



Proposed key performance indicator-based monitoring framework for agricultural innovation: Armenia's institutional model

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ABSTRACT

Background: The absence of a monitoring system for agricultural innovation technologies in Armenia impedes state support, policy effectiveness, and innovation control. This article presents an outline for a monitoring system focused on developing evaluation methods and key performance indicators (KPIs).

Methods: The research establishes methodological foundations for assessing the implementation levels, outcomes, and systemic impacts of innovative technologies through a comprehensive literature review (January 2015–September 2025) across Scopus, Web of Science, PubMed, Google Scholar, and FFHDJ.com, combined with field surveys across Armenian agricultural regions.

Results: The cluster approach ensures effective collaboration between the state, the private sector, and science, and education structures. Implementing the KPI system enables measuring the impact of innovation on agricultural enterprises' efficiency and competitiveness, while improving the targeting of state support. This comprehensive

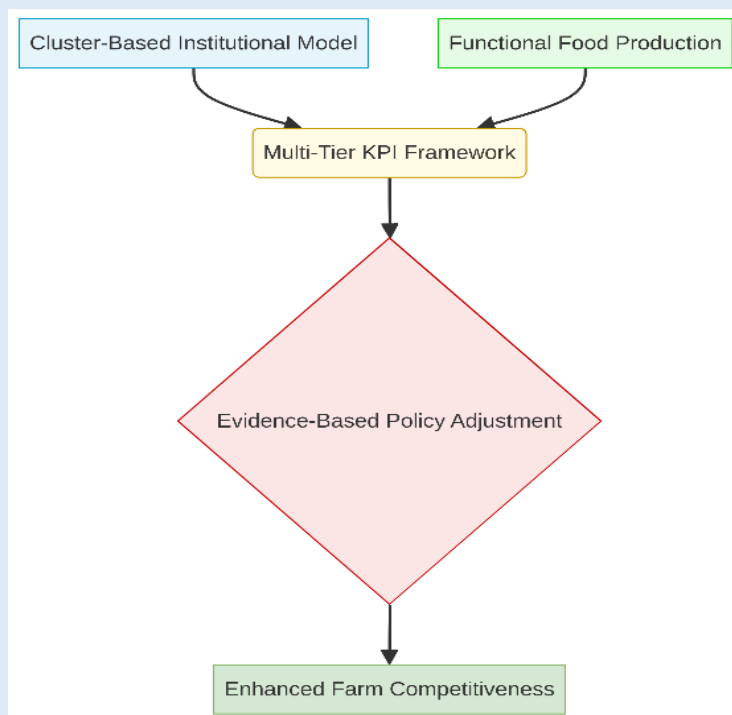
approach addresses the critical gap in Armenia's agricultural innovation monitoring by providing structural evaluation mechanisms.

Conclusion: Additionally, the framework incorporates functional food production as an emerging innovation direction, recognizing its potential for value addition and market competitiveness enhancement in Armenia's agricultural sector.

Novelty: This work closes a critical governance gap by providing actionable, Armenia-tailored indicators to monitor agricultural innovation in real time. Incorporating functional food production within the KPI set creates a new route for value addition and market competitiveness, directly linking state support to measurable results.

Novel KPI-driven Monitoring Framework for Armenia's Agricultural Innovation: The framework integrates a Cluster-Based Institutional Model with multi-tier KPIs, explicitly incorporating Functional Food Production to unify technological, economic, and health-oriented tracking. This enables evidence-based policy adjustment and enhances farm competitiveness.

Keywords: Agricultural innovation; monitoring system; key performance indicators (KPI); innovation governance; functional food; Armenia.



Graphical Abstract: Proposed key performance indicator-based monitoring framework for agricultural innovation: Armenia's institutional model

INTRODUCTION

Agriculture remains one of the cornerstone sectors of the global economy, with its economic significance having grown substantially in recent years. It has become a vital component in ensuring food security worldwide.

At the same time, global agriculture faces serious and multifaceted challenges. Unprecedented weather fluctuations driven by climate change, economic uncertainties, and geopolitical tensions have heightened risks across the sector. Rising costs of production resources and increasing climatic instability are undermining the resilience of farming systems.

As a consequence of climate change, food security issues are deepening in many countries. This underscores the fact that current agricultural systems still lack sufficient stability to adapt effectively to emerging conditions. This vulnerability is largely due to the limited adoption of innovative technologies and the continued dominance of traditional farming practices.

The interdependence between food production and environmental protection represents a crucial sustainability challenge. Traditional agricultural practices have contributed to environmental degradation through excessive consumption of water, fertilizers, and pesticides, resulting in soil degradation, water contamination, and biodiversity loss [1]. This necessitates a transition toward sustainable agricultural methods grounded in comprehensive policy frameworks and innovative technologies [2]. The implementation of innovative technologies will enable efficient resource utilization in agricultural economies, increase income, and consequently enhance the competitiveness of these economies. Food system innovation requires coordinated accelerators and collaborative frameworks that engage multiple stakeholders across the agricultural value chain [2].

