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From Resilience Diagnosis to Investment Prioritization: An Integrated Composite-Indicator Framework for Place-Based Agricultural Policy Across Romania's NUTS-2 Regions

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Abstract

The agricultural sector is increasingly exposed to a complex set of climatic, economic, and institutional pressures, indicating that resilience assessment alone is insufficient; investments must also be strategically directed toward strengthening resilience. In response, this study proposes an integrated framework for assessing the resilience of crop farms and supporting the strategic screening and relative prioritization of investments at the regional level. The framework is applied to Romania, which is administratively organized into eight NUTS-2 (Nomenclature of Territorial Units for Statistics) development regions. The framework combines a Farm Resilience Composite Index (ICRF)—structured around five interconnected pillars (productive, economic, technological, ecological, and organizational)—with a Strategic Resilience Investment Score (SRIS), designed to translate resilience diagnostic outcomes into strategic screening and relative investment priorities. The methodology integrates normalized regional sub-indicators, expert-based weighting, and catch-up gap measures relative to the observed regional benchmark. It further incorporates complementarity and substitution relationships among sub-indicators, thereby capturing the systemic nature of resilience. Robustness is ensured through sensitivity analysis, Monte Carlo simulations, and a leave-one-region-out jackknife procedure. The results indicate that investment priorities are not driven solely by the magnitude of regional deficits. Instead, they emerge at the intersection of catch-up needs, systemic relevance, and the stability of outcomes under uncertainty. Across all regions, production stability, access to the agricultural knowledge and innovation system (AKIS), and farm-level digitalization consistently emerge as cross-regional priorities. Moreover, at least two of the three initial priorities are retained in 55 of the 56 leave-one-region-out comparisons, indicating a high degree of robustness. In contrast, ecological, economic, and organizational indicators exhibit greater territorial specificity. Overall, the ICRF–SRIS framework provides a transparent and analytically grounded tool for supporting place-based agricultural policy and guiding investment allocation in the context of post-2027 Common Agricultural Policy (CAP).

Keywords: agricultural resilience; composite indicator; investment prioritization; CAP post-2027; Romania

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1. Introduction

In recent years, agriculture has been increasingly exposed to multiple pressures arising from heightened climate variability, volatility in input and output markets, geopolitical tensions, and growing constraints on natural resources. These challenges simultaneously test the capacity of farms to maintain their productive, economic, and ecological functions [1]. In this context, resilience has emerged as a central concept in the analysis of agricultural systems, evolving beyond its traditional interpretation as the capacity to return to a previous equilibrium. It is now understood as a multidimensional capacity encompassing three interdependent dimensions: robustness, adaptability, and transformability [1–3]. This multidimensional perspective suggests that a resilient farm is not merely one that absorbs shocks, but one that is also capable of, learning, reorganizing and, when necessary, transforming its structure and functions under conditions of uncertainty [4,5].

The multidimensional character of resilience implies that it cannot be captured adequately through a single indicator or dimension. The literature highlights that agricultural resilience emerges from the interaction of multiple factors, including production stability, economic viability, access to knowledge and innovation, technological capacity, ecological conditions, and human and organizational resources [1,6,7]. Empirical studies further show that agricultural resilience is unevenly distributed across territories and influenced by factors such as mechanization, human capital renewal, education, adaptive capacity, and institutional support [8,9]. Consequently, an increasing number of studies employ composite indicators that integrate heterogeneous sub-indicators into an aggregate measure that can be compared across territorial units [10–12]. While these tools offer important advantages of synthesis and comparability, they also raise methodological challenges related to normalization, weighting, and aggregation, as alternative methodological choices may substantially influence resulting rankings and interpretations [11,13].

The relevance of these tools is reinforced by the ongoing transformation of European agricultural policy. The European Commission's proposals for the 2028–2034 financial framework and the future post-2027 Common Agricultural Policy (CAP) indicate a stronger emphasis on simplification, flexibility, strategic planning, and the adaptation of interventions to specific territorial and sectoral needs [14,15]. Within this evolving policy framework, increasing importance is attached to objectives such as climate and economic resilience, farm competitiveness, innovation, digitalization, risk management, and the vitality of rural areas. As a result, there is a growing need for analytical tools capable of supporting territorially differentiated investment decisions by taking into account not only the aggregate level of performance, but also the specific configurations of vulnerabilities and capacities within each region [16,17]. In this context, agricultural resilience emerges not merely as a policy objective but also as a key criterion for the strategic allocation of limited resources.

Despite this need, many existing resilience assessment frameworks remain predominantly descriptive. They enable the ranking of territorial units and the identification of weaknesses, but typically stop at measuring resilience levels without providing an explicit rationale for prioritizing interventions [1,7]. Furthermore, many studies assess regional performance relative to a national average, an approach that can obscure both areas of exceptional performance and structural vulnerabilities, thereby reducing the visibility of substantial territorial heterogeneity [12]. Another common limitation is the treatment of resilience sub-indicators as independent elements aggregated linearly, overlooking the fact that resilience is shaped by interconnected components linked through complementarity and substitution relationships. From a policy perspective, these interdependencies are important because they may influence the effectiveness and strategic relevance of investment interventions [18]. Finally, although weighting choices schemes have a substantial influence

on composite indicator results, they are only rarely subjected to systematic robustness and sensitivity analysis [11,13].

These limitations point to a broader methodological gap. Existing composite-index frameworks are primarily intended to synthesize multidimensional information and provide an aggregate diagnosis of resilience, whereas multi-criteria decision-support frameworks are intended to evaluate, compare, and prioritize predefined alternatives based on multiple criteria and, where appropriate, decision-maker's preferences [12,19,20]. Between these two approaches, the analytical step through which the results of a composite diagnosis can be systematically used to identify resilience components requiring priority attention remains insufficiently developed. To address this gap, the proposed framework links resilience diagnosis with strategic prioritization by using the results of the composite resilience assessment to identify and prioritize sub-indicators according to three jointly considered dimensions: the magnitude of regional deficits, their structural importance within the resilience system, and their patterns of co-variation. This perspective is particularly relevant in agriculture, where identical policy instruments may generate different outcomes across regions due to variations in agro-climatic conditions, productive structures, technological levels, and organizational capacity [21–23]. Consequently, the analytical focus shifts from the question "Which region is more resilient?" to "Which components of the regional resilience system require priority attention?"

The present study addresses this gap by proposing an integrated framework for assessing and supporting strategic screening and relative prioritization of crop farms, applied to the eight NUTS-2 development regions of Romania. The focus on of the regional level is justified by the fact that agricultural resilience is not uniformly expressed across national territories, but is shaped by contextual factors such as farm structure, resource availability, technological level, human capital, and institutional capacity [24]. The proposed framework combines two complementary instruments. The first is a Farm Resilience Composite Index (ICRF), structured around five interconnected pillars—productive, economic, technological, ecological, and organizational—that collectively capture the main dimensions of agricultural sustainability and resilience. The second is a Strategic Resilience Investment Score (SRIS), conceived as a decision-support tool for strategic screening and relative prioritization of investments, rather than as a validated model for investment allocation. The SRIS integrates each region's need for catch-up with the effective importance of the corresponding sub-indicators and the need to preserve and consolidate existing capacities.

Unlike purely descriptive approaches, the ICRF–SRIS framework explicitly incorporates the relational structure among sub-indicators by integrating observed positive connectivity into the prioritization process, while retaining negative co-variation for descriptive and diagnostic purposes. The framework also evaluates selected methodological assumptions through sensitivity analysis, Monte Carlo simulation, and a leave-one-region-out procedure. This approach enables the identification of priority resilience components based not only on the magnitude of regional deficits but also on the effective importance and positive connectivity of the corresponding sub-indicators within the resilience system. The stability of these priorities is subsequently assessed across the alternative weighting schemes and regional-configuration scenarios. Through its application at the regional level, the study provides a transparent analytical basis for a place-based strategic screening and the relative prioritization of investments consistent with the post-2027 CAP orientation toward territorially differentiated interventions [14,25]. However, the framework should be understood as a decision-support instrument rather than as a substitute for political decision-making, stakeholder, or economic appraisal methods such as cost–benefit analysis.

2. Materials and Methods

2.1. Study Area

This study was conducted across Romania's eight NUTS-2 development regions: North-East, South-East, South-Muntenia, South-West Oltenia, West, North-West, Centre, and Bucharest-Ilfov. The regional scale was selected because agricultural resilience is not uniformly distributed across the national territory but is shaped by variations in territorial conditions, farm structure, natural resources endowments, technological developments, and human capital [24]. By focusing on the regional level, the analysis captures territorial disparities that may be concealed by the national-level averages and provides a more appropriate basis for the design and strategic targeting of territorially differentiated investment policies.

2.2. Conceptual Framework and Pillar Structure

The proposed framework for assessing the resilience of crop farms is structured around five interconnected pillars that collectively capture the main dimensions of agricultural sustainability and resilience. Its conceptual structure was drawn from established frameworks in the international literature on agricultural resilience [1,6,7,12], while being adapted to the specific realities, characteristics, constraints and development challenges of Romanian agriculture. Together, these pillars provide a comprehensive representation of the factors that shape the capacity of farms to withstand, adapt to, and transform in response to external shocks and long-term pressures. The five pillars are described below.

- **Pillar A—Productive** (I_{PROD}). This pillar assesses both the level of production and its stability over time. High but volatile production exposes farms to unpredictable losses in the face of climatic and market shocks; therefore, reduced production variability is treated as a fundamental component of productive robustness and, implicitly, of resilience [1,26].
- **Pillar B—Economic** (I_{EC}). This pillar reflects the financial viability and economic robustness of farms. The capacity to generate positive net margins and to maintain a controlled level of indebtedness determines farms' ability to absorb losses and to invest in adaptation, thereby constituting a central component of long-term resilience [27–30].
- **Pillar C—Technological** (I_{TEH}). Digitalization and access to agricultural knowledge and innovation systems (AKISs) are key factors of competitiveness, resource-use efficiency, and adaptive capacity. Emerging technologies—from precision agriculture to digital farm-management tools—are increasingly recognized as drivers of farm modernization and resilience [31–34].
- **Pillar D—Ecological** (I_{ECO}). This pillar highlights the balance between productivity and the conservation of natural resources including the precipitation regime, input management, crop diversity, and soil carbon conservation, which is decisive for long-term sustainability and adaptation to climate change. The precipitation regime directly conditions agricultural production, explaining a substantial share of yield variability [35]. Crop diversity can reduce production fluctuations caused by climate variability, enhancing resilience, while soil carbon conservation contributes to climate-change mitigation and to the long-term fertility of soils [36,37].
- **Pillar E—Organizational** (I_{ORG}). Generational renewal, the qualification of human capital, labor productivity, and risk-management instruments represent major challenges for European agriculture, where the average age of farmers exceeds 57 years [38,39]. Labor productivity and education condition the efficiency and adaptive capacity of farms [40,41], while insurance instruments strengthen farms' ability to absorb shocks [42].

Based on the conceptual framework outlined above, the 14 sub-indicators were selected to operationalize the five dimensions of resilience through measurable variables capable of capturing regional differences in the resilience of crop farms across Romania's eight NUTS-2 regions. In the context of this study, the sub-indicators were chosen and interpreted specifically from an agricultural resilience perspective, while acknowledging that some of them may also be relevant to other analytical perspectives. Their selection was guided by four complementary criteria: (i) conceptual relevance to the dimension of resilience represented by each pillar; (ii) support in the international literature for the indicator's relevance to agricultural resilience; (iii) the availability of official, reliable, and comparable data series for all eight NUTS-2 regions of Romania; and (iv) each indicator's ability to provide complementary information, avoiding excessive overlap between variables. Together, the 14 sub-indicators provide a coherent and operational framework for assessing and comparing resilience of crop farms at the regional level. While they capture the key dimensions of the resilience concept adopted in this study, they are not intended to provide an exhaustive representation of all factors that may influence agricultural resilience. Rather, they constitute a consistent and data-supported set of indicators designed to support regional resilience assessment and strategic prioritization.

2.3. Database

The analysis relies on secondary data covering a period of up to 20 years, with reference time windows adapted to the characteristics and availability of each indicator. The detailed sources and reporting periods are presented in Table 1. For each sub-indicator, the same reference period was applied across to all eight NUTS-2 regions, ensuring a consistent basis for cross-regional comparison within that indicator. Normalization prior to aggregation places the values on a common scale while preserving their relative ordering, but it does not eliminate the temporal heterogeneity of the underlying data. Consequently, the composite index should be interpreted as a regional resilience profile that combines long-term structural characteristics with the most recent available conditions, rather than as a fully synchronized assessment for a single reference year. The framework is therefore intended primarily for cross-regional comparison and strategic diagnosis, rather than for measuring year-on-year changes in resilience. As a result, differences in reference windows may reduce sensitivity to recent developments and may influence composite scores where regional positions have evolved over time.

Table 1. Sub-indicators of the five pillars.

