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Applicability of Online Sustainability Tools for Landscape Performance Assessment in South Korean Nursery Farm Complexes*

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한국 묘목 생산 단지에서 경관 성과 평가를 위한 온라인 지속 가능성 도구의 적용성*

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요 약

묘목 생산 단지(Nursery Farm Complex, NFC)는 원예 및 임업용 식물생산에 중요한 역할을 하지만, 지속 가능성을 유지하는 데 있어 여러 과제에 직면해 있다. 이러한 문제를 해결하고 장기적인 생존 가능성을 보장하기 위해서는 전략적 개입이 필요하다. 본 연구는 온라인 지속 가능성 평가 도구의 적용을 통해 한국의 묘목 생산 단지의 경관 성과를 평가하고, 특히 경관 성과 지수(Landscape Performance Index, LPI)에 중점을 두고 이를 분석하고자 한다. 경관 성과 지수는 모델 생산 단지의 지속 가능성 문제를 식별하고 온라인 의사결정 지원 도구가 경관 성과를 효과적으로 측정하는 방법을 입증하는데 기여하였다. 본 연구의 주요 목적은 LPI와 기타 도구들을 활용하여 지속 가능성 문제를

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평가하고, 개선이 필요한 주요 영역을 식별하며, 지속 가능성 결과를 향상시키기 위한 전략적 의사 결정을 지원하고자 한다. 생산 단지를 평가함으로써 본 연구는 의사 결정 지원 도구가 경관 성과를 효과적으로 측정하고 지속 가능성 문제를 해결하는 데 어떻게 기여할 수 있는지 강조한다. 이 연구는 식량 및 농업 시스템의 지속 가능성 평가(Sustainability Assessment of the Food and Agricultural System, SAFA), 농장 지속 가능성 준비 도구(Farm Sustainability Readiness Tool, FSRT), 농장 지속 가능성 평가(Farm Sustainability Assessment, FSA)도구의 잠재적 함의도 논의한다. 이러한 도구들은 묘목 농장 단지의 지속 가능성을 평가하고 벤치마킹할 수 있는 포괄적인 틀을 제공하여 우선순위가 높은 영역을 해결하는 데 있어 정보에 기반한 의사 결정을 가능하게 한다. 연구 결과는 이러한 도구를 활용하여 전체적인 지속 가능성 평가를 촉진하고 이해관계자 참여를 개선하며, 한국의 묘목 생산 단지에서 지속 가능한 발전을 지원할 수 있음을 시사한다. 본 연구는 한국의 묘목 생산 단지의 지속 가능성을 향상시키고, 더 나아가 이 지역의 지속 가능한 발전 목표에 기여하기 위한 도구들의 추가 연구 및 적용의 중요성을 강조한다.

Key Words: *Diagnosis Indicator, Livability, Rural Spatial Planning, Rural Vulnerability*

I. INTRODUCTION

Plants play a crucial role in both human well-being and environmental health. Numerous studies highlight the positive impact of human interaction with plants on mental and physical health (Twohig-Bennett & Jones, 2018). Trees, in particular, are vital for the well-being of communities (Turner-Skoff & Cavender, 2019). The presence of plants influences humans on psychological, physiological, and sociological levels (Lewis, 1995). Connecting with nature fosters social interaction, provides relief from daily stresses, and offers a sense of belonging and purpose (Kingsley et al., 2009). Activities like farming and gardening reduce stress by promoting engagement with natural elements, thus enhancing human health (Lin et al., 2018; Ossola & Hopton, 2018; Russell et al., 2013; Thompson et al., 2018). Additionally, plants contribute to social connectivity and strengthen community bonds (Alaimo et al., 2010; Kingsley et al., 2020; Kingsley & Townsend, 2006).

A Nursery Farm Complex (NFC) refers to a farm where visitors can engage in various activities such as viewing, purchasing, and experiencing diverse groups of plants, which offer notable physical and mental health benefits. These complexes provide urban residents with opportunities for meaningful interactions with nature, enhancing their well-being. However, such large-scale plant cultivation operations often require substantial inputs to meet global demands from various stakeholders (Sandhu et al., 2009). The intensive agricultural practices associated with these operations have made agriculture a significant driver of land-use change (Klein Goldewijk & Ramankutty, 2004; Singh, 2010; Vitousek et al., 1997), resulting in environmental degradation and the loss of critical Ecosystem Services (ES) (Tilman et al., 2001). NFC, as a site for farming, commerce, and other human activities, is not immune to sustainability concerns either

(Gonçalves & Alpendurada, 2005). Sustainable agriculture has become a key concept encompassing environmental soundness, productivity, economic viability, and social desirability (Schaller, 1993). ES can improve sustainable agricultural practices (Pellegrino & Bedini, 2013). International programs recognize ES as critical for sustainability policy-making (Huang et al., 2015). Thus, NFCs can leverage ES to meet their sustainability goals.

In response to the growing recognition of sustainable development in farmland and plant production complexes, various indicator-based sustainability assessment tools have been developed (Schader et al., 2014). While each tool has its unique characteristics, they differ in terms of applicability, target audience, indicators, requirements, and ease of use (De Olde et al., 2016). A common feature among them is their user-friendliness, which allows non-expert decision-makers to utilize them without requiring specialized knowledge (Arulnathan et al., 2020). These tools have the potential to provide fast and convenient sustainability assessments for farmers and other related professionals managing NFCs. However, due to the broad scope of sustainability (Coteur et al., 2018; Le Gal et al., 2011), it is hardly possible to develop a tool that provides both precisely quantified data and comprehensive analyses of multifaceted sustainable issues. Therefore, it is not surprising that these available tools either can provide one of two: either a quantitative analysis on a specific sustainability issue or a multi-faceted qualitative analysis (Denef et al., 2012).

While many case studies have demonstrated the successful application of these tools in assessing agricultural sustainability (Häni et al., 2003; López-Ridaura et al., 2002; Zahm et al., 2008), they have neither been widely used in South Korea nor applied to landscape performance analysis. As such, this study focused on identifying online sustainability tools that can be applied to South Korea's model farms, particularly in the context of NFCs.

Landscape Performance (LP) can be explained as the measure of how effectively landscape solutions can fulfill their intended purposes and contribute to sustainability. This includes assessing the environmental, social, and economic outcomes of a landscape project and understanding its impact on long-term sustainability goals (Ahern, 2013; Vicenzotti et al., 2016). For example, an NFC implementing water conservation practices can evaluate its effectiveness by measuring reductions in water usage and improvements in ecosystem health. Building on the LP, the Landscape Performance Metrics Index (LPMI) is a structured system of indicators designed to evaluate the sustainability of landscapes across multiple dimensions. LPMI integrates measurable parameters, such as energy efficiency, biodiversity, carbon sequestration, and community engagement, to assess overall landscape health (Yang et al., 2017; Landscape Performance Series, 2010).