One promising pathway lies in agricultural diversification toward high-value products. In response

to growing global health consciousness, the agricultural sector is increasingly exploring functional food production—an emerging market combining environmental stewardship with value creation. Functional foods, providing health benefits beyond basic nutrition, have experienced rapid global market growth. The market reached USD 364.22 billion in 2024 and is projected to reach USD 979.61 billion by 2034, with a compound annual growth rate of 10.4% [3]. In the United States alone, the functional food market reached USD 364.18 billion in 2024 [4]. The bioactive compounds found in functional foods—including polyphenols, carotenoids, and omega-3 fatty acids—have been shown to play crucial roles in disease prevention and health promotion [5]. Recent advances in understanding the mechanisms through which these bioactive compounds exert their health benefits have strengthened the scientific foundation for functional food development [6].

Key growth areas include protein products, probiotics, and postbiotics, with the current food landscape characterized by a shift toward health, personalization, and sustainability. Probiotics and postbiotics, in particular, have gained significant attention for their role in gut microbiome modulation and immune system enhancement [7]. Studies have demonstrated that dietary supplements incorporating bioactive compounds can address micronutrient deficiencies while supporting overall metabolic health [8]. However, challenges persist related to compound instability, scalability issues, and regulatory gaps, requiring continued innovation in processing technologies and regulatory frameworks.

This trend presents significant opportunities for Armenian agriculture to enhance value creation and market competitiveness through the cultivation of crops with enhanced nutritional profiles, including antioxidant-rich berries, omega-3-enriched products, and probiotic

dairy products. Recent research in Armenia has demonstrated the effectiveness of grafting techniques in enhancing bioactive compound content in watermelon, with grafted variants showing elevated levels of lycopene, ascorbic acid, total phenolics, and sugar content while exhibiting strong resistance to *Fusarium oxysporum* [9]. Additionally, research has shown that microbiological complexes can enhance bioactive compound production in greenhouse vegetables [10], and studies have confirmed the high nutritional value and bioactive compound content of various Armenian agricultural products, supporting their application in functional food development [11,12]. The agricultural sector's contribution to sustainable food systems extends beyond production to encompass environmental stewardship and climate resilience, with innovative agricultural practices playing a critical role in achieving global sustainability goals [13].

The integration of digital technologies in Armenian agriculture presents additional pathways for innovation enhancement. Innovation management in agricultural research increasingly emphasizes the systematic integration of digital tools and collaborative frameworks to translate research outcomes into practical applications [14]. Digital transformation encompasses precision farming technologies, sensor-based monitoring, satellite imagery, automated irrigation, and data analytics platforms. These technologies enable resource optimization, environmental impact reduction, and quality improvement—factors crucial for functional food production where bioactive compound content and nutritional consistency are paramount. Evidence from developing regions demonstrates that digitalization can contribute significantly to sustainable agricultural transformation, particularly when combined with appropriate capacity building and infrastructure development [15].

The adoption of artificial intelligence and climate-smart technologies represents the next frontier in agricultural innovation, enabling predictive analytics, automated decision-making, and enhanced resource efficiency [16]. In Armenia, digital agriculture adoption faces both opportunities and challenges. The country's internet penetration and growing tech sector provide a foundation for innovation, yet barriers persist, including limited digital literacy among smallholder farmers, insufficient rural infrastructure, and high investment costs [17]. In response, several initiatives have been undertaken in recent years to address these challenges, including the introduction of smart greenhouse technologies, weather monitoring stations, and mobile advisory services. The combination of these measures also opens the door for the effective application of digital tools in the functional food production sector, enabling precise regulation of bioactive compounds, ensuring their traceability for high-value markets, and establishing the necessary quality documentation for export.

Armenia's unique climate diversity, ranging from subtropical to alpine zones, combined with its rich biodiversity, traditional agricultural heritage, and emerging digital capabilities, provides natural advantages for developing authentic, high-value functional food products with strong positioning potential in both regional and international markets. The convergence of traditional knowledge, modern biotechnology, and digital innovation creates a distinctive value proposition for Armenian functional foods.

METHODS

Literature Search and Data Sources: This review was conducted through a comprehensive literature search across multiple scientific databases and open-access platforms to identify publications related to agricultural innovation monitoring systems, key performance

indicators (KPIs), and functional food production within the context of agricultural policy and innovation management. The following databases and sources were searched: Scopus, Web of Science, PubMed, Google Scholar, and the Functional Food Center journals available through *FFHDJ*. Additionally, statistical publications and official reports from the National Statistical Committee of the Republic of Armenia and the Ministry of Economy of Armenia were reviewed to supplement scientific findings with national data.

Search Strategy: A structured keyword search was applied, combining controlled vocabulary and free-text terms. Boolean operators (AND, OR) and truncations were used to broaden or refine the results. The final search strings included: ("agricultural innovation" OR "agro-innovation" OR "digital agriculture" OR "precision agriculture") AND ("monitoring system" OR "evaluation framework" OR "KPI" OR "key performance indicator") AND ("policy implementation" OR "institutional model" OR "innovation governance") AND ("functional food" OR "bioactive compounds" OR "value-added agriculture").