Pillar	Indicator	Name	Type	Period	Source
Pillar A	I_Q	Mean yield	Direct	2005–2024	AGR108A, AGR109A [43,44]
	Icv	Yield coefficient of variation	Inverse	2005–2024	
Pillar B	I_{MN}	Net margin	Direct	2019–2023	SE420, SE025,SE410, SE436, SE485 [45,46]
	I_{GI}	Debt ratio	Inverse	2019–2023	
Pillar C	I_{DIG}	Farm digitalization index	Direct	2019–2023	ef_mp_digi, ef_m_farmleg [47,48]
	I_{AKIS}	Access-to-services index (AKIS)	Direct	-	[32,49–51]
Pillar D	I_{PRECIP}	Mean precipitation	Direct	2008–2024	TOZ1334 [52]
	I_{NPK}	Fertilizer consumption	Inverse	2005–2024	AGR104A, AGR108A, [43,53]
	I_H	Shannon index	Direct	2020–2024	AGR108A [43,54]
	I_{SOC}	Soil-sequestered carbon	Direct	-	[36,55,56]
Pillar E	I_{AWU}	Labor productivity	Direct	2019–2023	SE010 [46]
	I_{EDU}	Education index	Direct	-	RGA 2020 [57,58]
	I_{AGING}	Aging index	Inverse	-	RGA 2020 [57,58]
	I_{ASIG}	Land insurance index	Direct	-	Aggregated regional values provided by a agricultural insurance company. Available on request (see Data Availability Statement).

Data compilation and initial processing were carried out in Microsoft Excel software, while the subsequent statistical analyses were performed in the R environment, through the RStudio interface (version 2026.04.0+526).

2.4. Indicator Normalization and Score Aggregation

To allow comparability among sub-indicators expressed in different units of measurement, all variables were normalized onto a common 1–10 scale using the min–max method, which transforms variables onto a common scale without altering the relative ordering of the observations [12]. Normalization was performed by relating each regional value to the range of variation observed for the respective sub-indicator across the eight NUTS-2 development regions of Romania. Thus, for each sub-indicator, the value 1 corresponds to the weakest observed regional performance, and the value 10 corresponds to the best observed regional performance.

For direct indicators, where higher values signal a positive contribution to the resilience of crop farms, normalization was carried out as follows:

$$I_{i,r}^{norm} = \frac{X_{i,r} - X_i^{min}}{X_i^{max} - X_i^{min}} \times 9 + 1, \quad (1)$$

For inverse indicators, where higher values signal vulnerability, the formula is defined as follows:

$$I_{i,r}^{norm} = \frac{X_i^{max} - X_{i,r}}{X_i^{max} - X_i^{min}} \times 9 + 1, \quad (2)$$

where $I_{i,r}^{norm}$ is the normalized score of sub-indicator i in region r; $X_{i,r}$ is the raw value of the sub-indicator; and X_i^{min} and X_i^{max} represent the minimum and maximum observed values for sub-indicator i.

After normalization, the sub-indicators were aggregated at the level of each pillar. For Pillar A, a weighted arithmetic mean was used, with an internal weight of 0.30 for mean yield and 0.70 for the coefficient of variation. The greater weight assigned to production stability reflects the conceptual focus of resilience on the capacity to maintain productive functions under disturbances and changing conditions [1,26]. This choice is consistent with studies that operationalize crop-production resilience through measures derived from the coefficient of variation [59], demonstrates that higher average yields may coexist with lower stability [60], and highlights that assessments based exclusively on mean yield may overlook the temporal variability and reliability of production outcomes across the years [61]. Accordingly, the 0.30/0.70 ratio represents a methodological operationalization of the greater relevance assigned to stability within the productive pillar, while the uncertainty associated with this weighting choice was evaluated through the Monte Carlo analysis described in Section 2.11. For the other four pillars, the score was computed as a simple arithmetic mean of the normalized sub-indicators, as the components were considered equivalent in terms of internal importance.

2.5. Indicator Weighting and Computation of the Effective Importance of Sub-Indicators

The relative weights of the five resilience pillars were determined using a direct expert-based weighting approach, a method widely employed in the construction of composite indices and consistent with multi-criteria assessment frameworks [10–12].

The weight elicitation involved a panel of three independent experts: Expert 1—agricultural economics specialist, Expert 2—agricultural economics specialist, and Expert 3—CEO of an agricultural enterprise. The composition was intended to combine academic expertise in agricultural economics with practical managerial experience in the agricultural sector. Each expert allocated a total of 100 percentage points across the five pillars according

to their assessment of the relative contribution of each pillar to the resilience of crop farms. The final pillar weights (Wp) were calculated as the arithmetic mean of their assessments (Table 2).

Table 2. Weights assigned by the three experts and the resulting aggregated pillar weights (%).

Pillar	Expert 1	Expert 2	Expert 3	*Wp*
Pillar A—I_{PROD}	20.0	20.0	20.0	20.0
Pillar B—I_{EC}	5.0	5.0	10.0	6.7
Pillar C—I_{TEH}	10.0	15.0	30.0	18.3
Pillar D—I_{ECO}	35.0	35.0	15.0	28.3
Pillar E—I_{ORG}	30.0	25.0	25.0	26.7
Total	100.0	100.0	100.0	100.0

Although the panel size was limited, the approach was designed to provide a transparent and informed weighting scheme reflecting both theoretical and practical perspectives on agricultural resilience. The influence of the resulting weights on the study out-comes was subsequently examined through sensitivity analysis and Monte Carlo simulation (Section 2.11), allowing the robustness of the results to be assessed with respect to this methodological choice [11,13].

On the basis of the weights assigned to the pillars and the internal aggregation structure, the effective importance of each sub-indicator was derived, computed as the product of the pillar weight (Wp) and the internal weight of the sub-indicator within the pillar. This step enables a transition from an aggregate assessment at the pillar level to a fine-grained prioritization at the sub-indicator level, which is necessary for informing precise investment interventions.

2.6. Computation of the Farm Resilience Composite Index—ICRF

The Farm Resilience Composite Index is computed as a weighted mean of the five pillars, using the weights derived in Section 2.5, as follows:

$$\mathrm{ICRF}_r = \sum_{p=1}^{5} W_p \times I_{r,p} \tag{3}$$

where

- ICRF_r is the resilience score of region r;
- $I_{r,p}$ is the normalized score of pillar p for region r;
- W_p is the weight of pillar p.

The ICRF is not used solely as a descriptive tool for ranking regions, but as a basis for building a prescriptive framework for the strategic prioritization of investments, aimed at answering the question "in which components of the system should there be investment to strengthen regional resilience?".

2.7. Analysis of the Relational Architecture of the Sub-Indicators

The relationships among the 14 sub-indicators were examined through the Pearson correlation coefficient [62], computed across Romania's eight NUTS-2 regions. These eight territorial units represent the complete population of Romanian development regions at the NUTS-2 level, rather than a sample drawn from a larger national population. However, the limited number of analytical units constrains inferential interpretation and may affect the stability of the correlation coefficients. Consequently, the correlations are interpreted descriptively, as patterns of co-variation among sub-indicators across regions,

and are not used for statistical significance testing or as evidence of causal, technical, or intervention effects.

The classification thresholds were informed by conventional effect-size benchmarks, particularly the reference values of approximately $|r| = 0.30$ for a medium association and $|r| = 0.50$ for a large association, while recognizing that the verbal interpretation of correlation magnitude varies across disciplines and should remain context dependent [63–65]. Within the present framework, thresholding was used as an operational filtering procedure for constructing the correlation network rather than as a statistical significance criterion [66]. For operational purposes, indicator pairs were classified into three mutually exclusive and collectively exhaustive categories: complementarity ($r > 0.50$), substitution ($r < -0.30$), and indifference ($-0.30 \leq r \leq 0.50$).

These categories are used as concise operational labels for patterns of regional co-variation among sub-indicators. Complementarity denotes positive co-variation exceeding the more restrictive threshold of 0.50, substitution denotes negative co-variation of at least moderate magnitude, and indifference encompasses relationships that do not satisfy either threshold. The categories do not imply causal relationships, technical substitutability, or that an intervention targeting one sub-indicator will necessarily generate changes in another.

The asymmetric thresholds reflect the distinct analytical roles assigned to positive and negative relationships within the framework. Only complementarity relationships are incorporated into the positive-connectivity factor and therefore contribute to the SRIS. The stricter positive threshold of $r > 0.50$ was selected to ensure that only sufficiently strong positive co-variations influence the prioritization process. By contrast, substitution relationships, identified at $r < -0.30$, are retained solely for descriptive and diagnostic interpretation of the relational structure and are not included in the calculation of the positive-connectivity factor. Indifference relationships likewise have no direct role in the SRIS values.

This procedure provides a descriptive representation of the co-variation structure among the resilience components through both a correlation matrix and a network of relationships. The network approach facilitates the identification of relatively central sub-indicators as well as positive and negative associations within the observed regional configuration [18]. Given that this structure is derived from a limited number of territorial units, its sensitivity to the inclusion of individual regions is subsequently examined through a leave-one-region-out analysis (Section 2.12).

2.8. Gap Analysis Relative to the Best Performance Benchmark: Catch-Up Gap

To identify the resilience components in which each region exhibits the greatest relative need for improvement, the distance of each sub-indicator from the highest performance observed among Romania's eight NUTS-2 regions was calculated. For each sub-indicator, the benchmark corresponds to the highest normalized score attained within the regional set; consequently, the benchmark region may differ across sub-indicators. Unlike approaches based on national averages, which may conceal both leading performance and structural weaknesses, this distance-to-benchmark method evaluates each region relative to the highest level empirically observed within the study [12].

This approach provides a more demanding and policy-relevant reference framework by highlighting the magnitude of the adjustment required to reach the best performance currently achieved within the national regional context.

The benchmark serves exclusively as an internal empirical reference for cross-regional comparison and strategic screening. It should not be interpreted as an efficiency benchmark, an externally defined policy target, or a performance level necessarily attainable by all regions. Furthermore, because the highest values may be observed in different

regions, the collective benchmark score does not represent a multidimensional performance profile simultaneously achieved by any single region. Rather, it constitutes a synthetic reference constructed from the best observed performance for each sub-indicator within the study population.

As all sub-indicators were previously normalized into a common 1–10 scale, the catch-up gap was calculated directly as the difference between each region's normalized score and the highest normalized score observed for the corresponding sub-indicator, as follows:

$$\mathrm{GAP}_{r,i} = X_i^{\max} - X_{r,i} \tag{4}$$

where

- $\mathrm{GAP}_{r,i}$ is the catch-up gap of region r for sub-indicator i;
- $X_i^{\max}$ is the best value observed for sub-indicator i;
- $X_{r,i}$ is the score of region r for sub-indicator i.

A low gap value indicates proximity to the frontier, while a high gap indicates a greater need for catch-up.

The gap is not, however, interpreted as the total investment need, because a high-performing region may still require maintenance and consolidation investments; for this reason, the gap analysis is used as one component of prioritization, not as the sole decision criterion. The resulting values provide a standardized measure of relative distance from the observed benchmark, allowing comparisons of catch-up needs across resilience dimensions while preserving the relative position of each region within the empirical distribution.

2.9. Strategic Resilience Investment Score: SRIS

To extend the resilience assessment beyond diagnosis and support strategic screening and relative prioritization, this study introduces the Strategic Resilience Investment Score (SRIS). The SRIS is conceived as an analytical decision-support tool that combines three dimensions: (1) the region's need for catch-up, measured through the catch-up gap; (2) the effective importance of the sub-indicator within the resilience system; and (3) need to preserve and consolidate existing capacities.

By integrating these dimensions, the SRIS provides a structured basis for identifying resilience components that may warrant priority attention. The SRIS is intended to support a preliminary stage of strategic screening and relative prioritization rather than to function as a stand-alone investment-allocation model. Accordingly, it does not determine the amount of investment required, nor does it account for intervention costs, expected returns, administrative feasibility, budgetary constraints, or stakeholder preferences. These considerations remain the subject of subsequent stages of policy design and decision-making.

The catch-up component is defined as follows:

$$\mathrm{SRIS}_{r,i}^{C} = \mathrm{GAP}_{r,i}^{\mathrm{norm}} \times \mathrm{EW}_i \times C_i \tag{5}$$

where

- $\mathrm{SRIS}_{r,i}^{C}$ is the catch-up component of the strategic score for region r and sub-indicator i;
- $\mathrm{GAP}_{r,i}^{\mathrm{norm}}$ is the normalized catch-up gap;
- EW_i is the effective weight of the sub-indicator i;
- C_i is the complementarity factor of the sub-indicator i.

The complementarity factor C_i is derived from the network of relationships among sub-indicators and expresses the extent to which a sub-indicator is connected to other resilience components through strong positive relationships. Operationally, it is measured as the normalized degree of positive connectivity of each sub-indicator within the correlation

network. Consistent with the interpretation provided in Section 2.7, the complementarity factor reflects only the observed relational position of the sub-indicator within the regional resilience structure. It does not estimate indirect or causal effects of investments nor does it imply that improvements in one sub-indicator will automatically generate changes in others.