While the LPMI generally serves as a broad framework applicable to diverse landscapes, making it an essential tool for comparing sustainability practices across regions and sectors, the Landscape Performance Index (LPI), is a specific adaptation of the LPMI framework tailored for evaluating the sustainability performance of NFCs. The LPI emphasizes metrics relevant to agricultural and nursery

Table 1. Characteristics of different online sustainability assessment tools

Tools	Source	Level of sustainability assessment	Constraints (if any)
SAFA	FAO, 2014; FAO, 2014a; FAO 2014b.	Multi-dimensional (Environmental, economic, social & governance)	N/A
Cool Farm Tool	Hillier et al., 2011; Kayatz et al., 2019.	Multi-indicator (Environmental)	N/A
RISE	Hani et al. (2003)	Multi-dimensional (Environmental, economic & social)	Inaccessible from Windows OS
FSA	SAI, 2018; SAI, 2019a; SAI, 2019b	Multi-dimensional (Environmental, economic & social)	N/A
SMART Farm Tool	Schader et al., 2014.	Multi-dimensional (Environmental, economic, social & governance)	Only available in the German language
Dairy Farms+	AGÉCO, 2016.	Multi-indicator (Environmental)	Not applicable outside of Canada. Needs a valid producer's license
FSRT	AFSE, 2018.	Multi-dimensional (Environmental, economic & social)	N/A
SENSE Tool	Ramos et al., 2016.	Multi-dimensional (Environmental, economic & social)	The software couldn't be downloaded from the website
OFoot	Carlson et al., 2016.	Single indicator	The server doesn't work outside of the 4 states in the USA
COMET-Farm 2.2	USDA, 2019.	Single indicator	Only applicable in the USA

operations, such as water management efficiency, carbon footprint reduction, and socio-economic impacts on local communities. This study leveraged the LPI to bridge the gap between theoretical sustainability assessments and practical applications for NFCs. These distinctions are critical to ensure clarity and precision in discussing landscape performance evaluation. They also highlight the unique application of the LPI framework to NFC contexts, aligning with the study's objectives.

NFCs represent a critical intersection of agriculture, commerce, and community engagement, making their sustainability a priority (Arulnathan et al., 2020). NFCs not only address urban residents' growing demand for nature-based interactions but also exemplify challenges in balancing productivity and sustainability. Internationally, tools like the LPI have demonstrated their utility in quantifying sustainability across diverse contexts (Ness et al., 2007). However, their potential for assessing landscape performance in NFCs, particularly in South Korea, remains under explored.

The primary aim of this study was to investigate how applicable is the LPI and other online tools are for assessing sustainability challenges in NFCs. By identifying critical areas

Table 2. Evaluation criteria and descriptions

Criterion	Description
Ease of use (Tool accessibility and interface)	How easy is it to find the tool online? Is the download, installation, and execution processes clear to understand?
Covered sustainability issues	Which sustainability domains and topics are covered? How expansive are the covered issues?
Required data and knowledge	To get the analysis results from the tool, what kinds of data are required? To answer the questions from the tool, what kinds of knowledge are required? Are the required data and knowledge too complicated or professional?
Outcome comprehensiveness and interpretation	What are the contents and format of the outcomes from the tool? Are the outcomes well-organized and easy to understand? Do the outcomes include comprehensive analyses that can help farmers (or other users of the tool) enhance the sustainability of their farms?
Compatibility with Landscape Performance Index	How well do the outcomes of the tool match with the topics listed in the Landscape Performance Index? Do the outcomes include the topics of Landscape Performance which are critical for NFCs?

for improvement and aiding in strategic decision-making, this research sought to demonstrate the effectiveness of these tools in evaluating landscape performance and addressing key sustainability issues through a model farm complex analysis.

This study focused on evaluating the applicability of LPI and other online tools, including Sustainability Assessment of the Food and Agricultural System (SAFA), Farm Sustainability Assessment (FSA), and Farm Sustainability Readiness Tool (FSRT), for NFC sustainability assessment. By comparing best-case and worst-case scenarios within a model farm setting, this research provides actionable insights into achieving sustainability goals. Additionally, it highlights limitations in the existing frameworks, emphasizing the need for tool adaptation to local contexts (Schader et al., 2014).

II. MATARIALS AND METHODS

1. Identification of Online Assessment Tools

Arulnathan et al. (2020) reviewed 19 online sustainability assessment tools based on their alignment with the Bellagio sustainability assessment and measurement principles (STAMP) (Bakkes, 2012). These tools are designed to evaluate sustainability across environmental, social, and economic dimensions, addressing the multi-faceted challenges associated with the NFCs. From this extensive review, we shortlisted 10 tools that initially aligned with our research objectives (Table 1).

To identify the most suitable tools for assessing landscape performance within NFCs in South Korea, we applied an additional set of criteria tailored to the specific context and objectives of this study. These criteria, detailed in Table 2, included factors such as multi-dimensional assessment capabilities, ease of use, geographic applicability, and

Table 3. Summary of the evergreen horticulture park's attributes

Attribute	Description
Farm Type	Type 3: Small independent specialized family farm
Specialization	Horticulture and nursery plants
Management Orientation	Commercial, family sustenance, and near-subsistence
LID Practice	Implementation of Low Impact Development (LID)
Location	Rural region in Gyeonggi Province, South Korea
Total Land Area	15 hectares
Farming System	Intensive horticulture and nursery production
Primary Crop Types	Flowering Plants: Roses, Orchids, Lilies, Chrysanthemums, Gerbera Daisies Ornamental Trees and Shrubs: Cherry Blossom Trees, Japanese Maple Trees, Azaleas, Camellias, Boxwood Shrubs Medicinal Herbs: Ginseng, Astragalus, Korean Mint
Greenhouse Area	5 hectares
Open Field Area	10 hectares
Irrigation Method	Drip irrigation and rainwater harvesting
Soil Management	Use of compost and natural fertilizers Regular soil testing and nutrient optimization
Pest and Disease Control	Integrated Pest Management (IPM) practices Biological control methods Minimal use of pesticides
Greenhouse Technology	Modern greenhouse structures for optimal conditions
Crop Rotation Plan	Systematic crop rotation to maintain soil health
Biodiversity Conservation	Dedicated area for native plant conservation
Waste Management	Composting of organic waste
Renewable Energy	Solar panels for greenhouse operations
Community Engagement	Workshops, training programs, educational tours
Seasonal Labor	Skilled workforce includes horticulturists, nursery specialists, irrigation technicians, farm managers, and seasonal laborers
Labor Force Size	Varies seasonally based on farm operations

compatibility with existing sustainability frameworks. Tools that did not meet these criteria were excluded from the final selection.

By refining our selection using these criteria, we ensured the chosen tools were not only relevant but also effective in addressing the specific objectives of this study.