In PubMed, Medical Subject Headings (MeSH) were also applied: "Agriculture"[MeSH] AND "Innovation"[MeSH] AND "Monitoring"[MeSH] AND "Functional Foods"[MeSH].

Filters were applied to include peer-reviewed journal articles, reviews, and reports published within the specified timeframe.

Timeframe and Language Criteria: The literature search covered the period from January 2015 to September 2025, ensuring inclusion of the most recent advancements in agricultural innovation monitoring and functional food production. Publications were limited to those available in English and Russian, while relevant Armenian-language statistical and policy sources were included for national contextualization.

Eligibility Criteria: Studies were included if they met the following criteria:

- Focused on agricultural innovation monitoring, KPI-based assessment frameworks, or functional food development;
- Described policy instruments, institutional models, or governance mechanisms in agriculture;
- Were peer-reviewed research articles, systematic or narrative reviews, or official institutional reports.

Exclusion criteria included:

- Non-agricultural innovation studies;
- Non-peer-reviewed materials (e.g., opinion pieces, news articles);
- Publications lacking methodological transparency or measurable indicators.

Data Extraction and Synthesis: The selected literature was screened in two stages: title/abstract review and full-text evaluation. Extracted data included study objectives, methodological approaches, policy frameworks, KPI structures, and outcomes. The synthesis emphasized comparative analysis across international practices (e.g., OECD, EU, Netherlands) and their applicability to Armenia's agricultural sector.

Limitations: The review acknowledges several limitations. First, the search was limited to five databases, potentially omitting relevant grey literature. Second, language restrictions in English, Russian, and Armenian may have led to the exclusion of studies published in other languages. Finally, variability in terminology and methodological heterogeneity across studies could affect cross-comparability of findings. Despite these limitations, the review provides a robust and reproducible foundation for understanding the methodological approaches used in developing KPI-based monitoring systems for agricultural innovation.

RESULTS

Armenia's climate is characterized by pronounced vertical zonation, and agriculture is practiced in all zones. The RA has ten agricultural regions. Our studies have focused primarily on 3 regions (Armavir, Gegharkunik, and Kotayk), which include the plain, foothills, and mountainous zones. The organizational basis of agriculture is formed by small farms. Approximately 317,000 peasant farms account for 94.2% of gross agricultural output value, with each farm averaging 1.48 hectares of land [18]. In essence, agriculture is conducted on more than 1.2 million land plots. In the focus regions, the total number of peasant farms was 29,737 in the Armavir region (9.4% of Armenia's total), 51,050 in the Gegharkunik (16.1%), and 12,325 in the Kotayk (3.9%) [19].

The issues in the agri-food system of the Republic of

Armenia, which remains unresolved, has become a factor hindering development. They naturally have a profound impact on farm activities and competitiveness. The influence of the mentioned issues is clearly evident in statistical data documenting downward trends in the leading agricultural economic indicators.

The share of Armenia's agriculture in GDP was around 10% (2023). The value of gross agricultural output decreased by 1,021.7 billion drams (2.28 billion euros) (Central Bank of Armenia)¹ compared to 2022, totaling 948.3 billion drams, which represents a 7.2% reduction compared to the same period of the previous year. The regional shares were 21.8% for the Armavir region, 11.6% for the Gegharkunik, and 8.7% for the Kotayk [20,21]. Table 1 presents gross agricultural output by sectors for 2019-2023.

Table 1. Gross Agricultural Output by Sectors 2019-2023, at Current Prices [20,21]

| N | | Crop Production | | | | | Livestock | | | | |
|----|-------------|-----------------|-------|-------|-------|-------|-----------|-------|-------|-------|-------|
| | | 2019 | 2020 | 2021 | 2022 | 2023 | 2019 | 2020 | 2021 | 2022 | 2023 |
| 1. | Armavir | 128.4 | 133.3 | 162.2 | 168.7 | 152.3 | 50.3 | 47.7 | 48.9 | 56.4 | 54.9 |
| 2. | Gegharkunik | 47.5 | 38.0 | 45.9 | 49.1 | 42.1 | 64.9 | 61.4 | 67.9 | 70.3 | 63.3 |
| 3. | Kotayk | 20.2 | 20.5 | 25.2 | 26.1 | 24.3 | 50.4 | 53.2 | 53.4 | 60.4 | 57.9 |
| | RA | 410.9 | 399.5 | 469.1 | 519.2 | 447.2 | 442.4 | 433.8 | 465.3 | 502.5 | 500.5 |

/ billion drams /

The shares of gross crop production output in the Armavir, Gegharkunik, and Kotayk regions in 2023 were 34.1%, 9.4%, and 5.4%, respectively. During the same period, the shares of gross livestock production output in these regions were 11.0%, 12.6%, and 11.6%, respectively. According to the structure of gross agricultural output by main sectors, Armavir region specializes in vegetable production, grain farming, potato cultivation, viticulture, fruit growing, and meat-dairy cattle farming; Gegharkunik region specializes in dairy-

meat livestock farming, grain farming, and vegetable production; while Kotayk region specializes in meat-dairy livestock farming, vegetable production, potato cultivation, grain farming, and fruit growing.