To avoid the erroneous interpretation that high-performing regional sub-indicator combinations no longer need investment, the model also includes a maintenance component defined analogously to Equation (5), as follows.

$$\mathrm{SRIS}_{r,i}^{M} = M_{r,i} \times \mathrm{EW}_i \times C_i \tag{6}$$

where *Mr,i* represents the level of maintenance of existing capacity, approximated by the current score of the sub-indicator. This component was introduced to ensure a balanced prioritization approach. While regions exhibit larger resilience gaps that require greater attention, those with established strengths should not be overlooked. Therefore, the current score captures the need to maintain and consolidate existing capacities, whereas the catch-up component prioritizes areas where efforts to reduce regional disparities are most needed.

The final score is defined as a combination of the catch-up component and the maintenance component:

$$\mathrm{SRIS}_{r,i}^{\alpha} = \alpha \times \mathrm{SRIS}_{r,i}^{C} + (1 - \alpha) \times \mathrm{SRIS}_{r,i}^{M} \tag{7}$$

where α is the strategic-orientation parameter that determines the relative emphasis placed on catch-up and maintenance. Low values of α emphasize the maintenance and consolidation of existing strengths, whereas high values place greater emphasis on reducing regional gaps.

This formulation supports the strategic screening and relative prioritization of investments by assigning higher priorities, not only to the larger deficits but also deficits affecting indicators of greater systemic importance for farm resilience.

2.10. Sensitivity Analysis of the Strategic Parameter α

To test the stability of priorities according to the orientation of public policy, nine alternative scenarios of the parameter α were defined (α = 0.1, 0.2, . . ., 0.9). Low values of α correspond to a policy oriented toward maintaining existing advantages, while high values correspond to a policy oriented toward reducing gaps relative to the performance frontier. For each scenario, the SRIS was recomputed for all regional sub-indicator pairs, and the stability of priorities was evaluated through the frequency with which each sub-indicator appears among the top three regional priorities [13].

2.11. Robustness Analysis Through Monte Carlo Simulation

Because the weights derive from expertise and entail uncertainty, the robustness of the results was tested through a Monte Carlo simulation with 10,000 iterations—a common approach for evaluating the stability of results with respect to parameter uncertainty [67,68]. In each iteration, the sub-indicator weights were randomly perturbed by approximately ±20% and then renormalized so that their sum remained equal to 1. For each set of simulated weights, the SRIS was recomputed, and the robustness of each sub-indicator was quantified through its probability of appearing among the top three regional priorities, defined as the proportion of simulations in which the sub-indicator appears in the top three. A sub-indicator with a high probability is therefore interpreted as a priority whose ranking remains stable under the tested weight perturbations. This probabilistic measure provides a distribution-based assessment of priority stability under uncertainty, complementing the deterministic results obtained from baseline weights.

2.12. Robustness Testing Through Leave-One-Region-Out Jackknife Analysis

Given that the analysis was conducted across Romania's eight NUTS-2 development regions, an additional robustness test was performed to assess whether the strategic investment priorities are disproportionately influenced by the inclusion of any single region in the sample. To this end, a leave-one-region-out jackknife procedure was applied [69]. By successively excluding each region and recomputing the SRIS, the procedure evaluates the stability of the resulting priorities and identifies potential cases in which the regional configuration exerts a substantial influence on the prioritization outcomes.

The entire SRIS workflow was recomputed eight times, with one region omitted in each iteration. At every step, the observed regional benchmark, the catch-up gap values, the correlation matrix, the complementarity factors, the SRIS scores, and the resulting priority ranking were recalculated. The expert weights were kept constant, as they express the conceptual importance of the sub-indicators and do not depend on the composition of the regional sample. For each region, the three highest-ranked SRIS priorities in the jackknife scenario were compared with those obtained in the baseline model (computed using the full sample), using the three leading priorities overlap indicator:

$$\text{Overlap}_{r,k} = \frac{\left|\text{T}_r^{full} \cap \text{T}_r^{(-k)}\right|}{3} \tag{8}$$

where

- T_r^{full} is the set of the three priorities for region r in the full model;
- $\text{T}_r^{(-k)}$ is the set of the top three priorities for region r recomputed after removing region k;
- $|\cdot|$ denotes the cardinality of the intersection.

A value of 1 indicates full retention of the three priorities, 0.67 the retention of two, and 0.33 the retention of only one. Average overlap values across all regions and iterations were used as a global indicator of priority stability.

Thus, the jackknife analysis provides an empirical assessment of whether the results are disproportionately influenced by any particular region and complements the α sensitivity analysis and the Monte Carlo simulation, by evaluating the stability of the results with respect to the observed regional configuration.

The three procedures presented in Sections 2.10–2.12 evaluate the robustness of the identified priorities with respect to selected sources of uncertainty: the strategic-orientation parameter α, variation in the weighting structure, and the influence of individual regions on the results. However, these checks do not constitute an exhaustive assessment of all possible methodological specifications. Alternative normalization procedures, alternative thresholds for constructing the correlation network, and other benchmark definitions were not examined. Consequently, the results should be interpreted within the context of the operational specification adopted in this study.

2.13. Construction of the Strategic Resilience Investment Matrix

As a final step, the results are synthesized into a strategic investment matrix that combines two dimensions: (1) average catch-up gap—the average intensity of the need for catch-up and (2) strategic importance—the effective importance of the sub-indicator within the resilience system. The median values of the two dimensions are used as transparent internal reference points to distinguish observations above and below the central tendency of the observed distribution. The median was preferred to the mean because it is less sensitive to extreme values. These reference values serve a descriptive and comparative purpose and should not be interpreted as normative policy thresholds or automatic triggers

for investment. Based on this classification framework, the regional sub-indicators are grouped into four strategic screening categories:

- Immediate investment: Sub-indicators with a high gap and high strategic importance. These represent the main priorities, because they combine a structural deficit with high potential for systemic impact.
- Maintaining strengths: Sub-indicators with a low gap but high strategic importance. These do not necessarily require catch-up, but must be supported to prevent the erosion of existing advantages.
- Long-term improvements: Sub-indicators with a high gap but lower strategic importance. These require interventions, but do not represent the first investment priority.
- Monitor: Sub-indicators with a low gap and low strategic importance. These must be monitored, but do not require major immediate interventions.

The strategic matrix provides a concise decision-support tool, translating the quantitative analysis into an accessible classification framework. It organizes the region's sub-indicator combinations according to their relative position within the observed distribution and facilitates comparison across regions. Since the quadrant boundaries are based on internal median-derived reference values, the resulting categories are intended to support strategic screening and the preliminary prioritization of regional investment needs. They should not, however, be interpreted as normative policy thresholds or direct investment recommendations.

During the analysis and preparation of this study, the generative AI tool ChatGPT (OpenAI, GPT-5.5) was used as an auxiliary support to assist in structuring the analytical workflow, to draft and debug the coding instructions used to run the analyses in the R environment, through the RStudio interface, and to identify candidate methodological options for assessing the robustness of the results given the small regional sample ($n = 8$). The conceptual framework, the selection of indicators, all analytical decisions, the final choice and implementation of the robustness tests, the verification of the results, and the interpretation of the findings were carried out and validated by the authors. AI tools were not used to generate, alter, or fabricate data or results, or to replace the authors' scientific judgment; all AI-assisted outputs were reviewed and validated by the authors, who take full responsibility for the content.

3. Results

3.1. Relational Architecture of the Sub-Indicators

The results of the correlation analysis indicate that regional agricultural resilience cannot be interpreted as a simple linear aggregation of independent sub-indicators. Rather, the resilience system exhibits a complex relational structure, in which the sub-indicators display varying patterns of regional co-variation, operationally classified as complementary, substitutive, or indifferent relationships (Figure 1).

The correlation matrix reveals several strong positive associations, including: I_{EDU}–I_{GI} ($r = 0.76$), I_{DIG}–I_{AGING} ($r = 0.75$), I_{CV}–I_{H} ($r = 0.73$), I_{GI}–I_{MN} ($r = 0.73$), I_{AKIS}–I_{ASIG} ($r = 0.68$), I_{EDU}–I_{Q} ($r = 0.66$), I_{PRECIP}–I_{Q} ($r = 0.62$) and I_{DIG}–I_{SOC} ($r = 0.61$). These patterns suggest pronounced positive regional co-variation between the respective sub-indicators, meaning that regions exhibiting comparatively high values in one dimension also tend to perform well in the associated dimension. However, these relationships reflect statistical association rather than causal dependence.

In parallel, the network also reveals strong negative regional co-variation, operationally classified as substitution: I_{Q}–I_{NPK} ($r = -0.83$), I_{AKIS}–I_{SOC} ($r = -0.81$), I_{AWU}–I_{PRECIP} ($r = -0.73$), I_{NPK}–I_{PRECIP} ($r = -0.71$), I_{NPK}–I_{EDU} ($r = -0.69$) and I_{H}–I_{ASIG} ($r = -0.61$). These results should be interpreted with caution, as they do not imply causal relationships but

rather reflect patterns of regional co-variation. Nevertheless, from a policy and decision-making perspective, they remain relevant because they identify pairs of sub-indicators exhibiting contrasting regional patterns, thereby highlighting potential trade-offs that should be considered in subsequent policy assessment and investment planning.

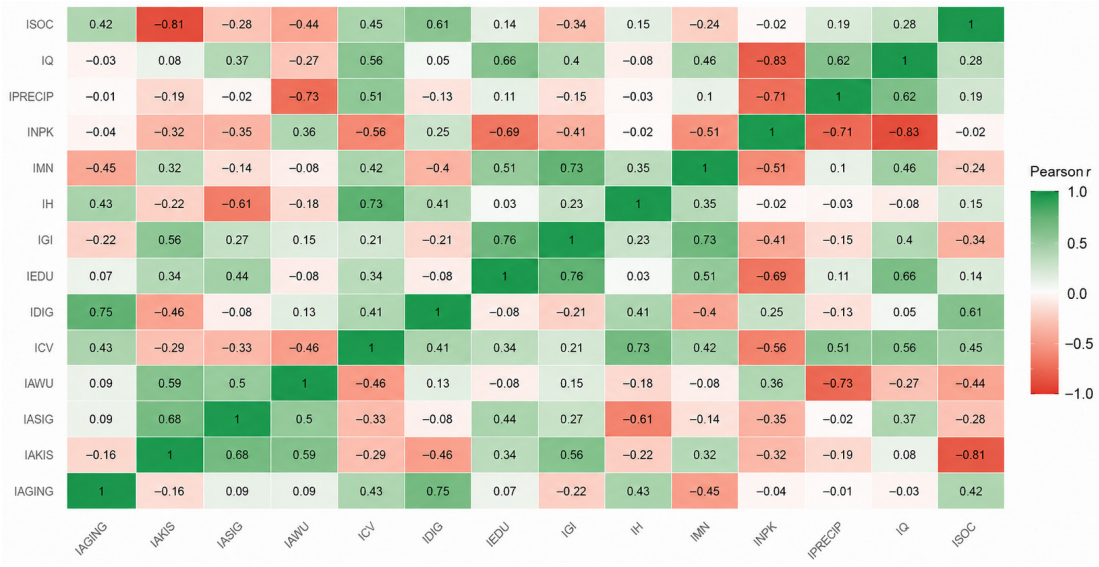


Figure 1. Correlation heatmap between resilience sub-indicators.

The relational analysis generated a total of 91 unique relationships among the 14 resilience sub-indicators, corresponding to all possible pairs of indicators. Of these, 13 relationships were classified as complementarity relationships (14.3%), 18 relationships as substitution relationships (19.8%), and 60 as indifference relationships (65.9%). This distribution (Figure 2), indicates that most relationships among sub-indicators are relatively weak or neutral. Nevertheless, the presence of a significant number of complementarity and substitution relationships suggests that agricultural resilience exhibits a structured pattern of regional interdependencies in which some components tend to co-vary positively, while others display contrasting regional patterns.

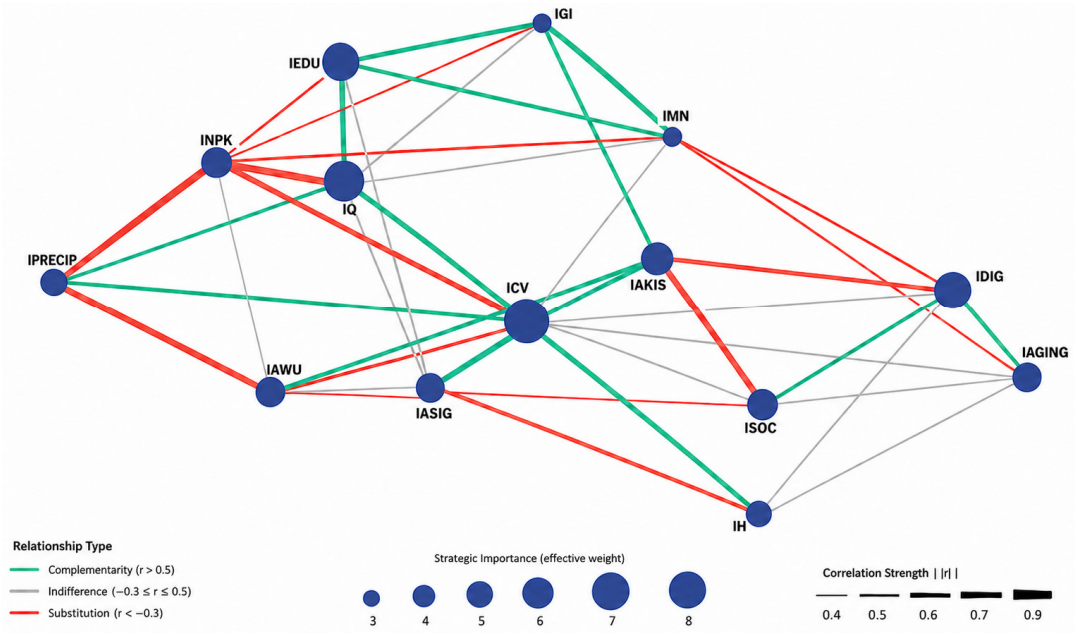


Figure 2. Network of relationships between farm resilience sub-indicators.