2. Case Study Site

As stated above, most of the tools are characterized as being easy and convenient to use and less time-consuming to perform, in addition to investigating several sustainability topics. Therefore, after the identification of the tools, in the next step of our research, we used all the three tools on "Evergreen Horticulture Park", a conceptual model NFC for horticultural plants based on the FAO Type 3 small independent specialized family farm' (FAO, 1996) to find out how effective and compatible they are and to compare the results of the tools.

1) Attributes of the Evergreen Horticulture Park

The case study centers on the "Evergreen Horticulture Park", a conceptual model nursery representing a typical NFC. This farm embodies characteristics of sustainable agricultural practices, incorporating low impact development

- Precision Agriculture
- Precision-based feedlot
- Fertilization
- Irrigation
- Machinery & Equipment
- Plant protection
- Weed management
- Field crops
- Stream restoration
- Pedestrian Walkway
- Farm waste recycling
- Reliable Harvest
- Solar/wind energy

Figure 1. Model NFC characteristics

(LID) strategies and integrating social, economic, and environmental goals. This conceptual model farm is an innovative and sustainable horticulture-focused nursery farm located in the serene countryside of South Korea. Spanning over 15 hectares of fertile land, the farm is a manifestation of eco-consciousness, showcasing the harmonious integration of modern agricultural practices with nature preservation. At the core of the farm, is its dedication to horticulture and nursery plant cultivation. The farm boasts an extensive array of horticultural crops, including orchids, exotic flowers, aromatic herbs, and a wide variety of ornamental plants. Table 3 provides an extensive summary of the attributes of the model NFC.

Embracing a holistic approach to sustainability, the farm exemplifies LID practices, striving to minimize its ecological footprint. This includes the adoption of efficient water management techniques, utilizing drip irrigation systems, and implementing rainwater harvesting to reduce water consumption. Moreover, renewable energy sources, such as solar panels, provide clean power for farm operations, further reducing greenhouse gas emissions.

The model farm stands as a testament to social responsibility, fostering a nurturing and inclusive environment. Its workforce consists of a diverse community of skilled farmers, with a strong emphasis on gender equality and worker well-being. Comprehensive training programs ensure the continuous professional development of the farm's staff, enhancing their skills and expertise. Additionally, the farm actively engages with the local community, organizing educational tours, workshops, and events to raise awareness about sustainable horticulture practices and promote environmental conservation. Economically, the farm thrives through meticulous cost management, ensuring the optimal utilization of resources while maximizing profitability. Its innovative spirit drives investment in cutting-edge precision farming technologies, enhancing crop yields and product quality. Diversification of income streams protects the farm from economic

Table 4. Condition of the evergreen horticulture park in best-case scenario.

Dimension	Indicator	Best-case score
Environmental	GHG emissions per hectare	1.8 kg CO2e/ha
	Water use efficiency	98%
	Biodiversity conservation	30% of land
Social	Gender equality in employment	70% female workforce
	Farm worker safety	No accidents
	Community engagement	Active engagement
Economic	Profitability	40% increase in net income
	Economic resilience	Diversified income streams
	Cost management	20% reduction in production costs
	Resource management	Efficient use of inputs
	Market access and diversification	Multiple sales channels, diversification
	Investment in innovation	Adoption of precision farming technologies

Table 5. Condition of the evergreen horticulture park in worst-case scenario.

Dimension	Indicator	Worst-case score
Environmental	GHG emissions per hectare	3.5 kg CO2e/ha
	Water use efficiency	85%
	Biodiversity conservation	No dedicated land
Social	Gender equality in employment	50% female workforce
	Farm worker safety	Multiple accidents
	Community engagement	Limited engagement
Economic	Profitability	20% decrease in net income
	Economic resilience	Sole reliance on one crop
	Cost management	10% increase in production costs
	Resource management	Inefficient use of inputs
	Market access and diversification	Dependence on a single buyer or market
	Investment in innovation	Limited adoption of new technologies

fluctuations, making it resilient even during challenging times.

A model NFC Farm will have the following characteristics (Figure 1)

2) Case Study Scenarios

For the purpose of the analysis, two scenarios were created in order to assess the sustainability tools' performance abilities in different conditions: best-case scenario (Table 4), and worst-case scenario (Table 5). The criteria were derived from industry benchmarks, global sustainability standards, and regional agricultural policies (FAO, 2014; Schader et al., 2014). The best-case scenario aligns with optimal practices observed in advanced nursery systems, while the worst-case scenario reflects common pitfalls in resource-intensive farming. These scenarios ensure a realistic yet challenging evaluation of the tools.

Each tool was applied to the evergreen horticulture park under the defined scenarios. The tools generated quantitative and qualitative outputs, which were analyzed to determine their strengths and limitations in addressing NFC sustainability challenges. This comparative analysis provided insights into the tools' diagnostic accuracy, ease of use, and relevance to regional contexts.

Ⅲ. RESULTS AND DISCUSSION

1. Selected Online Assessment Tools

Based on our criteria, we have identified three online assessment tools for this research, (a)SAFA, (b)FSA, and (c)FSRT. All three self-assessment tools offer a holistic framework that encompasses all aspects of sustainability schemes (Table 6) that can be used globally free of charge. SAFA, developed by the FAO, emphasizes a multi-dimensional assessment framework that integrates governance alongside environmental and socio-economic dimensions (FAO, 2014a). FSA focuses on intermediate benchmarking, offering insights into sustainability gaps through quantitative scoring (Varvaringos et al., 2023). FSRT, developed by AFSE, is particularly valuable for its diagnostic capabilities, providing customized action plans for improvement based on farm-specific data (AFSE, 2018). These tools encourage continuous improvement and build capacity for sustainability by providing an easy-to-use standardized system, which does not require external experts. In comparison to FSRT which is a completely online tool, SAFA is a downloadable software with a user-friendly interface and user manual, while FSA provides an Excel calculation sheet on its website.

In general, SAFA, FSA, and FSRT were chosen based on their proven ability to assess sustainability comprehensively. SAFA provides a broad framework covering governance and environmental impacts, while FSA and FSRT specialize in benchmarking and offering actionable insights (Schader et al., 2014; Zahm et al., 2008). These tools' user-friendliness and flexibility make them suitable for the complex needs of NFCs.

Apart from these three, the cool farm tool also did not have any constraints as well as having multi-indicators. However, this tool was excluded because, unlike the SAFA, FSA, and FSRT, its narrow focus on only the environmental aspect does not support comprehensive sustainability assessments needed for the NFCs. While the cool farm tool is effective for specific environmental metrics, such as greenhouse gas reductions (Hillier et al., 2011), it lacks multi-dimensional evaluation, including social and economic considerations. Thus, its limited customization for South Korea's agricultural conditions reduces its applicability. Therefore, the decision to omit the cool farm tools in this research was to ensure that the selected tools align with the study's objective of providing holistic sustainability evaluations for NFCs.

2. Result Comprehensiveness and Interpretation

The selected tools (SAFA, FSA, and FSRT) were applied to the evergreen horticulture park under both best-case and worst-case scenarios to evaluate their effectiveness in assessing sustainability comprehensively. These tools provide distinct but complementary approaches, which collectively address environmental, social, and economic dimensions of sustainability. Their combined application demonstrates their relevance and limitations, providing insights into their adaptability for South Korean NFCs.