To promote the development of peasant farms, the government has implemented diverse support programs, particularly to encourage the development of innovative technologies. The practical implementation of these programs can be assessed through an analysis of investment volumes. Within the framework of

supporting intensive horticulture development, 3,270 hectares of orchards were established in 2021-2024, 1,665 hectares of modern irrigation systems were installed, and 44 greenhouses equipped with innovative technologies covering 9.5 hectares were constructed. Farmers acquired 2,750 units of agricultural machinery and 2,410 units of agro-equipment, and 58 "Smart" livestock facilities were constructed. Overall, 131.3 billion drams (292.5 million euros) were spent from the budget in 2021-2024 for programs implemented in the agricultural sector [22]. Nevertheless, analysis of the current situation shows that the innovations introduced with state support are of a non-systematic nature. Specifically, the absence of an established advisory-information system in the Republic of Armenia has hindered ensuring the dissemination, follow-up impact, and synergistic effect of innovations introduced with state support. The problem is also rooted in the continued inadequacy of organized education-science-advisory infrastructures for comprehensive knowledge transfer, which has impeded the effective integration of innovative technologies in agricultural production and the transition to an innovative development path.

The application of cluster approaches will be of pivotal importance in the process of developing an appropriate monitoring system to ensure coordinated dissemination of innovations and effective monitoring. Cluster-based models facilitate knowledge exchange between farms, enable collective learning, and create synergies that amplify the impact of individual innovations. Such approaches have proven effective in countries like the Netherlands and Denmark, where

agricultural innovation clusters serve as hubs for technology transfer and continuous improvement [23].

In the Republic of Armenia, innovation monitoring systems are not currently in use. This institutional gap means that while technologies are being adopted, their effectiveness, scalability, and impact remain largely undocumented and uncoordinated. The absence of a systematic monitoring framework prevents the identification of best practices, limits knowledge spillovers across the sector, and hinders evidence-based policy adjustments.

Nevertheless, to assess the baseline situation and document current practices, field surveys were conducted on farms across different regions of the Republic. These surveys show that a number of advanced technologies are already being used, both within and outside the aforementioned programs, including smart barns, modern greenhouse solutions, drip irrigation systems, hail protection nets, and other advanced technologies. While this ad-hoc adoption demonstrates farmer willingness to innovate, the absence of systematic monitoring prevents determining which technologies perform optimally under specific conditions, identifying enabling and hindering factors for their adoption, and maximizing and replicating their benefits across the sector.

The introduction and effective application of innovations require evaluation and ongoing analysis of results based on clear, measurable indicators. Without such systematic assessment, it becomes impossible to:

- 1) Measure return on investment for state-supported programs;

- 2) Identify and replicate successful practices;
- 3) Detect and address implementation challenges early;
- 4) Adjust policies based on empirical evidence rather than assumptions.

In this regard, the implementation of a monitoring system holds strategic importance, contributing not only to the assessment of the effectiveness of state regulatory tools but also to the development of targeted and data-driven policies.

Given the importance of effective innovation management, various countries have created monitoring systems that evaluate results while simultaneously working to clarify development directions. These international experiences offer valuable lessons for Armenia's context, particularly regarding institutional arrangements, data collection methodologies, stakeholder engagement mechanisms, and the integration of monitoring into policy cycles.

In the Netherlands, innovation development in agriculture and horticulture is based on the Innovation Contracts mechanism, which is ensured through a collaboration between the state, science, and the private sector. Within the framework of these contracts, research directions, programs, and appropriate investment resources are defined with the aim of promoting the implementation and application of advanced technologies. The effectiveness of these contracts is continuously evaluated using an innovation monitoring system, with the results directly informing contract adjustments. The main monitoring tools are:

1. **TKI (Topconsortia voor Kennis en Innovatie, Top Consortia for Knowledge and Innovation) consortiums** - The Netherlands' leading knowledge and innovation consortiums present detailed annual reports that include analysis of implemented project activities, evaluation of achieved results, and impact measurement.

2. **Nominal monitoring at the ministerial level** – Employs a multi-layered monitoring system to evaluate science-industry collaboration. The Central Statistical Service (CBS) conducts quantitative analysis based on data from "Research and Development" expenditures and financial flows of companies operating in "Top Sectors." Meanwhile, the Panteia research organization complements the picture with qualitative analysis, identifying collaboration-promoting and hindering factors through surveys.

This system provides a comprehensive picture of the country's scientific and technological ecosystem and serves as a foundation for developing sectoral policies, implementing innovations, and evaluating results [24].

The OECD (Organization for Economic Cooperation and Development) conducts comprehensive monitoring in 54 countries, including 38 member states, 5 non-member EU countries, and 11 developing economies. The organization implements monitoring in the form of annual reports covering:

- Analysis of agricultural policy instruments;
- Recording changes in the structure of state support.

The OECD also conducts monitoring in the area of sector-related data management, promoting and supporting the expansion of innovation processes.

Innovation monitoring assessment includes the following key indicators:

- Control of data collection, storage, and application mechanisms;
- Ensuring data-driven decision-making capabilities;
- Promoting innovative solutions;
- Conducting comparative analysis between countries [25].