Figure 2 shows that I_{CV} occupies a central position in the architecture of resilience, having high strategic importance and multiple connections with other sub-indicators. Likewise, I_{AKIS}, I_{DIG}, I_{EDU} and I_{NPK} appear as relevant nodes, either through their strategic importance or through their position in the structure of relationships.

3.2. Catch-Up Gap Analysis Relative to the Observed Regional Benchmark

The catch-up gap analysis highlights significant regional differences relative to the best performance observed for each sub-indicator. Using the observed regional benchmark is more appropriate than reporting relative to the national average, because the average can conceal both performance peaks and structural vulnerabilities (Figure 3).

Region	IAGING	IAKIS	IASIG	IAWU	ICV	IDIG	IEDU	IGI	IH	IMN	INPK	IPRECIP	IQ	ISOC
West	1.82	1.29	0.00	2.05	0.88	3.85	0.00	1.36	5.37	2.41	9.00	1.33	0.00	2.73
South-West Oltenia	6.10	6.43	5.14	6.03	5.67	7.88	6.48	9.00	9.00	9.00	2.99	1.64	7.44	2.95
South-Muntenia	5.67	5.14	2.25	0.00	4.74	0.93	6.48	5.80	8.08	7.98	1.66	3.54	4.10	3.50
South-East	2.33	5.91	3.86	0.16	5.16	0.93	2.88	3.22	5.33	7.77	0.00	9.00	7.97	1.02
North-West	0.98	8.23	7.07	9.00	0.00	0.35	3.83	3.97	1.16	6.75	4.60	0.00	4.25	0.99
North-East	0.00	6.43	8.36	0.76	1.28	0.00	7.32	7.08	0.00	5.90	1.28	5.30	8.32	2.54
Centre	8.73	9.00	9.00	7.00	0.94	4.60	3.35	3.13	3.43	0.00	4.26	2.48	2.54	0.00
Bucharest-Ilfov	9.00	0.00	4.82	1.09	4.77	9.00	4.15	0.00	4.03	1.06	3.14	5.35	7.23	9.00

Catch-up GAP: 9.0, 7.5, 5.0, 2.5, 0.0

Small gap (0 – 2.5) *Region close to the best observed performance on this indicator*

Moderate gap (2.5 – 5.0) *Region has room for improvement*

Large gap (5.0 – 9.0) *Region far from the best observed performance; high priority for investment*

Figure 3. Catch-up gap to the best observed regional frontier.

The South-West Oltenia region displays one of the most vulnerable regional profiles, with maximum gap values for I_{GI}, I_H, and I_{MN} (9.00), accompanied by substantial gaps in I_{DIG}, I_Q, I_{EDU}, I_{AKIS}, I_{AGING} and I_{AWU}. This profile indicates the presence of multiple overlapping vulnerabilities across economic, technological, organizational, and productive dimensions. Consequently, the South-West Oltenia region does not face a single isolated constraint but rather a multidimensional vulnerability profile.

By contrast, the West region exhibits a profile closer to the observed regional benchmark, although not without intervention needs. The region has a zero gap for I_{ASIG}, I_{EDU} and I_Q, but a maximum gap for I_{NPK} (9.00), together with more moderate gaps in I_H and I_{DIG}. This result illustrates that a region performing well at the aggregate level may still exhibit specific vulnerabilities at the component level. Consequently, investment needs differ: in some cases, catch-up interventions are required, while in others maintenance or targeted corrective measures are more appropriate.

Another distinct profile emerges in the Centre region, which records the highest gap values for I_{AKIS} and I_{ASIG}, together with substantial gaps in I_{AGING} and I_{AWU}, while exhibiting minimal or near-zero gaps for I_{MN}, I_{SOC} and I_{CV}. This pattern indicates that the region's catch-up requirements are concentrated primarily in the organizational, demographic, and innovation-related dimensions of resilience, rather than being uniformly distributed across all sub-indicators.

3.3. Investment Prioritization Through the Strategic Resilience Investment Score (SRIS)

Unlike the gap analysis, which focuses solely on identifying relative deficits, the SRIS supports strategic screening and relative investment prioritization by integrating the magnitude of the gap with the effective importance and observed positive connectivity of the corresponding sub-indicator. Consequently, deficits of comparable size may be assigned different priority levels according to the to the systemic relevance and relational position of the sub-indicator within the resilience framework (Figure 4).



Figure 4. Strategic resilience investment score.

I_{CV} emerges as one of the most important investment priorities across regions, ranking among the highest priority sub-indicator in five regions, with SRIS values ranging from 0.045 in the West region to 0.082 in the South-West Oltenia region. This finding suggests that production stability constitutes a critical dimension of agricultural resilience. Achieving high production levels alone is therefore insufficient; production must also remain stable over time, particularly in contexts exposed to climatic and economic shocks.

I_{AKIS} appears as the second major strategic priority, ranking highly in six regions with SRIS values ranging from 0.057 to 0.076. This result is particularly relevant from a European policy perspective, as agricultural knowledge and innovation systems are recognized within the 2023–2027 CAP as key drivers of agricultural modernization, knowledge exchange, and digital transformation [49].

I_{DIG} represents the third recurrent strategic priority, with high SRIS values in four regions, ranging from 0.049 in the West region to 0.074 in Bucharest-Ilfov. This finding supports the view that digitalization is not merely a technological attribute, but a cross-cutting component of agricultural resilience. Existing research indicates that digital technologies, precision agriculture, and data-driven management systems can strengthen farms' capacity to manage risks, optimize resources use, and improve production-related decision-making [34].

The recurrent prominence of I_{CV}, I_{AKIS}, and I_{DIG} reflects both the regional patterns observed in the underlying data and the structure of the SRIS model, which integrates the catch-up gap with the effective weight and positive-connectivity factor associated with each sub-indicator. Their ranking should therefore be interpreted as the outcome of a model-based prioritization process rather than as a direct empirical measure of investment need.

At the regional level, the three leading priorities define distinct screening profiles (Figure 5): The South-West Oltenia region (I_{CV}, I_{DIG} and I_{AKIS}) requires an integrated strategy of production stabilization, digitalization, and access to knowledge. For the Centre region, the priorities are I_{AKIS}, I_{DIG} and I_{ASIG}, suggesting a strong need to strengthen innovation, digitalization, and risk-management instruments. The North-West region (I_{AKIS}, I_{AWU} and I_{ASIG}) indicates a profile focused on innovation, labor efficiency, and protection against risks. The Bucharest-Ilfov region (I_{CV}, I_{DIG} and I_{SOC}) suggests a different profile, in which digitalization and the natural capital of the soil become key components.

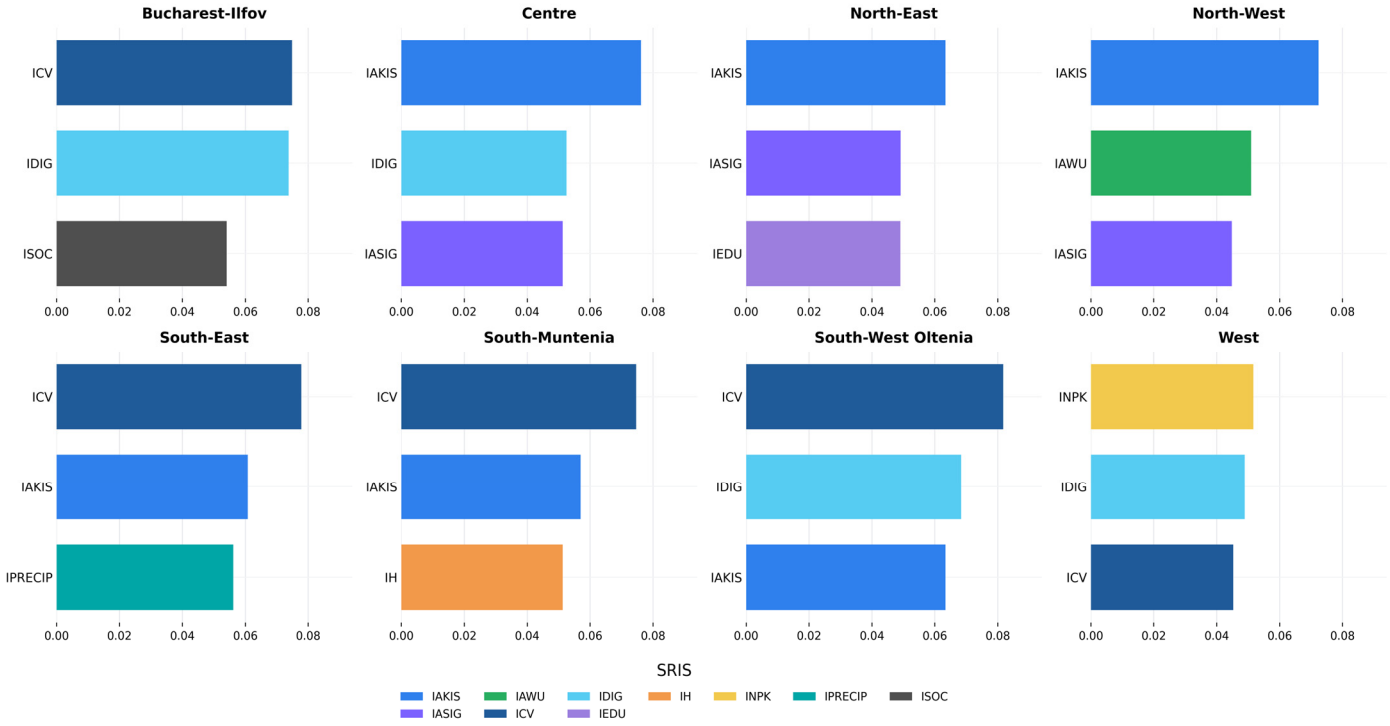


Figure 5. The three leading strategic resilience investment priorities by region.

An important result is that the largest gaps do not automatically become the largest SRIS priorities: in the South-West Oltenia region, I_{GI}, I_H and I_{MN} have maximum gaps, but not all appear in the final ranking of priorities. This demonstrates that the SRIS model does not allocate priority solely on the basis of deficit size, but identifies those deficits that occur in sub-indicators of high systemic importance.

3.4. Stability of Priorities Across Sensitivity Scenarios

The sensitivity analysis of the parameter α makes it possible to evaluate how priorities change when public policy attaches greater importance either to maintaining strengths or to closing gaps. This step is important because composite indices and prioritization scores can be sensitive to weighting assumptions; therefore, sensitivity testing is recommended in the methodology of composite indices and in complex decision models [12,68].

The sensitivity of the SRIS to the strategic orientation α is not uniform across regions, but reflects the structural resilience profile of each region (Figure 6). The West region recorded its highest SRIS values at $\alpha = 0.1$ (0.104), which declined to $\alpha = 0.7$ (0.052) before increasing slightly to $\alpha = 0.9$ (0.064). This pattern suggests that the region receives stronger support under scenarios emphasizing the maintenance and consolidation of existing strengths.

In contrast, the South-West Oltenia region exhibits the opposite behavior: its maximum SRIS increases steadily from 0.059 ($\alpha = 0.1$) to 0.094 ($\alpha = 0.9$), indicating that the region

benefits more from catch-up oriented scenarios, consistent with its profile of relatively large structural gaps. This contrast between the two regions illustrates how strategic orientation of the model influences investment priorities and reinforces the case for territorially differentiated investment policies.