1) Best-case scenario

(1) General Overview

The tools collectively highlight strong sustainability performance under the best-case

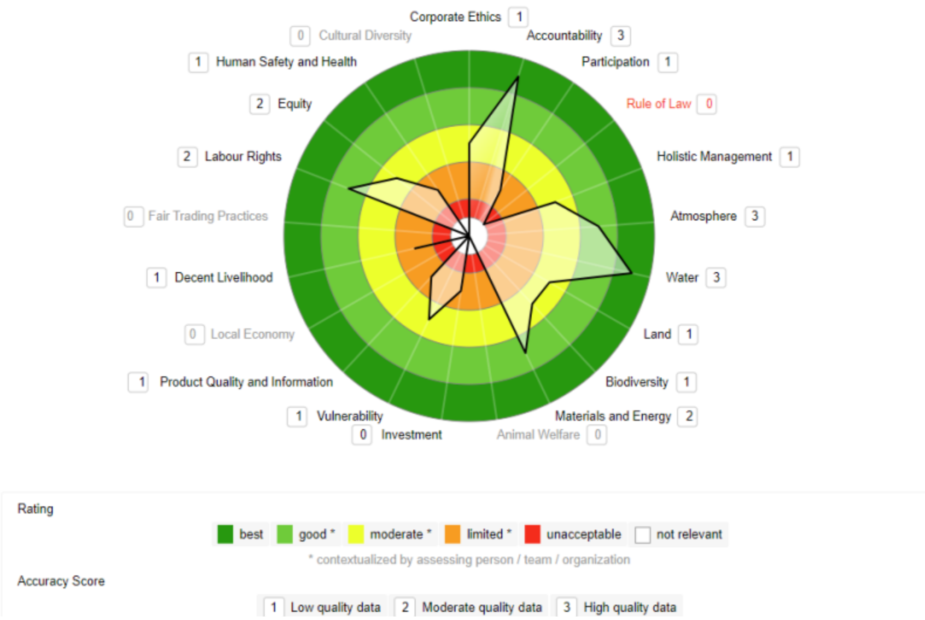

Figure 2a. Sustainability Assessment of the Food and Agricultural System overall performance for best-case scenario

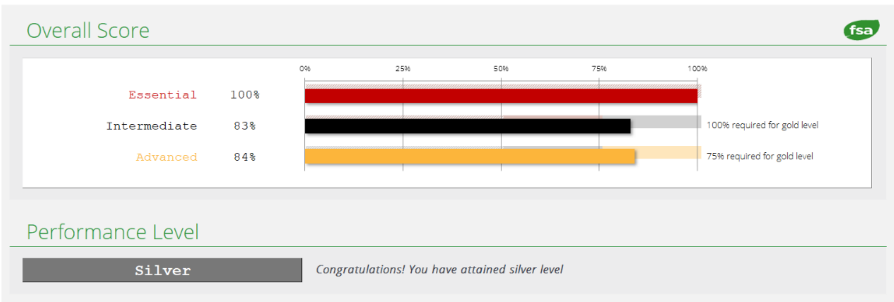

Figure 2b. FSA overall performance for best-case scenario

scenario, aligning with key sustainability goals. SAFA's polygon (Figure 2a) predominantly occupied the 'green' or 'dark green' regions, reflecting good and best ratings, respectively. Out of the 15 indicators assessed in SAFA polygon, 5 were marked in the green regions after excluding irrelevant indicators. This suggests notable strengths in specific areas such as labor rights, product quality, and accountability. However, it is important to clarify that the classification of these 5 indicators as "excellent" does not imply overall excellence but rather highlights the specific dimensions, where performance was strong. Additional efforts may be needed to address areas with moderate ratings to achieve a more balanced and comprehensive sustainability profile.

Similarly, FSA awarded a 'silver' badge (Figure 2b), indicative of intermediate and advanced compliance with sustainability metrics.

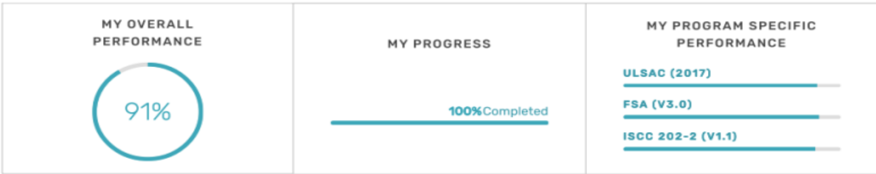

Figure 2c. FSRT overall performance for best-case scenario

FSRT's analysis revealed an 87% overall score (Figure 2c), confirming robust performance across dimensions while identifying specific areas for further enhancement.

(2) Key Strengths Identified

In terms of the environmental aspect, SAFA recognized the farm's efficient water use and strong soil health management practices, which were attributed to the adoption of LID strategies such as drip irrigation and rainwater harvesting (Figure 2a). However, it highlighted shortcomings in addressing air quality and greenhouse gas emissions, as well as biodiversity management. FSA similarly emphasized significant reductions in greenhouse gas emissions, supported by renewable energy utilization, such as solar panels, and crop rotation practices. Nevertheless, the farm scored only 67% for intermediate requirements and 50% for advanced requirements in air quality and emissions practices (Figure 3a). FSRT offered a unique diagnostic perspective, detailing actionable plans to enhance biodiversity and reduce air pollutants. Despite the overall environmental sustainability score of 87% for the best-case scenario, FSRT noted lower scores of 60% for land use and biodiversity management and 66% for air quality and greenhouse gas emissions (Figure 3b).

While on the contrary for the social performance, the farm performed exceptionally well in labor rights, gender equity (with 70% of the workforce being female), and workplace safety, achieving high scores across all tools. Both SAFA and FSRT highlighted the farm's

Figure 3a. Detailed Farm Sustainability Assessment Score for Best-case Scenario

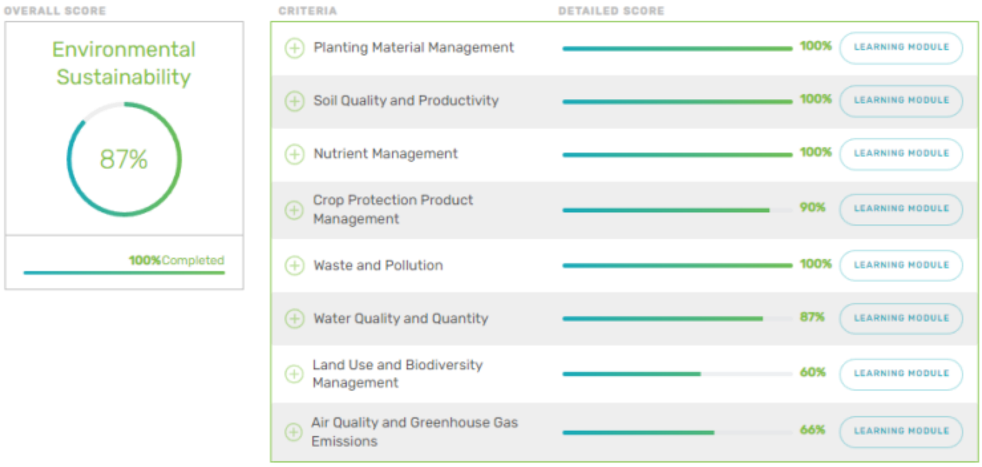

Figure 3b. Farm Sustainability Readiness Tool score on Environmental Sustainability for Best-Case Scenario

Table 7. Personalized action plans by Farm Sustainability Readiness Tool for environmental sustainability issues for best-case scenario.