International evidence indicates that innovation activity assessment in the agricultural sector is implemented through diverse rating frameworks and indicators. Notable examples include the European Innovation Scoreboard (EIS), which has been published annually since 2001 and provides a comparative assessment of research and innovation performance across EU Member States using 32 indicators covering framework conditions, investments, innovation activities, and impacts [25]. The Global Innovation Index (GII), published by the World Intellectual Property Organization (WIPO), ranks 133 economies based on approximately 80 indicators measuring innovation capacity and success, with the 2024 edition focusing on social entrepreneurship as a driver of innovation [26].

Sector-specific assessment frameworks are additionally utilized, including:

- **AIS (Agricultural Innovation Systems)**. This is a methodology developed by the FAO and the World Bank that examines innovation in the agricultural sector as an interconnected system. This system involves various participants, including individuals, institutions, and organizations, all operating within relevant policies and frameworks. It encompasses

the research and educational sectors, as well as entrepreneurship.

- **AKIS (Agricultural Knowledge and Innovation Systems)**. Supported by the European Union, this system establishes connections among various structures and individuals to promote collaborative learning, generate new knowledge, and develop, disseminate, and apply agricultural technologies. The AKIS framework was included in the 2021-2027 Common Agricultural Policy as one of its ten priorities, focusing on cooperation among research institutes, advisory services, educational institutions, and farmers.
- Previous models mainly concentrated on enhancing scientific capacities, but they have since evolved into more open and flexible approaches that consider the needs of all stakeholders within the AIS and AKIS systems.

These multi-dimensional monitoring frameworks are fundamental to innovation policy formation, comparative analysis, and performance monitoring in agricultural sectors globally.

Innovation monitoring is also examined in scholarly literature, with notable work including "Monitoring the Effectiveness of Innovation Activities in Agriculture" by Elena Derunova et al. The research emphasizes external and internal methodologies for innovation evaluation. The authors propose innovation effectiveness indicators derived from expert survey findings. The developed agricultural innovation effectiveness monitoring methodology is grounded in evaluation criteria encompassing state significance, accessibility, cost-

effectiveness, technical-economic performance, and safety levels. The study presents enhancement strategies for innovation management in agricultural and agro-industrial sectors, established through institutional approach development and systematic innovation effectiveness assessment [27]. In their article "Drivers and Barriers to Digital Agriculture Implementation: A Mixed Methods Analysis of Challenges and Opportunities in Latin America," Tyce Dibbern et al. used a mixed methods approach, integrating literature reviews, document analysis, and experimental research to gain a deeper understanding of the barriers and drivers of digital agriculture in the specific context of Latin American countries. In this regard, the authors developed four phases: data collection and processing, data matching, literature analysis, and comparison of identified barriers [17].

Valentyna Voronkova and her co-authors present in their work "The Impact of Digital Innovations on Sustainable Agricultural Practices in Europe" an assessment of digital innovations in European agriculture by applying a multidisciplinary methodology that combines systems analysis, Agile methodology, and multidimensional mathematical methods, demonstrating that precision agriculture, IoT sensors, artificial intelligence, and robotics result in 30-40% cost reduction and significant productivity increase. The authors show that the analysis results reveal the triple positive impact of digital technologies by ensuring economic efficiency, environmental protection, and sustainable socio-economic development of rural areas. The research conclusions indicate that digital innovations play a crucial role in strengthening sustainable and competitive agricultural systems within the context of the EU's

Common Agricultural Policy [28]. In their study "Towards Sustainable Food Systems: Developing a Monitoring Framework for the EU", Svetlana Achts and colleagues propose a comprehensive framework for monitoring the sustainability of EU food systems. This framework encompasses social, environmental, economic, and institutional dimensions. They emphasize that such a multidimensional approach is essential for developing evidence-based policies and effectively managing the transition toward sustainable food systems [29].

These international scholarly contributions, along with the practical monitoring experiences from the Netherlands, OECD, and other countries, underscore the critical importance of establishing systematic innovation monitoring frameworks in agriculture. However, in the Republic of Armenia, the institutional and regulatory environment for such monitoring remains underdeveloped. The sector is regulated by the law "On State Support for Innovation Activities", which only specifies the areas of state support for innovation activities, but the law does not define the monitoring process. This legislative gap means there is no formal mandate, methodology, or institutional responsibility for tracking and evaluating the outcomes of innovation investments in agriculture. In this regard, the research group, having studied the existing international experience detailed above-including the Dutch Innovation Contracts model, OECD monitoring practices, and the multi-dimensional frameworks proposed by Derunova, Dibbern, Voronkova, Sachs and others-has developed a roadmap for the "Implementation and Evaluation of an Innovation Monitoring System" (Table 2).