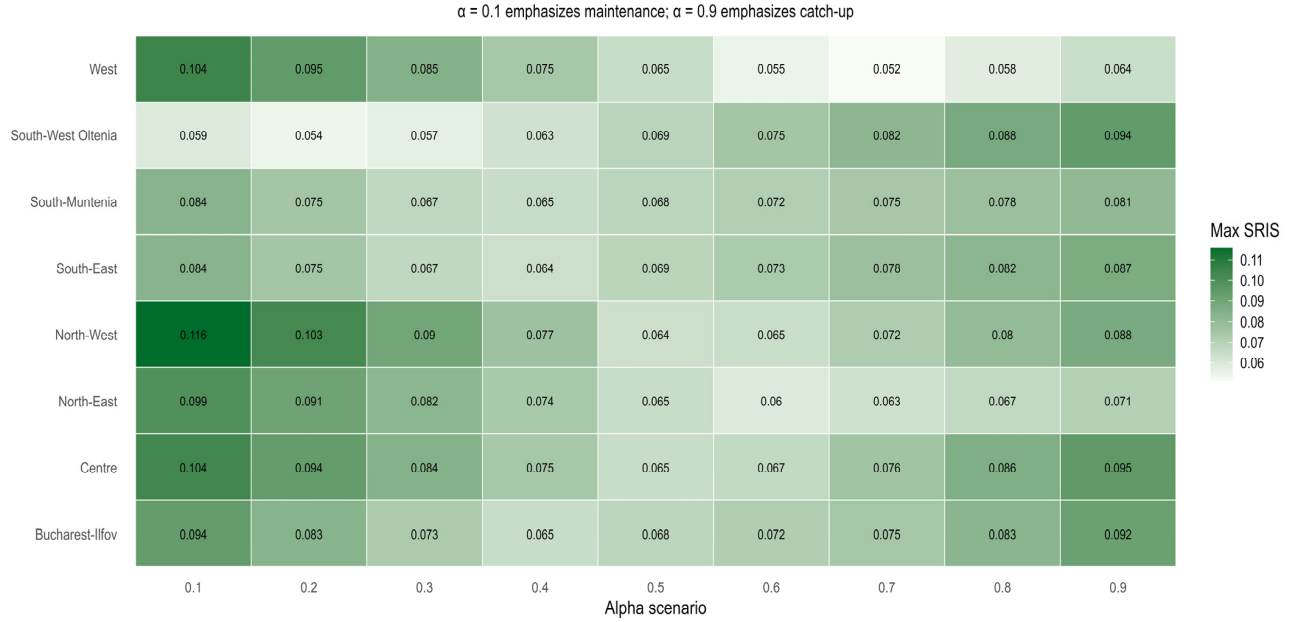


Figure 6. Sensitivity of regional maximum SRIS to alpha scenarios.

In contrast to the heterogeneity of regional responses, the analysis of the stability of the three leading priorities reveals a core set of priorities that remains invariant across the full range of strategic orientation (Figure 7). Across all eight regions, I_{CV}, I_{AKIS} and I_{DIG} consistently rank among the three most frequent priorities throughout the interval α = 0.1–0.9, with I_{CV} emerging as the most frequently selected sub-indicator overall. This persistent dominance, observed across all regional profiles rather than only at the aggregate level, suggests that these three domains can be regarded as "no-regret" priorities, whose strategic relevance remains largely independent of the chosen policy orientation.

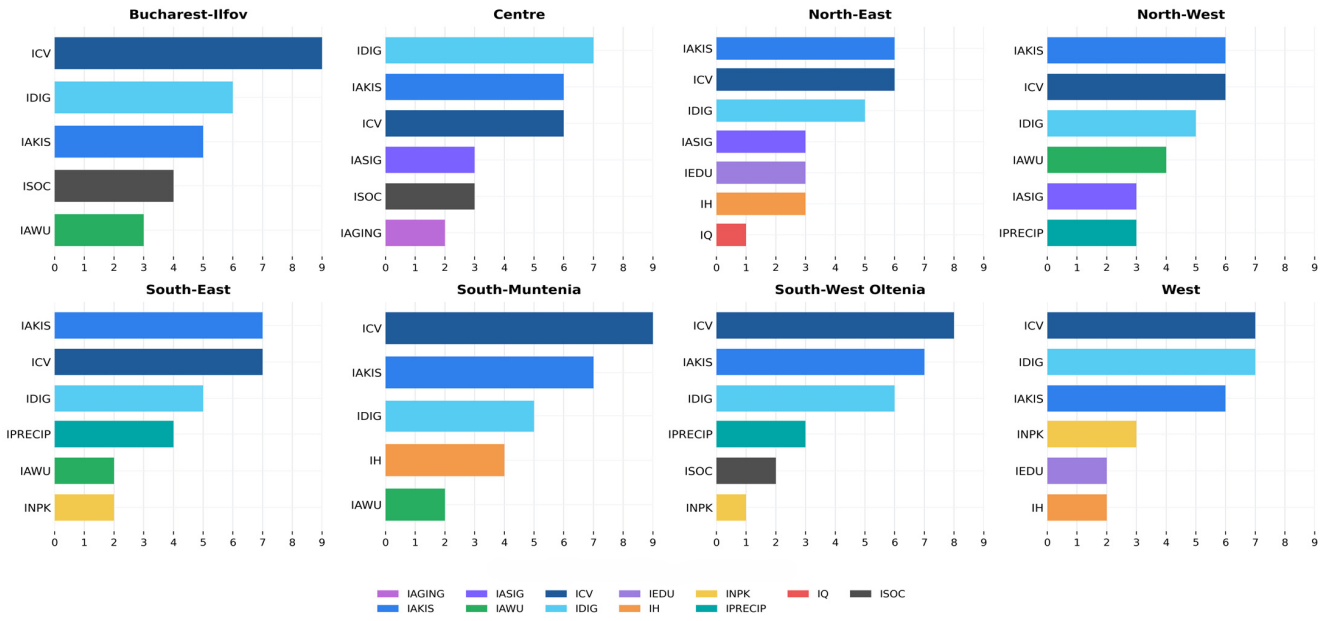


Figure 7. Stability of three leading SRIS priorities across alpha scenarios.

Beyond this common core, the secondary priority positions (places 4–6) vary across regions. Examples include I_H in the North-East, South-Muntenia, and West regions; I_{PRECIP} in the North-West, South-East, and South-West Oltenia regions; and I_{SOC} in Bucharest-Ilfov and the Centre region. This dual structure—a stable core of common priorities, complemented by a set of territorially differentiated priorities—directly supports the need for an investment strategy that combines horizontal measures implemented at the national level with interventions tailored to the specific characteristics and resilience profiles of individual regions.

3.5. Robustness of Priorities Through Monte Carlo Simulation

The Monte Carlo simulation confirms the robustness of the results under uncertainty regarding the sub-indicator weights (Figure 8). At the global level, I_{CV}, I_{AKIS} and I_{DIG} remain the most robust priorities: I_{CV} exhibits the highest average probability of appearing in the three leading priorities, followed closely by I_{AKIS} and then by I_{DIG}, a hierarchy that confirms the results obtained through the SRIS and through the α sensitivity analysis (Sections 3.3 and 3.4).



Figure 8. Monte Carlo robustness of three leading SRIS priorities.

At the regional level, robustness is heterogeneous: in the South-West Oltenia region, I_{CV}, I_{DIG} and I_{AKIS} have high probabilities of appearing in the three leading priorities (production stability, digitalization, and access to innovation); in the North-West region, I_{AKIS} reaches a very high probability (the consolidation of knowledge and innovation systems); and in the South-East region, I_{CV}, I_{AKIS} and I_{PRECIP} appear as robust priorities (production stability combined with innovation and water-resource management).

The distribution of probabilities confirms that, despite the variability introduced by weight uncertainty, the principal sub-indicators largely preserve their strategic importance. Consequently, the identified priorities cannot be attributed solely to a specific weighting configuration, but instead appear to reflect robust structural features of the agricultural resilience system.

Beyond frequency-based selection, the distribution of SRIS scores further confirms the stability of the main priorities (Figure 9). For the robust priorities identified in each

region, the simulated SRIS values remain high and closely clustered, without approaching zero even when the weights derived from expert assessment are perturbed by ±20%. The interquartile ranges are narrow relative to the distance from the origin, and the medians preserve the regional ranking obtained in the baseline model—I_{CV} in the South-West Oltenia region and I_{AKIS} in the Centre and North-West regions maintain consistently high SRIS values throughout the simulations. This indicates that the prioritization of these sub-indicators is driven by the structural characteristics of the resilience system, rather than by a particular weighting configuration.

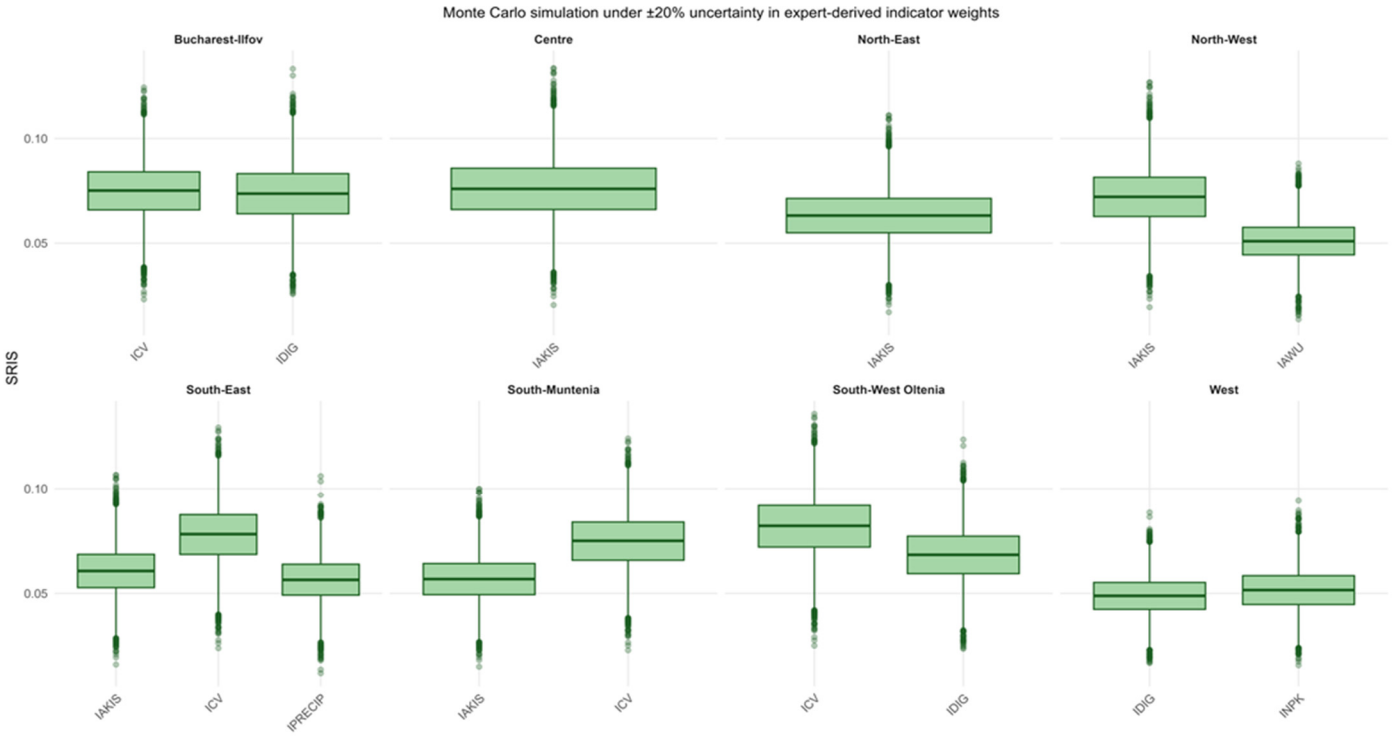


Figure 9. Distribution of SRIS for robust strategic priorities.

3.6. Robustness of SRIS Priorities Through Leave-One-Region-Out Jackknife Analysis

To verify whether the strategic investment priorities depend disproportionately on the presence of any single region, a leave-one-region-out jackknife analysis was applied. The procedure consisted of recomputing the entire SRIS model eight times, successively removing one region and comparing the resulting three leading priorities with those obtained in the full model.

The results indicate a very high degree of stability of the SRIS priorities under the leave-one-region-out procedure. Across the 56 valid region–iteration comparisons, the mean top- three overlap was 91.1%. Of these comparisons, 42 (75.0%) fully retained the three priorities of the baseline model, 13 (23.2%) retained two of the three priorities, and a single case (1.8%) retained only one common priority. Thus, in 55 of 56 cases (98.2%), at least two of the three initial priorities remained unchanged. This result indicates that the SRIS priorities are not dominated by any single region and that the investment hierarchy is robust with respect to the successive removal of regional observations.

Figure 10 confirms this pattern: most cells display a 3/3 or 2/3 overlap. The most stable regions—West, South-West Oltenia, South-Muntenia, North-West, and Bucharest-Ilfov regions—have an average overlap of approximately 95.2%, the South-East and Centre regions have an average overlap of approximately 90.5%, and the North-East region, the most sensitive region, recorded an overlap of 71.4%, but nonetheless retains, in most iterations, at least two of the three priorities.