Section	Action plans	Corresponding Indicator	Related sustainability Programs
Economic Viability	Keep records of land ownership/rental/lease and comply with regulations.	Land tenure	FSA (V3.0), ISCC 202-2 (V1.1), ULSAC (2017)
	Keep a detailed inventory of capital assets and farm inputs.	Inventory of capital assets	FSA (V3.0), ISCC 202-2 (V1.1)
	Develop a business plan to optimize profitability considering yield, quality, and return on investment.	Business plan	FSA (V3.0), ISCC 202-2 (V1.1), ULSAC (2017)
Environmental Sustainability	Prepare a cropping plan before each crop year to ensure high-quality seeds.	Cropping plan	FSA (V3.0), ISCC 202-2 (V1.1)
	Monitor and control the spread of invasive species.	Management of invasive species	FSA (V3.0), ISCC 202-2 (V1.1), ULSAC (2017)
	Implement a soil management plan.	Soil management plan	ULSAC (2017), ISCC 202-2 (V1.1)
Social Responsibility	Pay wages that meet or exceed the minimum required by law.	Wages	FSA (V3.0), ISCC 202-2 (V1.1), ULSAC (2017)
	Assess health and safety risks and develop a plan to control exposure.	Health and safety risk assessment	FSA (V3.0), ISCC 202-2 (V1.1), ULSAC (2017)
	Provide appropriate health and safety training for all workers.	Health and safety training	FSA (V3.0), ISCC 202-2 (V1.1), ULSAC (2017)

active community engagement programs, including educational workshops and environmental awareness campaigns, as key contributors to social sustainability (Figure 2a).

In the case of economic dimension of the farm, profitability metrics demonstrated a 40% increase in net income under the best-case scenario, driven by efficient resource management and market diversification. FSA specifically emphasized cost optimization achieved through advanced precision farming technologies (Figure 3a).

(3) Quantitative Comparison

FSRT's overall score of 87% surpassed those of SAFA and FSA, reflecting its diagnostic and action-oriented design. For land use and biodiversity management, FSRT scored 66%, which was comparable to SAFA's 67% but higher than FSA's 60% (Figure 3b). Similarly, for air quality and greenhouse gas emissions, FSRT scored 60%, aligned with SAFA's 67% and notably higher than FSA's 50% (Figure 3a).

The findings underscore the complementary strengths of the three tools. FSRT stands out for providing specific action plans, aligning with FAO guidelines, and delivering personalized recommendations (Table 7). SAFA offers a comprehensive governance framework, while FSA delivers intermediate benchmarks for performance. Employing these tools together provides a holistic and balanced approach to sustainability assessment.

2) Worst-case scenario

(1) General Overview

Under the worst-case scenario, sustainability performance exhibited severe deficiencies across governance, environmental management, and economic resilience dimensions. SAFA's

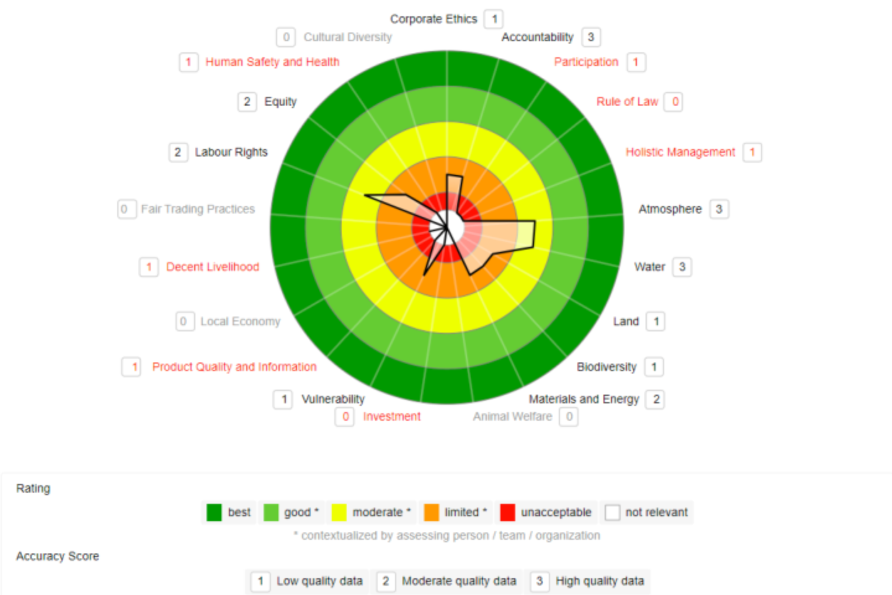

Figure 4a. Sustainability Assessment of the Food and Agricultural System Overall Performance for Worst-case Scenario

Figure 4b. Farm Sustainability Assessment overall performance for worst-case scenario

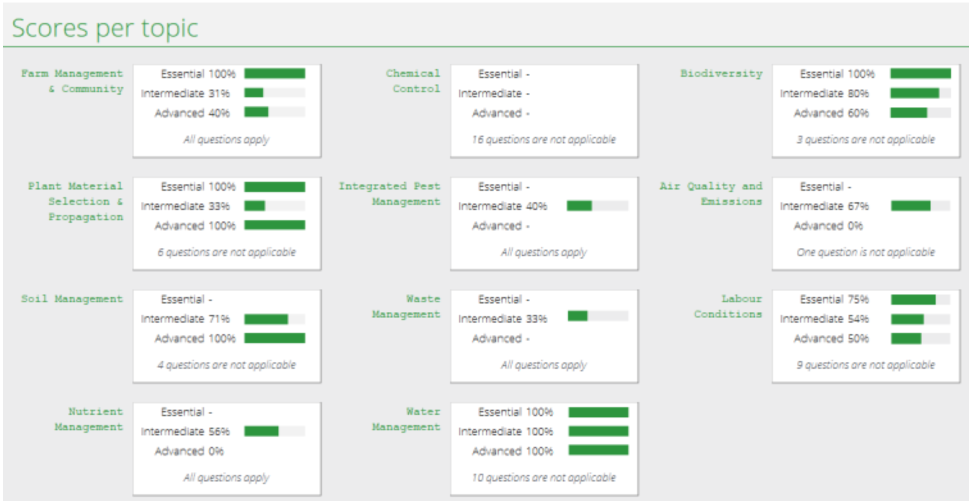

Figure 4c. Detailed Farm Sustainability Assessment score for worst-case scenario

polygon largely occupied the 'red' and 'orange' regions (Figure 4a), reflecting poor ratings in Corporate Ethics and Participation, both scoring 1/5. These results underscore inadequate governance, accountability, and stakeholder engagement. Environmental Integrity also suffered significantly, with particularly low ratings for air quality and biodiversity management, signifying the farm's failure to effectively address climate impacts or biodiversity preservation.