Table 2. Proposed roadmap draft for innovation monitoring system implementation and evaluation 2026-2031.

| Phase | Phase name | Year of Implementation | Description | Activities | Institutional Cooperation | Risks and Mitigation Measures |
|-------|-------------------------------------|------------------------|--|--|---|---|
| | Drafting and adoption of legal acts | 2026-2027 | <p>Development of a concept for "Implementation of Innovation Monitoring System," which should include general provisions, define key objectives, develop approaches and methods, identify the current state characteristics and challenges, possible directions for their resolution, present the concept's advantages and financial assessment.</p> <p>Development and implementation of a draft law "On Innovation Monitoring System" of the Republic of Armenia, which will provide/present the system's fundamental concepts, purpose and objectives, subject of regulation, scope of operation, responsible parties and other provisions.</p> <p>Simultaneously, development of legislative packages for responsible clusters ensures innovation implementation.</p> | Development of legislative packages, holding public discussions, adoption of packages | The Government of the Republic of Armenia, RA Chamber of Commerce, RA Ministry of Economy, local governments, international organizations, ANAA, farms, independent experts | <p>Risks:</p> <p>Incompletely developed legislative packages</p> <p>Organization of formal (non-substantive) public consultations</p> <p>Political pressure affecting the content and direction of the process</p> <p>Ineffective practical implementation of the adopted legislative frameworks</p> <p>Mitigation options: Application of the Regulatory Impact Assessment (RIA) methodology to assess the impact of laws, creating a stakeholder map for public discussion, creation of an independent expert council, and creation of a feedback system.</p> |
| | Implementation of innovations | 2026-2030 | <p>Conducting surveys on innovation demand within agricultural farms to identify challenges, priorities, and existing innovations. Establishing information dissemination groups that will raise awareness about the importance of functional food, increasing farm efficiency, income growth, and work facilitation. In each regional consolidated community, 3 agricultural farms will be selected to serve as demonstration farms, implementing both accessible innovative technologies and functional food production methods. The primary objective of this phase is to establish sustainable interaction among farms-specialists-organizations-government, founded on the dissemination of information regarding innovations and the additional positive impacts of bioactive compounds in food products. At the end of the phase, mapping results</p> | Formation of demonstration farms, dissemination of innovations, mapping, creation of clusters responsible for the introduction of "Agro-innovations" | Government of the Republic of Armenia, Ministry of Economy of the Republic of Armenia, Food Safety Inspection Body of the Republic of Armenia local governments, international organizations, ANAA, farms | <p>Risks:</p> <p>Lack of trust/resistance/innovation technologies among farmers, financial constraints, deepening social inequality, low creditworthiness of farmers, financial instability of demonstration farms, technological illiteracy, lack of provision of advisory services.</p> <p>Mitigation measures:</p> <p>Organize open classes, field demonstrations, visits to demonstration farms. Include farmers as beneficiaries in mapping activities. Involve donor organizations, expand state support programs, promote farm-private sector partnerships. Include micro and small farms in demonstration farms. Select demonstration farms in enlarged communities, ensuring territorial balance. Create</p> |

| Phase | Phase name | Year of Implementation | Description | Activities | Institutional Cooperation | Risks and Mitigation Measures |
|-------|--|------------------------|---|---|---|---|
| | | | will be summarized and an innovation map will be created according to types and geographical distribution. | | | communication platforms, providing discussion platforms. Organize face-to-face meetings |
| 3. | Determining the levels of the monitoring system and setting objectives | 2027-2028 | The monitoring system will consist of micro-, meso-, and macro-levels, encompassing individual farms, communities, regions, as well as the entire republic. The system objectives will emphasize data collection sources and methods, tools for monitoring the innovation implementation process in farms, conducting comparative analyses between regions, and evaluating the effectiveness of state support programs and innovation implementation. Indices/KPIs will be developed for summarizing results, which will also define target values. | System design, structure approval, evaluation methodology development, pilot program implementation in Kotayk, Armavir, and Gegharkunik regions | RA Chamber of Commerce, RA Ministry of Economy, local governments of Kotayk, Armavir, Gegharkunik regions, ANAU, rural economies | Risks: Low involvement of local structures, imperfection of legal acts, lack of independent and appropriately specialized experts Mitigation methods: Conclusion of agreements between participating structures, regular discussion and adoption of legislative packages, involvement of international experts |
| | Development and approval of the structure of the monitoring database | 2028-2029 | For database development purposes, create a farm registry, an interactive innovation map, a KPI data warehouse with time series, and a passport of farm potential assessments. For data security and quality management purposes, develop data reliability verification mechanisms, security standards, and double-checking procedures through independent experts. | Monitoring, data collection, development and dissemination of improvement recommendations | Agricultural Innovation Monitoring Center, local governments, farms, cooperatives of Kotayk, Armavir, Gegharkunik regions | Risks: Incomplete and/or late or incomplete data collection, lack of necessary specialists and experts Mitigation methods: Setting a clear monitoring frequency and assigning responsible units, continuous training of analysts, experts and coordinators |
| | Implementation of a monitoring system in the Republic of Armenia | 2030-2031 | Full deployment of the system in all regions of the Republic of Armenia, formation of monitoring groups with the involvement of local governments, effective use of the potential of active and leading economic operators. | Launch of full implementation in the republic, data collection, primary analysis, report development and publication | RA Chamber of Commerce, the Ministry of Economy, local governments, ANAU and regional scientific and educational centers, farms, cooperatives, suppliers, agro-startups | Risks: * Leakage of collected data, skepticism and/or lack of participation of stakeholders, incorrect analyses and/or biased approach Mitigation measures: Development of data privacy policy and implementation of contract, provision of advice, distribution of information leaflets (on the purpose of data collection, benefits and confidentiality), access to open sources and provision of simple explanations |

* All risks presented in previous stages may be encountered in this stage.

