing livestock manure and by-products (12-1) are sufficiently considered.

Second is the nationally led and operated 'Smart Farm Innovation Valley.' MAFRA announced plans for the creation of 'Smart Farm Innovation Valley' (MAFRA, 2018) in 2018 with its main objective of attracting around 5,000 young farmers (18–40-year-old) and growing not just the agricultural sector, but also related industries like production and distribution through reinvestment. Core facilities of smart farm innovation valley are 1) education center and 2) smart farm demonstration complex where young farmers are trained and then offered to lease a parcel in the valley and 3) youth rental smart farm to work for partner companies or start a start-up. In the section 'smart farm business infrastructure establishment,' the policy specifically mentions the development of data collection, forecasting and control system for pest control, however as pest control is not included into the K-SDGs, the consideration of such environmental issues cannot be reflected in the policy analysis table (Table 2). Besides pest control, the policy does not directly address any of the environmental aspects in the main part; however, it does include an appendix with an explanation of smart farm operation and points out CO_2 emission monitoring as one of its core functions. No direct strategies for methane reduction are elaborated. Therefore, besides an increase in yield, a core goal of SF (SDG 2-3), this policy does not link with any of the 17 K-SDG targets.

Third, the analyzed policy is the 'Fruit Tree Smart Farm Expansion Policy' (MAFRA, 2021). Its goal is to secure the competitiveness of fruit products by reducing labor and producing high-quality fruit (SDG 2-3) through ICT facilities. Farmers are eligible for grants and loans to support the implementation of smart farm equipment. Additionally, those who have experienced at least a 30% loss due to natural disasters can apply for special provisions, including deferred loan repayment and reduced interest rates. The mention of natural disasters is the sole point in which the policy acknowledges the existence of environmental issues. The policy primarily focuses on environment monitoring and analyzing ICT-related technology for crop yield maximization and improvement of the farming environment, and it explains the steps of loan/grant acquisition.

The policy titled 'Smart Farm 30% Expansion through Field-Focus and Private Sector' was published in the second half of 2022, outlining a detailed plan to drive innovation in the agricultural sector. The policy is a response to the sluggish progress troubled by the slow improvement of farmers' technology, knowledge capabilities, trust, practical skills, slow growth of R&D and data sharing. The purpose of the new policy recommendations is to drastically improve not only productivity (SDG 2-3), but also the sustainability and resilience of agriculture and the need to resolve challenges like pests and natural disasters. This indicates a more holistic understanding of agriculture and a step away from the one-dimensional pursuit of technological and economic advancements. When it comes to specific actions, policy mentions optimization of production such as water, especially in the case with drought vulnerable crops, (SDG 6-4) and fertilizers (SDG 15-3), handling livestock manure in an eco-friendly manner by turning it into biochar or solid fuel (SDG 12-1). In contrast to other policies that do not dive into details on water and irrigation systems, this policy dedicates a section to water dissemination technology in case of drought, which not only saves water but also improves efficiency (SDGs 6-1, 6-4). However, although the Netherlands case study is referenced as an example of geothermal energy heating, the policy does not directly suggest similar renewable energy or energy-saving plans in the application of smart farm technology.

Table 2. K-SDG targets directly addressing the 6-agriculture related environmental issues

	K-SDG targets \ Smart Farming Policy	Smart Farm R&D	SF Innov. Valley	Fruit Tree Smart Farm	SF 30% Expansion	Total
Zero Hunger	2-3	■	■	■	■	4/4
	2-4					
Clean Water & Sanitation	6-1				■	1/4
	6-3					
	6-4				■	1/4
	6-6					
	6-7					
Clean Energy	7-2	■				1/4
Innov. & Tech.	9-5	■				2/4
Responsible Consumption	12-1	■			■	2/4
	12-3	■	■	■	■	4/4
Climate Action	13-2	■				1/4
	13-4	■				1/4
Life on Land	15-1					
	15-4					
	15-3				■	1/4
	15-7					
Total		7/17	2/17	2/17	6/17	**17/68**

Note: Innov. & Tech. = Innovation and Technology

V. Discussion and Policy Recommendations

1. On track

Alongside K-SDGs which Korea classified as environmental (7, 12, 13, 14, 15), targets belonging to K-SDGs 2 and 6 just as successfully integrate at least one of the six environmental issues. Relating to the food production system from the growing and protecting diverse seeds to disposing or resource recycling stage, K-SDG targets 2-3, 2-4 and 12-3 all addressed more than one environmental issue. This indicates an understanding and effort to create a more sustainable domestic agricultural industry as well as the food supply chain (processing, transporting, selling, consuming).