According to the FSA assessment, the farm received a "white" badge (Figure 4b), signifying minimal adherence to acceptable sustainability standards. Financial viability scored only 31% in intermediate responsibilities (Figure 4c), revealing poor risk management and financial instability.

Particularly concerning was nutrient management, which scored 0% in advanced levels, highlighting critical deficiencies in production standards. The farm's environmental performance was similarly inadequate, with 0% for air quality and greenhouse gas emissions and only 33% for waste and pollution management (Figure 4c), underscoring the urgent need for emissions reduction and improved waste

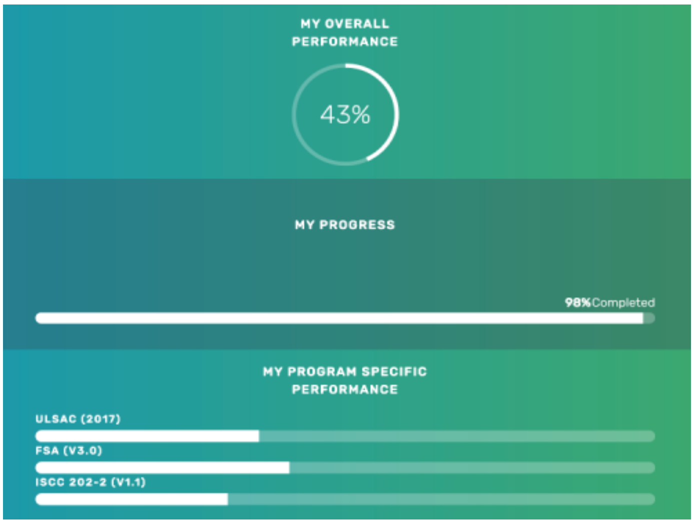

Figure 4d. Farm Sustainability Readiness Tool overall performance for worst-case scenario

management practices.

Similarly, FSRT reported severe shortcomings, with an overall environmental sustainability score of 33% (Figure 4d). Although FSRT provides personalized action plans to address sustainability challenges (Table 8), the farm

Table 8. Personalized action plans by FSRT for environmental sustainability issues for worst-case scenario.

Section	Top 3 action plans	Corresponding indicator	Related sustainability programs
Economic Viability	Keep records of proof of land ownership/rental/lease and comply with regulations.	Land tenure	FSA (V3.0), ISCC 202-2 (V1.1), ULSAC (2017)
	Keep a detailed inventory of all capital assets and farm inputs.	Inventory of capital assets	FSA (V3.0), ISCC 202-2 (V1.1)
	Develop a business plan to optimize profitability considering yield, quality, and return on investment.	Business plan	FSA (V3.0), ISCC 202-2 (V1.1), ULSAC (2017)
Environmental Sustainability	Prepare a cropping plan before each crop year to ensure high-quality seeds.	Cropping plan	FSA (V3.0), ISCC 202-2 (V1.1)
	Monitor and control the spread of invasive species.	Management of invasive species	FSA (V3.0), ISCC 202-2 (V1.1), ULSAC (2017)
	Implement a soil management plan.	Soil management plan	ULSAC (2017), ISCC 202-2 (V1.1)
Social Responsibility	Pay wages that meet or exceed the minimum required by law.	Wages	FSA (V3.0), ISCC 202-2 (V1.1), ULSAC (2017)
	Assess health and safety risks and develop a plan to control exposure.	Health and safety risk assessment	FSA (V3.0), ISCC 202-2 (V1.1), ULSAC (2017)
	Provide appropriate health and safety training for all workers.	Health and safety training	FSA (V3.0), ISCC 202-2 (V1.1), ULSAC (2017)

appears ill-prepared to implement these strategies effectively (Figure 4e).

(2) Key Challenges Identified

In the environmental aspect, the greenhouse gas emissions rose to 3.5 kg CO2 e/ha, and water use efficiency dropped to 85%. Furthermore, no land was allocated for biodiversity conservation, reflecting limited ecological foresight and a lack of strategic environmental planning. On the other hand, labor rights weakened, as evidenced by a rise in workplace accidents and reduced gender equity, with only 50% of the workforce comprising women. Community engagement activities also diminished, eroding social cohesion and limiting local participation, thereby weakening the farm's social foundations.

In terms of the economic dimensions, profitability declined by 20%, while production costs rose by 10%, highlighting significant economic vulnerabilities. Additionally, the farm's heavy reliance on a single buyer increased financial risks and reduced market resilience, making the overall economic framework less stable.

(3) Quantitative Comparison

SAFA highlighted governance shortcomings, with scores of 1/5 in stakeholder engagement and ethical labor practices (Figure 4a). The FSA's "white" badge further emphasized systemic weaknesses in financial viability, including a 0% score in nutrient management (Figures 4b and 4c). FSRT, while identifying severe shortfalls, also proposed targeted interventions, such as waste recycling programs and invasive species control, providing actionable recovery pathways (Figure 4d and Table 8).

These findings underscore the necessity of integrating governance-oriented tools like SAFA with action-focused frameworks like FSRT. This comprehensive approach enables stakeholders to tackle multifaceted sustainability challenges effectively, even under adverse conditions, and offers a balanced pathway for addressing critical deficiencies.

IV. IMPLICATIONS OF THE ONLINE SUSTAINABILITY ASSESSMENT TOOLS

1. Comparative Analysis

Given the multifaceted challenges of sustainability in South Korea's NFCs, tools such as the SAFA, FSA, and FSRT offer comprehensive frameworks to evaluate and improve sustainability performance across environmental, economic, and social dimensions. This section elaborates on the implications of these tools with a clearer interpretation of their evaluation criteria and justification for their suitability and excellence.

1) SAFA: A Holistic Framework for Comprehensive Assessment

SAFA provides a comprehensive evaluation framework for sustainability, integrating environmental, economic, social, and governance indicators. Its multi-dimensional approach empowers NFCs in South Korea to identify weaknesses and prioritize areas for improvement effectively. By conducting a detailed assessment of sustainability performance, NFCs can craft targeted strategies to enhance their sustainability efforts (Schader et al., 2014; López-Ridaura et al., 2017). SAFA's diverse indicators offer a robust mechanism for prioritizing improvement areas, aligning performance goals with sustainability benchmarks.