Source: The table was compiled by the author

In the third stage of the proposed roadmap, a monitoring system structure should be developed and implemented. The structure distinguishes micro-, meso-, and macro-levels, where the macro-level covers the entire RA. At this level, a council and an “Agricultural Innovations Monitoring Center” should be formed, which will play the role of a facilitator and will also be included in the responsible clusters as a separate link. The center can operate as a state non-profit organization, which will be financed from the state budget, donors and service provision. Initially, the center will need ten employees

who will cooperate with monitoring groups involved in the meso- and micro-levels. The groups will be formed with the support of regional administrations, community administrations and with the direct participation of the regional representation of the Statistical Committee of the Republic of Armenia. In the first year of the center’s operation, about 40.0 million drams of financial resources will be needed, which will include a salary fund and technical means.²

The structure of the monitoring system is presented in Figure 1.

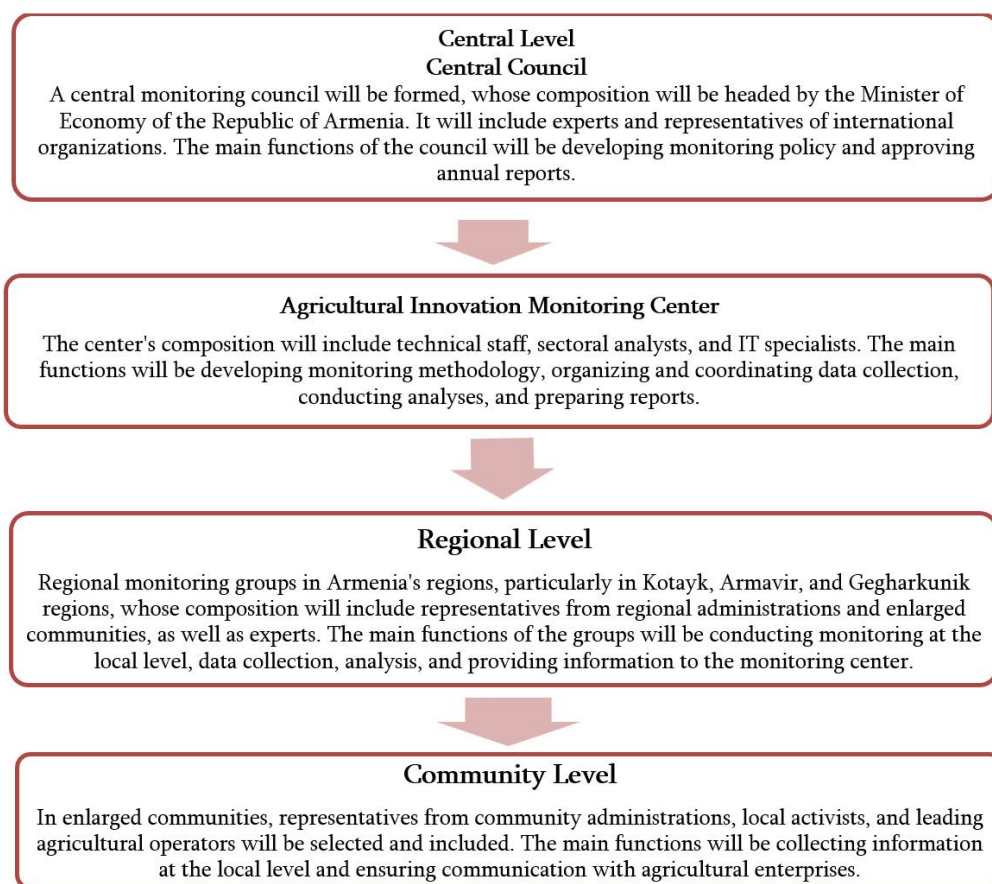


Figure 1. Proposed structure of the monitoring system

Source: The figure was compiled by the author

The primary function of the Agricultural Innovation Monitoring Center should be the development, improvement, validation, and implementation of monitoring methodology. Our research has advanced

methodological approaches that can be used in the monitoring system to assess the implementation and dissemination of agricultural innovations. The method is based on indices or KPIs (Key Performance Indicators),

which will enable the evaluation of innovation implementation levels and effectiveness in Armenian farms. KPIs will be formed through primary data collection, with information sources including targeted and semi-annual surveys and questionnaires conducted at farms and focus group discussions at the community level.

For KPI development purposes, the research team has compiled a "Farm Innovation Technology Needs Assessment" questionnaire and conducted telephone interviews with approximately 100 farms. The proposed KPIs for monitoring innovation implementation in farms and creating a monitoring database encompass 6 main directions: innovation technology adoption, economic efficiency, knowledge and skills development, marketing and export capabilities, efficient resource utilization and environmental sustainability, and cooperative collaboration. The baseline values for the proposed Key Performance Indicators (KPIs) were established by combining expert judgment and the results of a preliminary pilot survey conducted across three key agricultural regions of Armenia. The KPI system for assessing innovation implementation also incorporates target benchmarks.