Twenty-five percent of the K-SDGs are linked with the specific strategies outlined in SF policies. Notably, all the SF policies cover targets 2-3 (sustainable food production systems) and 12-3 (minimizing food loss). This alignment is anticipated, given that the primary objective of SF is to boost crop yield and enhance production quality. Moreover, SDG 12-1 (sustainable consumption and production) has two policies mentioning livestock manure to increase resource circulation. Actions described in 'Smart Farm R&D' and 'Smart Farm 30% Expansion' also contribute to some other SDG targets like water reduction and efficiency, renewable energy, GHG emission reduction and appropriate use of fertilizers. Overall, however, these policies underperform in acknowledging and proposing technologies that address all six environmental concerns comprehensively.

Smart farm field observations show a somewhat different picture as both farm's farmers obtained organic farming and environmentally friendly farming certificates and operate their farms with vigorous consideration of their impact on the environment and continuously seek for new advancements and innovations to reduce their energy and water consumption. They do not refer to national policies as the main motivation for an organic mode of production and consider policy strategies and funding as a small contribution toward the large sum of investment needed by small and medium farmers to venture into and develop smart farms. Rather than policies, they are guided and motivated to act environmentally friendly by personal beliefs, consumer demands, and willingness to pay more for organically and domestically produced food.

2. Shortcomings

There are two significant shortcomings of K-SDGs when it comes to the integration of environmental issues related to agriculture into its targets. Even though pest control has become a growing concern, with regional agricultural institutions emphasizing the need for stronger responses to create a more stable environment (RDA, 2023), environmentally friendly methods for treating and controlling emerging pests have yet to be included in any of the SDG targets. Since pest control inevitably involves chemicals (Bae et al., 2021) it is imperative to create an indicator measuring pest control in relation to soil, crop and forest health within at least one of the SDGs. Monitoring and control of pest are mentioned in two of the four analyzed SF policies, although no specifics are made whether the control is inorganic or eco-friendly. Second is the lack of direct linkage between agriculture and GHG emissions, specifically methane. South Korea joined the global methane pledge (GMP) in 2021 at COP26 under President Moon and pledged to reduce 30% of its global emissions by 2030 but is yet to include active strategies for such measures in any of the SDG targets.

The agricultural industry's CO_2 emissions were at 3.2% of national GHG emissions in 2021, (E-Nara index 2022), while agriculture and food waste produce 44% of all national methane emissions, with 52% coming from the rice fields, and 48% from the livestock industry (Nongsaro, 2022).

Smart Farm Policy's shortcomings are particularly apparent in terms of linking with the clean and efficient use of water resources and protection of biodiversity, land degradation and sustainable land use with three out of four policies not touching upon such issues. Moreover, significantly fewer linkages are identified between targets and policies primarily designed to distribute subsidies or other monetary support for technological implementation such as the SF Innovation Valley and Fruit Tree SF, as they fail to support any of the K-SDGs outside the scope of food production and consumption (SDG targets 2-3, 12-3). Evident are missed opportunities for using SF technologies to control the quality and pesticide contamination of water and soil and reusing the treated sewage water (SDGs 2-3, 15-3) for not only livestock maneuver, but also water-focused resource circulation (SDG 12-1). Moreover, policies do not strategize for the promotion of a combination between organic and SF practices (SDG 9-5), missing an opportunity to expand smart organic farming, which is a common sustainable farming practice amongst smaller farming operations (Doshi et al., 2019).

3. Policy Recommendations for 'greening' the Korean smart farming policy

First, the Korean SF policy does not consider methane emissions in any of the analyzed policies despite Korea's NDC pledge to reduce 40% of GHG emissions until 2030 (Bureau of Climate, Environment and Science 2021). To close the gap, Korea ought to consider integrating its current definition of SF with the principles of climate-smart agriculture (CSA) and carbon-smart agriculture, particularly in the rice fields that cover more than 50% of agricultural land in South Korea and produce 50% of all methane emissions coming from agriculture. SF policies should be rethought to include the triple win, an integrated approach of managing landscapes while ensuring sustainable food production that does not worsen the climate change impacts conceptualized by the World Bank (World Bank, 2021). Triple win project simultaneously aims for an increase in productivity, enhanced resilience to climate change stress on the environment such as droughts and pests, and reduced emissions. In its Climate-smart agriculture and the SDG report, FAO (2019) introduces three pillars of CSA framework based on the triple win approach for the assessment and mapping of CSA-SDG linkages (synergies and trade-offs) in developing countries. The three pillars are divided into increased productivity and incomes, building resilience and adaptation to climate change, and reducing and/or removing GHG emissions. CSA pillar that is reported to have the highest number of positive effects and lowest number of trade-offs is the GHG emission reduction pillar, an area in which Korean SF policy still lacks clear strategies and measures, particularly for methane emissions. Therefore, a policy priority when amending and creating new SF policies for South Korea is to collaborate with research institutes and universities working on a rice paddy and livestock methane reduction technology and farming techniques such as water management, tillage, and organic fertilizer (Shin et al. 1996; Saha et al., 2022) and financially support their development and together come up with strategies for implementation onto not only large, commercial smart farms, but also smaller ones.