SAFA's benchmarking capability allows NFCs to compare their sustainability performance with other farms, regions, or global value chains, enhancing their competitiveness in a transparent and accountable market (FAO, 2014). Additionally, the tool's versatile indicators facilitate focused interventions, such as reducing greenhouse gas emissions by 20% or improving water-use efficiency by 15%, as demonstrated in real-world applications (Schader et al., 2014; López-Ridaura et al., 2017). These advancements appeal to environmentally conscious consumers, increasing marketability and ensuring SAFA's practical utility for strategic decision-making (FAO, 2014).

However, SAFA's reliance on extensive data and the need for technical expertise can limit its accessibility for smaller NFCs. Addressing this challenge through capacity-building programs to train NFC staff in data collection and interpretation is crucial for maximizing the tool's potential.

2) FSA: A Tool for Risk Management and Stakeholder Engagement

FSA offers a practical tool for NFCs in South Korea to evaluate and enhance their sustainability performance across economic, social, and environmental dimensions. This tool emphasizes risk management and stakeholder engagement, equipping NFCs with the insights necessary to address challenges like climate change and water scarcity effectively (Zahm et al., 2008; Schader et al., 2014). By identifying potential risks and developing mitigation strategies, FSA empowers NFCs to manage sustainability-related risks proactively.

The FSA excels in identifying risks such as water scarcity, biodiversity loss, and climate change, enabling NFCs to implement preventive measures (Zahm et al., 2008; Schader et al., 2014). By fostering trust among regulators, customers, and local communities, FSA enhances stakeholder engagement. For instance, achieving an FSA "silver" rating demonstrates advanced sustainability practices, boosting stakeholder confidence (Varvaringos et al., 2023). Furthermore, the tool simplifies complex sustainability challenges into manageable actions, such as enhancing biodiversity by planting native species in underutilized areas, as evidenced in recent applications (López-Ridaura et al., 2017).

Nonetheless, the FSA's applicability to South Korea could be enhanced by incorporating region-specific indicators. Metrics tailored to Korea's unique biodiversity and land-use patterns would improve its relevance, ensuring a more localized and effective application.

3) FSRT: Tailored Solution and Action Plans for Sustainability Gaps

FSRT provides NFCs in South Korea with personalized action plans to address sustainability gaps. By evaluating performance across a range of indicators, FSRT offers actionable insights to improve practices such as resource efficiency, waste management, and biodiversity conservation (López-Ridaura et al., 2017). This diagnostic approach enables NFCs to transition effectively toward sustainable farming practices, strengthening their long-term viability.

Unlike SAFA and FSA, FSRT delivers tailored solutions for specific gaps. For instance, if an NFC underperforms in waste management, FSRT provides step-by-step guidance for composting and recycling (López-Ridaura et al., 2017). Additionally, the tool evaluates an NFC's readiness to adopt sustainable practices, ensuring that strategies are context-appropriate and feasible (Schader et al., 2014). By addressing issues like climate resilience and resource efficiency, FSRT enhances an NFC's ability to withstand environmental and market shocks. Studies reveal that farms implementing FSRT-based plans experienced a 25% increase in profitability and a 30% reduction in resource wastage (Zahm et al., 2008).

Despite its strengths, FSRT lacks the granularity required to address all sustainability aspects relevant to NFCs in South Korea. Some indicators may be more applicable to certain farming operations, and the tool might overlook unique challenges faced by individual NFCs. To ensure a comprehensive and context-specific sustainability approach, FSRT should be used alongside tools like SAFA and FSA (Schader et al., 2014).

2. Compatibility for Assessing Landscape Performance

LP serves as a measure of how effectively landscape solutions achieve their intended goals while contributing to the overarching objectives of sustainability. This evaluation framework integrates the triad principle of environmental, economic, and social dimensions (Vicenzotti et al., 2016; Ahern, 2013). The LPI and the LPMI offer structured methodologies for assessing LP, enabling systematic evaluations of how landscapes fulfill sustainability criteria. The three online decision-support tools (SAFA, FSA, and FSRT) demonstrated their potential (refer to III: RESULTS AND DISCUSSION) to calculate

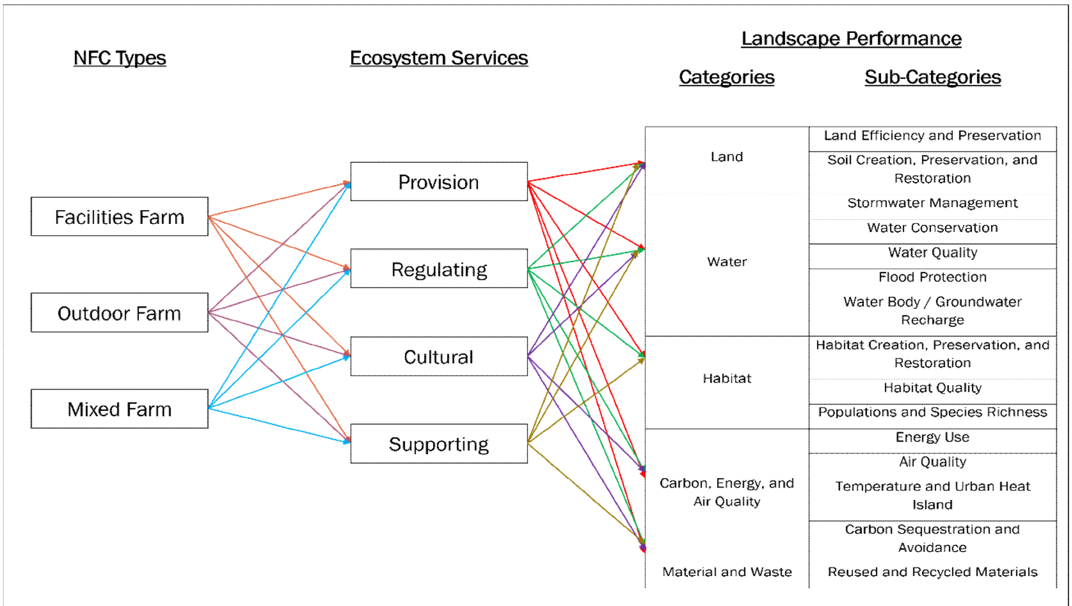

Figure 5. Criteria for landscape performance metric index in accordance with Nursery Farm Complex

and assess the LP of South Korean NFCs, in conjuction with the LPI and the LPMI.

1) Correspondence Between Tools and Landscape Performance Indices

The conceptual framework of the LPI and LPMI emphasizes quantifiable metrics, enabling an objective evaluation of sustainability performance in landscapes. Figure 5 illustrates the criteria for the LPMI as applied to NFCs, showcasing the integration of environmental, economic, and social indicators that underpin the LP assessment. These indices necessitate metrics that are both quantifiable and actionable, aligning with the core functionality of the selected tools.