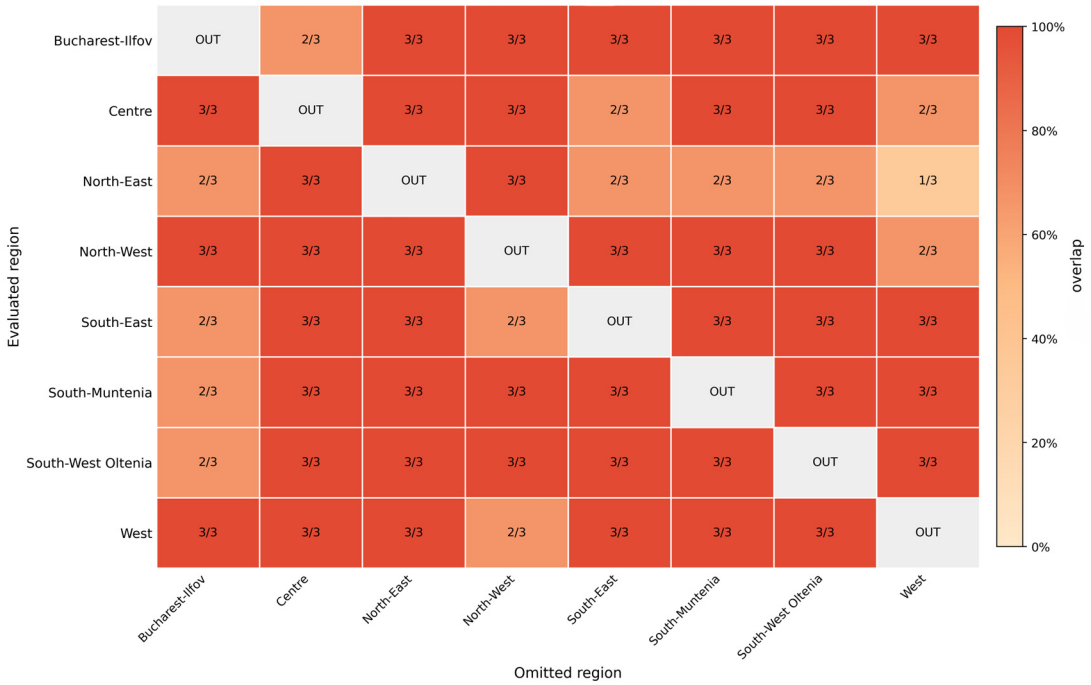


Figure 10. Leave-one-region-out robustness of three leading SRIS priorities.

The only case with a 1/3 overlap occurred for North-East region when the West region was omitted. In this iteration, the baseline priorities I_{AKIS}, I_{ASIG}, and I_{EDU} changed to I_{AKIS}, I_{CV}, and I_{PRECIP}. Thus, I_{AKIS} remained stable, whereas I_{ASIG} and I_{EDU} were the unstable baseline priorities in this specific iteration. In all other non-identical comparisons, only one of the three baseline priorities was changed. Outside of the North-East region, priority substitutions were limited and involved a single baseline priority at a time. Specifically, I_{ASIG} was replaced in the Centre and North-West regions; I_{AKIS} in South-Muntenia and South-West Oltenia; I_{AKIS} or I_{PRECIP} in the South-East region; I_{SOC} in Bucharest-Ilfov; and I_{CV} in the West region.

At the aggregate level, the frequency across the jackknife iterations further corroborates the stability of the prioritization results: I_{AKIS} is the most frequently selected sub-indicator among the top three leading priorities (39 appearances), followed by I_{CV} (38) and I_{DIG} (28). The persistent prominence of agricultural knowledge and innovation systems, production stability, and digitalization indicates that these priorities are not driven by the inclusion of any particular region but represent structurally robust outcomes of the SRIS framework.

Because the analysis covers Romania's eight NUTS-2 development regions, the successive exclusion of each region provides a direct test of the extent to which the priorities depend on any single territorial unit. The fact that the main priorities are generally preserved across the jackknife iterations supports the robustness of the SRIS framework as a tool for regional screening and relative prioritization of investments. Nevertheless, the sensitivity observed for the North-East region suggests that priorities located near the decision margin should be interpreted with caution, as their ranking may be more susceptible to changes in the regional configuration.

3.7. Strategic Resilience Investment Matrix

The strategic investment matrix synthesizes the results into a territorially oriented decision tool: each regional panel positions the sub-indicators according to the catch-up gap (horizontal axis) and strategic importance (vertical axis), separating them into four quadrants: immediate investment, maintain strengths, long-term improvement, and monitor (Figure 11). Thus, the matrix shows not only where gaps exist, but also whether

they occur in domains of high systemic relevance. At the regional level, the strategic profiles are clearly differentiated. The South-West Oltenia region concentrates the broadest set of immediate priorities (I_{CV}, I_{AKIS}, I_{DIG}, and I_H)—a multidimensional vulnerability that requires an integrated strategy of production stability, innovation, digitalization, and diversification—while I_{PRECIP}, I_{NPK} and I_{SOC} appear primarily in the maintenance zone. The South-East region exhibits a similar profile of extensive intervention (I_{CV}, I_{AKIS}, I_H, and I_{PRECIP}), combining productive, technological, and ecological components, while the South-Muntenia region adds, to the immediate priorities (I_{CV}, I_{AKIS}, and I_H), a series of strengths to be conserved (I_{DIG}, I_{NPK}, I_{SOC}, and I_{PRECIP}).

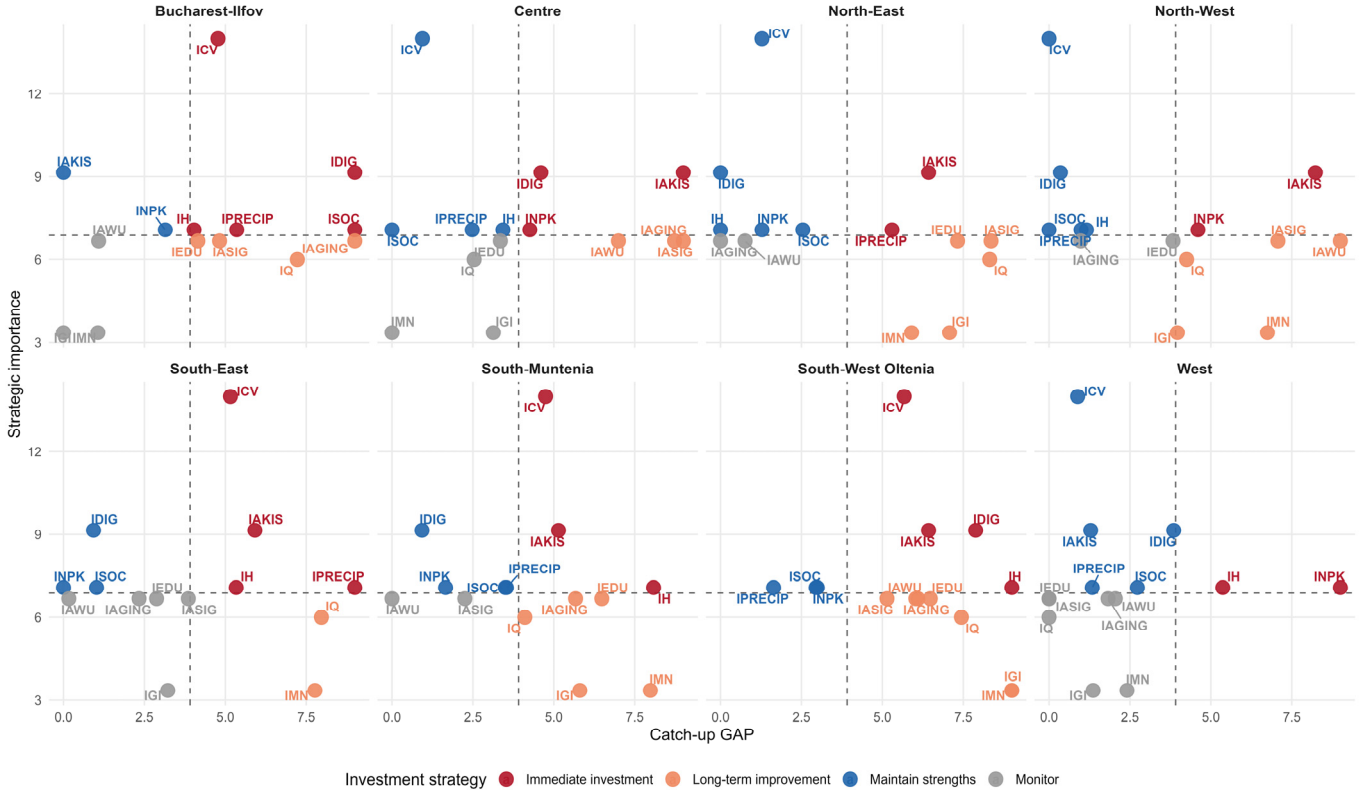


Figure 11. Regional strategic resilience investment matrix.

To enhance the accessibility of the strategic matrix and facilitate cross-regional comparison across regions, Table 3 summarizes the classification of each region–sub-indicator combination across the four screening categories. The table complements Figure 11 by providing a concise and systematic overview of the priorities identified for each region, while preserving the comparative and non-normative interpretation of the median-based classification framework.

By contrast, the West region places most components (I_{CV}, I_{AKIS}, I_{DIG}, I_{PRECIP}, and I_{SOC}) in the maintenance quadrant, with I_H and I_{NPK} in immediate intervention, reflecting a high-performing region that requires the protection of existing advantages rather than broad catch-up interventions. A similar pattern appears in the North-West region (immediate intervention in I_{AKIS} and I_{NPK}) and the Centre region (immediate priorities of I_{AKIS} and I_{DIG}, with I_{CV} already consolidated). The North-East region combines a dual need—I_{AKIS} and I_{PRECIP} in immediate intervention (knowledge/innovation and water management)—with a set of components to be conserved, while Bucharest-Ilfov has an atypical, urban-influenced profile: immediate priorities for I_{CV}, I_{DIG}, I_H, I_{PRECIP} and I_{SOC}, with I_{AKIS} and I_{NPK} in maintenance.

Table 3. Regional classification of sub-indicators across the four strategic screening categories.

Region	Immediate Investment	Maintain Strengths	Long-Term Improvement	Monitor
Bucharest-Ilfov	I_{CV}, I_{DIG}, I_{PRECIP}, I_H, I_{SOC}	I_{AKIS}, I_{NPK}	I_Q, I_{EDU}, I_{AGING}, I_{ASIG}	I_{MN}, I_{GI}, I_{AWU}
Centre	I_{DIG}, I_{AKIS}, I_{NPK}	I_{CV}, I_{PRECIP}, I_H, I_{SOC}	I_{AWU}, I_{AGING}, I_{ASIG}	I_Q, I_{MN}, I_{GI}, I_{EDU}
North-East	I_{AKIS}, I_{PRECIP}	I_{CV}, I_{DIG}, I_{NPK}, I_H, I_{SOC}	I_Q, I_{MN}, I_{GI}, I_{EDU}, I_{ASIG}	I_{AWU}, I_{AGING}
North-West	I_{AKIS}, I_{NPK}	I_{CV}, I_{DIG}, I_{PRECIP}, I_H, I_{SOC}	I_Q, I_{MN}, I_{GI}, I_{AWU}, I_{ASIG}	I_{EDU}, I_{AGING}
South-East	I_{CV}, I_{AKIS}, I_{PRECIP}, I_H	I_{DIG}, I_{NPK}, I_{SOC}	I_Q, I_{MN}	I_{GI}, I_{AWU}, I_{EDU}, I_{AGING}, I_{ASIG}
South-Muntenia	I_{CV}, I_{AKIS}, I_H	I_{DIG}, I_{PRECIP}, I_{NPK}, I_{SOC}	I_Q, I_{MN}, I_{GI}, I_{EDU}, I_{AGING}	I_{AWU}, I_{ASIG}
South-West Oltenia	I_{CV}, I_{DIG}, I_{AKIS}, I_H	I_{PRECIP}, I_{NPK}, I_{SOC}	I_Q, I_{MN}, I_{GI}, I_{AWU}, I_{EDU}, I_{AGING}, I_{ASIG}	—
West	I_{NPK}, I_H	I_{CV}, I_{DIG}, I_{AKIS}, I_{PRECIP}, I_{SOC}	—	I_Q, I_{MN}, I_{GI}, I_{AWU}, I_{EDU}, I_{AGING}, I_{ASIG}

The matrix confirms that priorities should not be defined uniformly at the national level: the same sub-indicator may represent an "immediate investment" in one region and a "strength to be maintained" in another. These findings support a "place-based" resilience policy approach: South-West Oltenia, South-East, and South-Muntenia regions require integrated interventions in the productive, technological, and ecological domains, while West, North-West, and Centre regions require a combination of maintaining existing advantages and addressing targeted vulnerabilities.

4. Discussion

4.1. From Regional Diagnosis to Strategic Investment Prioritization

The results of this research support the view that the assessment of regional agricultural resilience should not be limited to the construction of a composite index or the ranking of territorial units. Although the ICRF provides a synthetic measure of farm resilience across Romania's eight NUTS-2 regions, its analytical value becomes more meaningful when used as a starting point for identifying the resilience dimensions that warrant priority consideration. In this respect, the main contribution of this study lies in the transition from a predominantly diagnostic framework focused on measuring resilience levels, to a decision-support framework aimed at strategic screening and the relative prioritization of investments. This approach is consistent with the literature on composite indices, which emphasizes that such tools should not be interpreted merely as ranking devices, but as instruments for synthesizing complex information to support public decision-making, provided that their methodological assumptions remain transparent and their results are interpreted with appropriate caution [11,12,41].