Moreover, the incorporation of triple win approach, particularly the CSA second pillar, approach is especially relevant amidst Korea's recently announced plans to expand the use of 'made in Korea' SF technology internationally through the Official Development Assistance (ODA) program for developing nations in Southeast Asia and Africa (Han, 2023). An SF technology application that overconsumes water and energy, increases the levels of GHG emissions, and the use of inorganic fertilizers harming the quality of soil, ground water and biodiversity would exacerbate the environmental issues of already climate change-vulnerable developing countries.

Second, FAO (2019) recommends developing appropriate national and local institutions that synchronize mandates and ensure horizontal and vertical coordination within and among sectors and stakeholders as important guidelines for the implementation of CSA to achieve the SDGs and its NDC. Currently, smart farm policy is primarily developed within the Ministry of Agriculture, Food and Rural Affairs and occasionally by the Ministry of Science and ICT, Ministry of Trade, Industry and Energy, Ministry of Environment, and Ministry of Rural Development Affairs. The Ministries collaborate with each other, as well as with universities and research organizations (Kim et al., 2017). It is critical to minimize the discrepancies and consolidate the understating of SF's goals and priorities across different ministries to avoid limiting the policies to one-faceted strategies for economic growth of the agricultural sector, environmental protection or technology implementation (Lee et al., 2015). Sung et al. (2022) suggest that achieving the targets is better done through local-level governance of SDGs by including representatives of local governments in SDG target mediation and construction. As an example of increasing the connectivity between ministries and the committee constructing the SDGs, Sweden puts the implementation of the 2030 Agenda on the whole government by having each ministry prepare issues depending on their responsibilities under the minister for public administration, all while ensuring the participation of regional government, private sector, civil society, and research community. The

Netherlands similarly formed a network of regional government and ministry focal points chaired by a high-level coordinator (OECD, 2017). Moreover, the effectiveness of the Korean primarily top-down policy approach of creating the policies at the highest ministerial level and distributing its planned projects and funding schemes downwards to farmers and local governments (O'Shaughnessy et al., 2021; Kim, 2020) should be evaluated, and a more place-need based collaborative and local participatory approach to policymaking can be considered (Makate, 2019).

VI. Conclusion

This paper conceptualized SF as a sub-category of sustainable agriculture due to its large, but still untapped potential to expand beyond the original goal of maximization and simplification of yield production and use the SF technological innovation to lessen a region's agricultural environmental issues. To research whether the current direction of SF policies go beyond its narrow definition, this paper chose South Korea as a case study and discovered linkages between SF policy and the K-SDG targets aiming to improve the current agricultural environmental issues. Linkages provide a methodological approach to analyzing the extent of current policymaking's contribution towards a more sustainable agriculture.

First, this paper performed a literature survey of global research to identify 11 SDGs (1, 2, 6, 7, 8, 9, 11, 12, 13, 14, 15) that are achievable through SF. The next step was to contextualize the 11 SDGs within the case study, which was done by extracting the corresponding 11 Korean SDGs (K-SDGs) and their 68 targets. The targets were carefully reviewed to identify K-SDG targets addressing Korea's six pressing agricultural environmental issues (KMA, 2020). In this process, 17 K-SDG targets belonging to 7 K-SDGs (2, 6, 7, 9, 12, 13, 15) were identified, with four K-SDGs simultaneously addressing two environmental issues. Results show SDG's largest strength was found in addressing the water related issues (Nam et al., 2015) and shortcomings in insufficient consideration of controlling and minimizing the widely spread use of inorganic fertilizers (Lim et al., 2021) as well as linking SDG targets with reducing methane emissions in its most pressing industries, livestock and rice production.