SAFA, developed by the FAO, incorporates a multidimensional framework that evaluates sustainability through an extensive indicator set covering governance, environmental integrity, economic resilience, and social well-being (FAO, 2014). These dimensions directly correspond to the LPI's triad principles. For example, SAFA's environmental indicators encompass resource use efficiency, biodiversity conservation, and greenhouse gas emissions reduction, which align with LPI's environmental criteria. Similarly, SAFA's governance and social indicators overlap with the economic and social dimensions of the LPI, enabling a comprehensive assessment of landscape sustainability (Govindarajulu, 2014).

FSA, designed to assess farm-level sustainability, offers specific metrics for evaluating economic viability, environmental impact, and social responsibility. This tool provides quantifiable data through self-assessment questionnaires, aligning with the LPMI's requirement for measurable indicators. The FSA framework enables the evaluation of criteria such as land tenure security, cropping plans, and biodiversity management, which are integral components of the LPMI (Schader et al., 2014). Additionally, its emphasis on strategic risk management and stakeholder engagement complements the LPI's holistic approach to sustainability assessment.

FSRT uniquely combines diagnostic capabilities with the generation of tailored action plans, making it particularly compatible with the LPMI. By identifying site-specific challenges and providing actionable recommendations, FSRT aligns with the LPI's goal of fostering adaptive management strategies in landscape sustainability (Meuwissen et al., 2019). For instance, FSRT's indicators for soil health management, water resource efficiency, and labor practices align seamlessly with the economic, environmental, and social dimensions outlined in Figure 5.

2) Application to South Korean Nursery Farm Complexes

The operational structure of NFCs in South Korea presents unique sustainability challenges, including land-use optimization, water resource management, and biodiversity conservation. The compatibility of SAFA, FSA, and FSRT with the LPI and LPMI frameworks positions these tools as valuable resources for assessing and enhancing the LP of NFCs.

Figure 5 demonstrates the criteria for the LPMI, emphasizing metrics such as greenhouse gas emissions, crop diversification, and social equity. These criteria are inherently quantifiable, mirroring the indicator-based approaches employed by the selected tools. SAFA's comprehensive governance metrics, FSA's detailed risk assessments, and FSRT's diagnostic precision collectively address the multifaceted sustainability issues faced by NFCs. Moreover, these tools offer a level of granularity that aligns with the LPMI's objective of providing actionable insights for landscape management.

Although these tools have yet to be specifically applied to NFCs in South Korea, their global applicability and methodological alignment with the LPI suggest significant potential for their use in this context. By leveraging these tools, NFC managers can generate reliable sustainability assessments, identify priority areas for intervention, and implement targeted strategies to enhance the LP of their operations.

Ⅴ. CONCLUSION

1. Summary of Findings

NFCs operate as dynamic, multifunctional entities that blend agricultural production, commercial services, and recreational opportunities. They offer substantial benefits to physical and mental well-being, foster community engagement, and contribute to local economies. However, the sustainable operation of NFCs remains a critical challenge due to their environmental footprint, economic dependencies, and social obligations. This study has demonstrated the compatibility of three online decision-support tools (SAFA, FSA, and FSRT) with the LPI. These tools provide valuable frameworks for assessing and improving sustainability outcomes across environmental, economic, and social dimensions. Their ability to quantify key indicators and identify gaps in sustainability performance underscores their potential for guiding NFCs toward more sustainable practices.

2. Tool Strengths and Capabilities

The SAFA, FSA, and FSRT tools offer distinct yet complementary strengths that enhance their applicability to NFCs. SAFA provides a comprehensive indicator framework that addresses diverse sustainability issues, including greenhouse gas emissions, labor practices, and resource efficiency. Its benchmarking capabilities enable stakeholders to compare performance and prioritize interventions effectively. FSA emphasizes risk management and strategic planning, equipping NFCs to mitigate climate-related vulnerabilities and optimize resource use. This tool fosters transparency, which can strengthen stakeholder relationships and market competitiveness. FSRT stands out for its diagnostic features, which generate tailored action plans addressing specific site-level challenges such as biodiversity conservation, invasive species management, and soil health. Collectively, these tools offer a robust, multifaceted approach to sustainability evaluation, making them highly relevant for NFCs.

The triad principle of sustainability, addressing environmental, economic, and social dimensions, forms the foundation of both the LPI and the tools examined in this study. This alignment makes SAFA, FSA, and FSRT particularly suited for NFCs, which inherently balance these three pillars. The tools not only identify sustainability gaps but also provide actionable insights for enhancing operational efficiency, resilience, and stakeholder engagement. Their compatibility with the LPI suggests their potential for comprehensive sustainability assessments that can be tailored to the unique features and demands of NFCs. By integrating these tools into their operational strategies, NFCs can improve their long-term viability while contributing to broader sustainability goals.

3. Research Limitations

While this study highlights the potential of SAFA, FSA, and FSRT, several limitations hinder their practical applicability in South Korea. Firstly, these tools have not yet been applied to real-world NFC operations in the region, leaving their effectiveness unvalidated in local contexts. Secondly, the generic nature of these tools does not fully account for region-specific challenges such as South Korea’s unique land-use patterns, water resource management needs, and biodiversity priorities. This limitation necessitates the incorporation of localized metrics and regulatory considerations. Thirdly, the study lacks a detailed comparative analysis of the tools under varying operational conditions, which limits the ability to determine their relative strengths and weaknesses.

4. Future Directions

To address these limitations and unlock the full potential of these tools, future research must focus on three critical areas. First, localizing the tools by incorporating region-specific criteria, including native biodiversity metrics, water management strategies, and compliance with South Korean agricultural regulations, will enhance their relevance and precision. Second, conducting real-world case studies in operational NFCs across diverse regions in South Korea is essential. These studies will provide empirical data to validate the tools’ effectiveness and identify potential improvements. Third, developing a structured comparative framework to evaluate the relative performance of these tools under different scenarios will enable stakeholders to make informed decisions about their adoption and implementation. Such efforts will not only strengthen the tools’ applicability but also generate valuable insights into their adaptability and scalability.

5. Concluding Remarks

The findings of this study underscore the transformative potential of SAFA, FSA, and FSRT in advancing the sustainability performance of NFCs. These tools provide comprehensive assessment frameworks that can guide NFCs in identifying and addressing sustainability gaps, benchmarking performance, and implementing targeted interventions. By leveraging these tools, NFCs can enhance their operational resilience, foster stronger stakeholder relationships, and contribute to sustainable development in South Korea’s healthcare plant production industry.

However, realizing this potential requires adapting these tools to local contexts and validating their utility through practical application. Future research must bridge global best practices with local realities to ensure that NFCs in South Korea not only achieve their sustainability objectives but also serve as models of sustainable agricultural innovation. By harmonizing ecological integrity with economic productivity and social well-being, NFCs can play a pivotal role in advancing global sustainability efforts. This integrated approach will ensure a prosperous and sustainable future for NFCs, aligning their operations with both regional priorities and international sustainability standards.

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