European studies consistently highlight the multidimensional and context-dependent character of farming-system resilience, although they differ substantially in analytical scale and methodological design and purpose. Using FADN data from nine European countries, Slijper et al. [28] identified significant variations in robustness, adaptability, and transformability across countries and farm types. Participatory assessments conducted by Paas et al. [7] in several European farming systems, including the extensive sheep-farming system of Huesca, revealed context-specific vulnerabilities, critical thresholds, and potential future configurations of development pathways. At the subnational level, Buzási et al. [70]

examined drought vulnerability and policy preparedness across Hungarian NUTS-3 regions, highlighting territorial mismatches between levels of vulnerability and institutional response. Other studies have established more explicit links between resilience assessment and strategic decision-making, including the identification of alternative farming systems and stakeholder supported strategies [71], the evaluation of CAP contributors to robustness, adaptability, and transformability in the Netherlands [72], and the analysis of economic resilience among Spanish field-crop farms [73].

These studies are not directly comparable with the present results because they differ in geographical scale, unit of analysis, indicator selection, and analytical purpose. Rather than assessing resilience trajectories, evaluating policy impacts, or identifying specific adaptation pathways, the ICRF–SRIS framework occupies a complementary position by providing a standardized screening stage for all eight Romanian NUTS-2 regions and by linking the composite diagnosis to the relative prioritization of resilience components. The framework is not intended to prescribe specific policy measures or estimate their effects. Instead, it identifies the resilience domains in which subsequent participatory assessment, stakeholder consultation, and economic, technical and feasibility analysis may be most effectively focused.

This distinction gains relevance in the context of the forthcoming post-2027 CAP (2028–2034). The European Commission's proposals emphasize the need for a more strategic, flexible, and evidence-based allocation of funds, with a focus on climatic, economic, and systemic resilience; the transition toward sustainable production systems, digitalization, and knowledge (AKIS); and territorially differentiated (place-based) approaches [14,15]. A high or low composite score does not, in itself, provide sufficient guidance on where and how to intervene. A region may occupy a relatively good position in the overall ranking while still displaying critical vulnerabilities in specific strategic components; conversely, a region with a low overall score may exhibit multiple deficits not all of which have equal systemic importance or impact potential. Using the ICRF exclusively as a ranking tool would therefore be insufficient for informing investment policies aligned with the objectives post-2027 CAP.

The proposed framework (ICRF–SRIS) overcomes this limitation by integrating the catch-up gap analysis, the effective weights of the sub-indicators, and their observed positive connectivity. Thus, the composite score becomes an analytical tool for strategic screening and relative prioritization of investments, allowing the identification of components in which regional gaps, effective importance, and relational position overlap. The SRIS operationalizes this transition from diagnosis to prioritization. Unlike approaches based exclusively on deficits, the SRIS identifies those sub-indicators that maximize the impact of investments within specific regional contexts—a requirement reflected in post-2027 CAP proposals emphasizing national and regional flexibility, as well as the efficient use of funds [14,15].

By combining composite scoring with a strategic prioritization logic, this research indicates that regional resilience can be assessed not only as a current state but also as a basis for identifying areas that warrant further policy attention and analysis. This shift from diagnosis to prioritization represents a central methodological contribution of the study and provides a transparent analytical foundation for more differentiated and territorially sensitive investment planning, grounded in the structural characteristics of regional resilience profiles.

4.2. Resilience as a Relational Structure of the Sub-Indicators

The results of the correlation analysis and of the relational network of sub-indicators show that regional agricultural farm resilience cannot be interpreted as a sum of indifference

components. The presence of complementarity, substitution, and relationships shows that the sub-indicators do not act in isolation, but form a systemic structure in which certain components reinforce one another, while others may reflect potential trade-offs. This finding is consistent with the classical perspective on resilience, which defines systems not only through the performance of their component elements, but through their capacity to maintain functionality under disturbance, reorganization, and change [3,74].

In this sense, the network of relationships among sub-indicators offers a richer interpretation than a simple analysis of individual values. Indicators in complementarity relationships can signal domains in which coordinated interventions could generate cumulative effects on resilience. By contrast, strong negative relationships —such as that between productivity and fertilizer consumption (I_Q–I_{NPK})—may indicate areas in which sectoral policies applied in isolation risk producing contradictory effects, reflecting the well-known tensions between productive intensification and ecological sustainability [75]. This interpretation aligns with the social-ecological literature, according to which resilience is an emergent property of complex systems, resulting from interactions, feedbacks, and adaptive capacities, not merely from the performance of separate components [2,3].

Applying this perspective to regional agricultural systems is important because farms do not function as fully autonomous, independent units, but are integrated into broader economic, technological, ecological, and institutional structures. Farm resilience depends on the interaction between production stability, economic viability, access to knowledge, the level of digitalization, the quality of natural resources, and organizational capacity. The framework proposed by Meuwissen et al. [1] emphasizes precisely this need to assess the resilience of agricultural systems in relation to multiple functions, challenges, actors, and capacities, not merely through isolated indicators.

This relational interpretation provides an analytical bridge to discussions on the post-2027 CAP, without translating the results into direct public-policy prescriptions. Rather, the network of sub-indicators suggests that the prioritization of investments for resilience can be analyzed not only at the level of isolated indicators, but also through possible combinations among productive, technological, ecological, and organizational components. In this sense, the proposed framework can contribute to identifying areas in which integrated interventions would merit closer evaluation, especially where the needs for catch-up overlap with strategic importance and with the complementarity relationships among sub-indicators. Nonetheless, this approach should be understood as analytical support for the decision-making process rather than as a normative recommendation, as the identified relationships are descriptive in nature and require further validation.

4.3. Key Priorities: ICV, IAKIS, and IDIG

One of the most important results of the research is the identification of a core of robust priorities, represented by production stability (I_{CV}), access to AKIS services (I_{AKIS}), and farm digitalization (I_{DIG}). These three components appear recurrently in the SRIS analyses, in the sensitivity scenarios for the parameter α, in the Monte Carlo simulation, and in the leave-one-region-out jackknife analysis. Their strategic relevance, therefore, does not depend on a single weighting configuration or on the presence of a particular region in the sample, but rather reflects the underlying structural dynamics of regional agricultural resilience.

The first robust priority is production stability, captured through the sub-indicator I_{CV}. This result confirms that productive resilience cannot be assessed solely through the average level of production, but must also include the capacity of the agricultural system to reduce the volatility of results over time. In agricultural systems, high but unstable production can expose farms to significant losses in the face of climatic, economic, or market shocks. The

specialized literature emphasizes that stability, robustness, vulnerability, and resilience are distinct but interdependent concepts, and that the capacity to maintain performance under variability is a central component of the resilience of agricultural systems [26].

The second robust priority is access to AKIS services. The importance of I_{AKIS} indicates that agricultural resilience depends not only on physical or economic resources, but also on the capacity of farmers to access knowledge, advice, innovation, and support networks. Agricultural knowledge and innovation systems (AKISs) and advisory services have become essential elements of the current CAP programming period (2023–2027), supporting the transition toward more sustainable agricultural models [76]. The inclusion of AKISs in national strategic plans represents an important step towards stimulating agricultural innovation in Europe [77], with AKISs treated as a central element of the cross-cutting objective of modernization through knowledge, innovation, and digitalization [49].

The third robust priority is farm digitalization, captured through the sub-indicator I_{DIG}. The recurrence of this indicator in the prioritization scenarios shows that digitalization should not be interpreted as a mere technological modernization, but as a cross-cutting component of resilience. Digital innovations can strengthen the adaptive capacity of farms. Precision technologies, sensor-based monitoring, and data-management systems allow the optimization of inputs, better resource management, and faster decisions under climatic and market uncertainty [78,79]. Thus, digitalization contributes directly to reducing the farms' exposure to shocks and enhancing production resilience [80]. However, harnessing this potential depends not only on the adoption of equipment, but also on organizational changes, digital skills, and the integration of data into decision-making processes [34].

These priorities should not be interpreted as reflecting only magnitude of the observed regional gaps. Their ranking is also influenced by the weighting structure and the positive-connectivity structure embedded in the SRIS framework. Accordingly, therefore, they represent model-based priorities derived from the combination of empirical data and methodological assumptions, intended to support strategic screening and relative prioritization rather than to prescribe specific investment decisions.

Therefore, the triad I_{CV}–I_{AKIS}–I_{DIG} can be interpreted as a set of no-regret priorities for strengthening regional agricultural resilience. Production stability reduces exposure to volatility, AKISs support the capacity for learning and innovation, and digitalization provides the technological infrastructure needed for monitoring, adaptation, and efficiency. Taken together, these three components suggest that agricultural resilience cannot be strengthened through material investment alone, but requires a combined focus on production stabilization, knowledge capital, and digital transformation.

Although I_{CV}, I_{AKIS} and I_{DIG} form the most solid core of strategic priorities, the other sub-indicators should not be interpreted as lacking relevance. Their role is instead territorially differentiated and dependent on the regional profile of vulnerabilities. For example, ecological indicators such as I_{PRECIP}, I_{NPK}, I_{H} and I_{SOC} are important for explaining exposure to agro-climatic conditions, input pressure, crop diversity, and the quality of soil resources. Similarly, organizational indicators such as I_{AWU}, I_{EDU}, I_{AGING} and I_{ASIG} reflect the capacity of farms to mobilize human capital, manage risk, and sustain the continuity of holdings. Economic indicators, I_{MN} and I_{GI}, remain relevant for the capacity to absorb financial shocks, even if they do not always appear in the group of the most robust SRIS priorities. Thus, the distinction between the dominant sub-indicators and the others is not one of relevance versus irrelevance, rather one of global stability versus regional specificity.

To avoid an overly normative interpretation, the SRIS results can be discussed in terms of a logic of support for strategic planning rather than as direct public-policy recommendations. From this perspective, the identified priorities do not automatically determine which instruments should be funded, but show where three elements relevant to the in-

vestment decision overlap: the regional need for catch-up, the systemic importance of the sub-indicator, and the stability of the result across robustness scenarios. This approach aligns with the logic of the CAP Strategic Plans, which seek to combine interventions and to use instruments coherently according to territorial objectives and needs. In the context of post-2027 discussions, where the emphasis is placed on simplification, flexibility, and adaptation to local needs and sectoral challenges, such a framework can offer analytical support for the differentiated discussion of investments in resilience, without substituting for the political decision itself.

4.4. Territorial Differentiation and Place-Based Policies

The results obtained highlight that the resilience of agricultural farms has a territorially differentiated structure, and that investment priorities cannot be formulated uniformly for all regions. Although certain components, such as production stability, AKISs, and digitalization, appear as robust priorities at the general level, the combination of vulnerabilities differs significantly across regions. This finding underscores the need for a place-based approach, in which public interventions are adapted to the specific profile of each territory, to the available resources, to local constraints, and to existing institutional capacities. The literature on regional development emphasizes that territorial disparities cannot be efficiently explained or corrected through uniform policies, because regions differ in economic structure, institutional capital, connectivity, natural resources, and historical development trajectories [16,17,81].

This perspective is relevant in agriculture, where regional performance is simultaneously influenced by agro-climatic conditions, productive structures, access to knowledge, technological level, socio-demographic characteristics, and organizational capacity. Consequently, the same policy instruments can have different effects in different regions. The OECD emphasizes that rural regions represent complex and diverse socio-economic systems, and that policies must take into account the differences among territories, not merely general sectoral objectives [21,22]. In the same vein, the European Union's long-term vision for rural areas emphasizes the need for stronger, connected, resilient, and prosperous rural territories, which presupposes interventions adapted to local needs and to the capacities of rural communities [25].

The SRIS results clearly illustrate this territorial logic. The South-West Oltenia region appears as a region in which priorities are more strongly associated with closing gaps, especially through production stability, digitalization, and access to AKISs. By contrast, the West region indicates a logic closer to maintaining and consolidating existing capacities, even if certain targeted vulnerabilities remain relevant. The Centre region highlights a different configuration, in which access to AKISs, digitalization, and agricultural insurance acquire greater strategic importance. These differences demonstrate that resilience is not merely an aggregate property of regions, but the outcome of specific territorial combinations of vulnerabilities, capacities, and systemic relationships.

This interpretation is also compatible with the logic of smart specialization, according to which regional development must be built on specific combinations of local resources, competencies, advantages, and opportunities, not on standardized intervention models [23,82]. Applied to the resilience of agricultural farms, this perspective implies that investments must be directed not only toward regions with low scores, but toward those components where intervention can generate the greatest strategic effect in the respective regional context. In addition, the current structure of the 2023–2027 Common Agricultural Policy, based on national strategic plans and on the combination of support instruments for income, rural development, and market interventions, provides an institutional framework in which such territorial prioritizations can be integrated more explicitly [83].

Therefore, the ICRF–SRIS framework provides a methodological foundation for more differentiated regional agricultural policies. It enables the transition from a uniform or purely compensatory allocation of resources to a strategic allocation in which priorities are defined based on deficit levels, effective importance, and systemic potential. This approach contributes to the design of more efficient interventions, capable of simultaneously addressing structural gaps in vulnerable regions while supporting the maintenance and consolidation of advantages in higher-performing regions.

4.5. From Strategic Screening to Practical Implementation and Monitoring

Within the proposed framework, the SRIS results should be viewed as the starting point for a broader decision-making process rather than a direct recommendation for action. A high priority score identifies a resilience component or domain that merits further attention, but it does not specify which measures should be implemented or how resources should be allocated. Translating screening results into practical interventions requires considerations of regional characteristics, stakeholder perspectives, available policy instruments, and the costs, expected benefits, administrative feasibility, and budgetary implications of alternative actions. This sequence is consistent with the farming-system resilience literature, which emphasizes the integration of quantitative assessment with contextual analysis, participatory processes, and strategies supported by relevant policy actors [1,71].