Lastly, four SF policies were read thoroughly to find linkages between its strategies and implementation measures and the 17 K-SDG targets. A considerably low number of 17 out of theoretically possible 68 linkages suggests insufficiency in the extent of current SF policies' contribution to addressing the environmental issues. While each policy displays shortcomings in specific K-SDG categories, a common trend across all four policies is the prioritization of

SF as a means of food production (K-SDG 2-3) and food consumption (K-SDG 12-3) over the rest of K-SDG targets. Two policies, 'Smart Farm R&D and 'Smart Farming 30 & Expansion,' however, do crate more diverse linkages, one linking seven and the other six times. The most apparent shortcomings are the lack of incorporating plans for GHG emission reduction, particularly methane, renewable energy, organic farming, preservation of biodiversity of crops, water and soil health.

To ensure a more sustainable development of agriculture, South Korean policymakers should consider the World Bank's (2021) triple win concept, which incorporates enhanced resilience of agriculture with emission reduction. This is not only crucial for South Korean farmers, but also for climate-change-vulnerable developing countries in Africa and Southeast Asia, which are the target markets for Korean export of 'K-Farming' technologies through ODA (Han, 2023; MAFRA, 2024). Moreover, the governance of K-SDGs and synergetic collaboration between respective ministries should be enhanced for a more sustainable and environmentally cautious K-Farming.

Making assessments of SF based on a literature review and investigation of policy without conducting interviews with related policymakers, politicians and Korean national SDG committee members is a limitation to a more holistic and practical understanding of intentions and obstacles involved in SF policymaking. Moreover, as policy texts tend to be vague, broad and often vary from the actual on-field applications, it is difficult to conclusively claim that such texts and perfectly reflect the real state of SF in South Korea. For example, 'Smart Farm Innovation Valley' policy does not specifically mention its efforts for connecting smart and organic farming, RE100 energy efforts and low-emission livestock farming, nevertheless, such positive steps towards applications of climate-SF are currently on the way to its realization (Kim, 2022). Moreover, two smart farm observations and interviews unveiled farmers' vigor and dedication to organic SF, creating innovations to save energy and water and reuse resources with minimal influence of national policies. Despite such limitations, this paper identifies pressing policy improvements for greening Korean smart farming and suggests a new methodological approach for policy analysis applicable to any sustainability issue in any nation state with national SDG commitments.

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Appendix

Table A1. Number of times sustainable agriculture was mentioned as a contributor to SDG (1-8) in previous research (research paper N=12)

Dimension	Reference	SDG							
		1	2	3	4	5	6	7	8
		No Poverty	Zero Hunger	Health and Well-being	Quality Education	Gender Equality	Clean Water and Sanitation	Affordable and Clean Energy	Decent Work and Econ. Growth
Sustainable Agriculture	FAO (2019)		x				x	x	
Sustainable Agriculture	Nhemachena et al (2018)	x	x				x	x	
Smart Farming	Musa at el. (2022)		x						x
Smart Farming	Ashir et al. (2022)						x	x	x
Smart Farming	Balafoutis et al.								
Smart Farming	Musa and Basir (2021)		x						
Smart Farming	Pereira et al (2022)						x	x	
Smart Farming	Haque et al (2021)		x						
Climate Smart Farming	Richard et al (2021)		x						
Climate Smart Farming	Schaafsma et al (2019)		x						
Climate Smart Farming	Hellin and Fisher (2019)								
Carbon-Smart Farming	Maraseni (2021)	x	x						
Total	12	2	8				4	4	2

Table A2. Number of times sustainable agriculture was mentioned as a contributor to SDG (9-17) in previous research (research paper N=12)

Dimension	Reference	SDG								
		9 Industry, Innovation, Infra.	10 Reduced Inequalities	11 Cities and Communities	12 Consumption and Production	13 Climate Action	14 Life Below Water	15 Life on Land	16 Peace, Justice and Institutions	17 Partnership for Goals
Sustainable Agriculture	FAO (2019)	x			x	x				
Sustainable Agriculture	Nhemachena et al (2018)					x	x	x		
Smart Farming	Musa at el. (2022)				x					
Smart Farming	Ashir et al. (2022)	x		x	x					
Smart Farming	Balafoutis et al.	x				x		x		
Smart Farming	Musa and Basir (2021)									
Smart Farming	Pereira et al (2022)	x		x						
Smart Farming	Haque et al (2021)									
Climate Smart Farming	Richard et al (2021)					x		x		
Climate Smart Farming	Schaafsma et al (2019)					x				
Climate Smart Farming	Hellin and Fisher (2019)									
Carbon-Smart Farming	Maraseni (2021)					x		x		
Total	12	4		2	3	6	1	5		