The parameter α can facilitate this process by enabling the exploration of alternative strategic orientations. Lower values place greater emphasis on maintaining and consolidating existing capacities, intermediate values balance maintenance and catch-up objectives, and higher values prioritize components exhibiting larger relative catch-up needs. These configurations should not be interpreted as budgetary scenarios or optimal solutions. Rather, they provide a means of examining how priority structure changes under different strategic assumptions. Selecting an operational configuration would therefore require clearly defined policy objectives and consultation with public authorities, professional organizations, advisory services, researchers, and farmers.

The identified priorities may also have broader implications for rural development. Components related to agricultural knowledge and innovation systems, education, generational renewal, labor use, and risk management are closely associated with the development of human capital, the continuity of agricultural activity, access to advisory services, and the adaptive capacity of rural communities [7,84,85]. However, these effects were not measured directly in the present study and should therefore be regarded as potential areas for further investigation rather than demonstrated outcomes of the SRIS-based prioritization.

Monitoring should distinguish between updating the regional diagnosis and evaluating the effectiveness of specific interventions. Periodic recalculation of the sub-indicators, the catch-up gap, and the SRIS scores would make it possible to track changes in the regional resilience profiles' priority structures over time. By contrast, assessing the effects of a specific measure would require baseline values; predefined objectives; output, result, and impact indicators; and comparable data collected before and after implementation. This distinction is consistent with the CAP monitoring and evaluation framework, which differentiates the monitoring of implementation progress from the evaluation of effectiveness, efficiency, and impacts [86]. It is also consistent with the decision-intelligence perspective, in which diagnosis, prioritization, implementation, and monitoring are understood as iterative and adaptive stages of a continuous learning process [87].

4.6. Territorial Transferability and Future Validation of the ICRF–SRIS Framework

The dimensionless structure of the ICRF-SRIS framework enables its application at other territorial levels, including NUTS-3 regions, provided that complete, comparable and officially available data exists for all analytical units. However, such applications would not involve the direct transfer of the scores, benchmarks or priority structures obtained for Romania's eight NUTS-2 regions. Each new implementation would require a reassessment of indicator relevance, the use of consistent reference periods, recalculation of the normalization and benchmark values, reconstruction of the sub-indicator co-variation network, and, where appropriate, revisions of the weighting scheme to reflect the territorial scale and analytical objectives.

Likewise, application in other countries or agricultural contexts would require adaptation of the indicator framework to the institutional, economic, ecological, and social characteristics of the system under investigation. The framework is therefore transferable as an analytical procedure rather than as a predefined set of results. Its outputs remain contingent on the territorial configuration, data availability, and methodological assumptions adopted in each application.

Future research could support further validation through pilot applications at finer territorial scales, such as the NUTS-3 regions, as well as through structured consultation with regional stakeholders. Additional analyses could examine the sensitivity of results to alternative normalization methods, weighting schemes, and network-construction procedures, and could incorporate information on implementation costs, expected benefits, and administrative constraints. Longer-term validation may also involve ex post evaluation of selected interventions to assess whether SRIS-identified priorities are associated with measurable improvements in regional resilience capacities. Accordingly, the present study should be viewed as providing an analytical foundation for strategic screening and relative prioritization rather than as a complete operational decision-making framework. Integrating an ICRF-SRIS approach into practical policy processes will require further contextual validation, stakeholder engagement and empirical assessment of its usefulness under real-world decision-making conditions.

4.7. Limitations

Although the ICRF–SRIS framework provides an integrated approach for assessing and prioritizing regional agricultural resilience, the results should be interpreted in light of several methodological and empirical limitations. The first limitation concerns the level of aggregation adopted in the analysis. This study was conducted across Romania's eight NUTS-2 development regions and facilitates the comparison of regional profiles but does not capture the internal heterogeneity of agricultural holdings, the differences between small and large farms, or local variations within the same region. Consequently, the results should not be interpreted as direct farm-level diagnoses, but as aggregate regional profiles of farm resilience.

A second limitation derives from the small size of the regional sample. The correlations among sub-indicators are computed on eight observations, which limits the possibility of robust statistical inferences. For this reason, the relationships identified in the network of sub-indicators should be interpreted cautiously and descriptively, as indications of regional co-variation, not as evidence of causal relationships. This caution is especially important when complementarity or substitution relationships are used to discuss investment priorities: they may signal potential synergies or trade-offs, but they do not demonstrate causal mechanisms without additional analyses on longer time series or on microeconomic data.

Another limitation concerns the selection and availability of indicators. The proposed framework integrates productive, economic, technological, ecological, and organizational

dimensions; however, farm resilience is a broader concept that may also include other components, such as access to markets, the structure of value chains, the quality of local governance, irrigation infrastructure, social capital, or institutional capacity. In addition, the indicators used come from secondary sources and cover different time periods, depending on data availability. This approach allows the construction of a comparable regional framework, but may introduce differences in temporality among the components of the index.

The weighting of indicators represents an additional source of uncertainty. Although expert-based weighting allows specialized knowledge to be incorporated into the construction of the index, the panel consisted of only three participants, including two agricultural economists, and may therefore not fully reflect the diversity of disciplinary and stakeholder perspectives relevant to agricultural resilience. Sensitivity analyses, Monte Carlo simulation, and the leave-one-region-out procedure were included specifically to evaluate the robustness of the results with respect to these methodological choices. However, these exercises assess stability only with respect to the dimensions examined and do not eliminate uncertainty associated with other methodological assumptions. In particular, the study does not evaluate alternative normalization procedures, different thresholds for constructing the correlation network, or alternative definitions of the regional benchmark used to calculate catch-up gaps. Future research could strengthen the robustness assessment through a systematic comparison of these alternative specifications and their implications for resilience scores and priority rankings.

The min–max normalization method and the reporting relative to the observed regional benchmark also have specific limits. This approach is useful for comparing regions with one another, but the benchmark used is a relative one, defined by the best performance observed in the sample, not by a normative or technically optimal threshold. Thus, a region close to the observed benchmark is not necessarily high-performing in an absolute sense, but only relative to the other regions included in the analysis. Similarly, a high gap indicates a distance from the best observed regional performance, not necessarily the exact size of the investment needed for catch-up.

In addition, the SRIS must be interpreted as a tool for analytical support, not as a direct mechanism for resource allocation. The strategic score combines the deficit, the effective importance, and systemic complementarity, but it does not explicitly include intervention costs, administrative feasibility, budgetary constraints, social acceptability, or institutional implementation capacity. Consequently, the results can contribute to the discussion of regional priorities, but they cannot substitute for detailed economic analysis, the consultation of relevant actors, and the political decision itself.

Finally, the relevance of the framework for the discussions on the post-2027 CAP must be understood with caution. The study proposes a method for organizing and interpreting regional information on resilience, but it does not formulate direct prescriptions for the future agricultural policy. Its contribution consists rather in providing a transparent framework through which territorial differences, catch-up needs, and possible combinations of interventions can be explored. Practical validation of this framework would require its application to more detailed data, the periodic updating of the indicators, and the testing of results in dialogue with public authorities, farmer organizations, advisory services, and other actors involved in the planning of agricultural investments.

5. Conclusions

The present study proposes an integrated framework for assessing and prioritizing the resilience of crop farms and supporting strategic screening and relative prioritization at the regional level, using the eight NUTS-2 development regions of Romania as the empirical

space of analysis. By combining the Farm Resilience Composite Index (ICRF) with the Strategic Resilience Investment Score (SRIS), the paper goes beyond a strictly descriptive approach to resilience and proposes a prioritization logic that simultaneously considers the need for catch-up, the systemic importance of the sub-indicators, and the maintenance of existing regional capacities.

The results confirm that agricultural resilience is not uniformly distributed across regions and cannot be explained through a single dimension—productive, economic, technological, ecological, or organizational. On the contrary, resilience emerges as the result of the interaction between production stability, economic viability, access to knowledge and innovation, technological capacity, ecological conditions, and organizational resources. This perspective is consistent with the literature on the resilience of agricultural systems, which emphasizes the multidimensional character of resilience and the importance of robustness, adaptability, and the capacity for transformation in the face of shocks and uncertainties [1,7].

An important finding of the analysis is the recurrent prominence of three sub-indicators—the yield coefficient of variation (I_{CV}), access to agricultural knowledge and innovation systems (I_{AKIS}), and farm digitalization (I_{DIG})— across both the prioritization and robustness assessments. These sub-indicators consistently appear among the highest-ranking priorities in the SRIS results, the alternative α scenarios, the Monte Carlo simulation, and the leave-one-region-out jackknife analysis. This consistency suggests that I_{CV}, I_{AKIS} and I_{DIG} constitute a robust cross-cutting analytical core for understanding regional agricultural resilience. Their recurrent prominence should not be interpreted as resulting solely from the magnitude of the observed regional deficits, as it also reflects the weighting scheme and positive-connectivity structure embedded in the SRIS framework. Accordingly, they should be understood as model-based priorities emerging from the interaction between empirical regional patterns and explicit methodological assumptions. However, this finding should not be interpreted as a uniform policy prescription or as a direct measure of investment need. Rather, it indicates that these dimensions warrant systematic consideration in strategic screening and relative prioritization processes. The leave-one-region-out analysis further supports the robustness of this result, showing that at least two of the three baseline priorities were retained in 55 of the 56 comparisons, although the North-East region exhibited greater sensitivity than the other regional profiles.

The study also highlights the need for a territorially differentiated interpretation of resilience. The strategic matrix shows that the same component can play different roles depending on the regional profile: in one region it may indicate a need for catch-up, in another it may reflect a strength that requires maintenance, and in another it may require only monitoring. This finding reinforces that strategic screening and relative prioritization should not be reduced to a uniform national hierarchy, but analyzed in relation to specific territorial profiles and to the position of each component in the regional architecture of resilience.

From an applied perspective, the results suggest that regional resilience priorities can be examined through a combination of cross-cutting directions and territorial adaptation. Production stability (the yield coefficient of variation), access to AKISs, and digitalization can be treated as dimensions that merit systematic evaluation, while the secondary priorities should be interpreted according to the specific vulnerabilities and capacities of each region. In the context of the discussions on the post-2027 CAP, this approach can offer analytical support for more flexible strategic planning that is more sensitive to territorial differences and better grounded empirically.

Overall, the contribution of the study is analytical rather than normative. The ICRF–SRIS framework does not directly establish agricultural policy priorities nor does it substi-

tute for political decision-making, stakeholder consultation, or complementary appraisal methods such as cost–benefit analysis. Instead, it provides a transparent and systematic approach for organizing regional resilience information and identifying situations in which catch-up needs, effective importance, and observed positive connectivity converge. As such, the framework functions as an analytical decision-support tool for strategic screening and relative prioritization, with potential relevance for informing discussions on the design and targeting of post-2027 CAP interventions.

The framework is not intended as a stand-alone investment allocation model. It does not incorporate intervention costs, expected benefits, administrative feasibility, budgetary constraints, or stakeholder preferences. Consequently, translating the identified priorities into operational measures requires subsequent stakeholder engagement together with feasibility, economic, and impact assessment.

Periodic recalculation of the sub-indicators, catch-up gap values, and SRIS scores may support the updating of the regional resilience diagnoses and priority structures over time, whereas the evaluation of specific interventions would require predefined objectives and comparable before-and-after data.

The ICRF-SRIS framework is also transferable as an analytical procedure to other territorial scales, including NUTS-3 regions, provided that complete and comparable data are available. However, each new application would require the recalculation of normalization and benchmark values, reconstruction of the relational structure amongst sub-indicators, and, where appropriate, revisions of the weighting scheme to reflect the characteristics and objectives of the new analytical context.

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Abbreviations

The following abbreviations are used in this manuscript:

NUTS	Nomenclature of Territorial Units for Statistics
ICRF	Farm Resilience Composite Index
SRIS	Strategic Resilience Investment Score
AKIS	Agricultural Knowledge and Innovation System
CAP	Common Agricultural Policy
OECD	Organisation for Economic Co-operation and Development
RGA	General Agricultural Census
I_{PROD}	Pillar A—Productive
I_{EC}	Pillar B—Economic
I_{TEH}	Pillar C—Technological
I_{ECO}	Pillar D—Ecological
I_{ORG}	Pillar E—Organizational
I_{Q}	Mean Yield
Icv	Coefficient of Production Variability
I_{MN}	Net Margin
I_{GI}	Degree of Indebtedness
I_{DIG}	Farm Digitalization Index
I_{AKIS}	Index of Access to AKIS Services
I_{PRECIP}	Mean Precipitation
I_{NPK}	Fertilizer Consumption
I_{H}	Shannon Diversity Index
I_{SOC}	Soil-sequestered Carbon
I_{AWU}	Labor Productivity
I_{EDU}	Education Index
I_{AGING}	Aging Index
I_{ASIG}	Land-insurance Index
CEO	Chief executive officer

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