1. Innovation Technology Implementation Level

1.1. Modern Agricultural Machinery Application Coefficient

$$KPI_{AM} = \frac{\text{Number of farms using modern agricultural machinery}}{\text{Total number of farms}} \times 100\%, (1)$$

Measured in percentages (%), where the baseline value is 15%. *Target Value:* During monitoring system implementation period: $KPI_{AM} > 30\%$, after complete system implementation: 50% and above.

1.2. Drip Irrigation System Implementation Coefficient

$$KPI_{DIS} = \frac{\text{Number of farms using drip irrigation systems}}{\text{Total number of farms}} \times 100\%, (2)$$

Measured in percentages (%), where the baseline value is 30%. *Target Value:* During the monitoring system implementation period: $KPI_{DIS} > 50\%$, after complete system implementation: 70% and above.

1.3. Smart Agricultural Equipment Application Coefficient

$$KPI_{SAE} = \frac{\text{Number of farms using smart technologies}}{\text{Total number of farms}} \times 100\%, (3)$$

Measured in percentages (%), where the baseline value is 2%. *Target Value:* During monitoring system implementation period: $KPI_{SAE} > 10\%$, after complete system implementation: 20% and above.

1.4. Functional Food Production Coefficient

$$KPI_{FFP} = \frac{\text{Number of farms producing functional food products}}{\text{Total number of farms}} \times 100\% (4)$$

Measured in percentages (%), where the baseline value is 0.2%. *Target Value:* During the monitoring system implementation period: $KPI_{FFP} > 5\%$, after complete system implementation: 15% and above.

For the Functional Food KPI, only farms that produce raw materials or products containing scientifically verified levels of bioactive compounds are included. Verification is carried out through accredited laboratory analysis, in which concentrations of key bioactive components (such as polyphenols, antioxidants, and probiotic indicators) are tested against recognized functional food standards. Farms whose products meet these scientific criteria are classified as functional food producers. This classification forms the basis for calculating the Functional Food KPI, using the formula already defined in the methodological framework.

2. Economic Efficiency

2.1 Yield Growth per Hectare After Innovation Implementation

$$KPI_{\text{yield}} = \frac{\text{Yield after innovation} - \text{Yield before innovation}}{\text{Yield before innovation}} \times 100\%, (5)$$

Measured in percentages (%), where the baseline value is 5%. *Target Value:* During the monitoring system implementation period, $KPI_{\text{yield}} > 10\%$, after complete system implementation: 20% and above.

2.2. Investment Payback Period

$$KPI_{\text{inv}} = \frac{\text{Innovation cost}}{\text{Annual additional income from innovation}}, (6)$$

Measured in years, where the baseline value is 7 years. *Target Value:* Up to 3 years.

2.3. Agricultural Product Cost Reduction Coefficient

$$KPI_{\text{CR}} = \frac{\text{Cost before innovation} - \text{Cost after innovation}}{\text{Cost before innovation}} \times 100\%, (7)$$

Measured in percentages (%), where the baseline value is 0%. *Target Value:* During the monitoring system implementation period: $KPI_{\text{CR}} > 5\%$, after complete system implementation: 15% and above.

3. Knowledge and Skills Development

3.1. Training Participation Coefficient

$$KPI_{\text{TR}} = \frac{\text{Number of farms that completed training}}{\text{Total number of farms}} \times 100\%, (8)$$

Measured in percentages (%), where the baseline value is 10%. *Target Value:* During the monitoring system implementation period: $KPI_{\text{TR}} > 30\%$, after complete system implementation: 70% and above.

3.2. Advisory Services Usage Frequency (Annual)

$$KPI_{\text{AS}} = \frac{\text{Number of advisory visits}}{\text{Total number of farms}}, (9)$$

Measured in visits/year, where the baseline value is < 1. *Target Value:* During the monitoring system implementation period: $KPI_{\text{AS}} > 1$ visit/year, after complete system implementation: 3 visits/year.

3.3. Internet Access and Digital Tools Application Coefficient

$$KPI_{\text{DT}} = \frac{\text{Number of farms using digital tools}}{\text{Total number of farms}} \times 100\%, (10)$$

Measured in percentages (%), where the baseline value is 20%. *Target Value:* During the monitoring system implementation period: $KPI_{\text{DT}} > 40\%$, after complete system implementation: 70% and above.

4. Marketing and Export

4.1. Export Volume Growth Coefficient

$$KPI_{\text{EV}} = \frac{\text{Export volume after innovation} - \text{Export volume before innovation}}{\text{Export volume before innovation}} \times 100\%, (11)$$

Measured in percentages (%), where the baseline value is 2%. *Target Value:* During the monitoring system implementation period: $KPI_{\text{EV}} > 5\%$, after complete system implementation: 10% and above.

4.2. Online Commerce Usage Coefficient

$$KPI_{\text{OC}} = \frac{\text{Number of farms conducting online ecommerce}}{\text{Total number of farms}} \times 100\%, (12)$$

Measured in percentages (%), where the baseline value is 5%. *Target Value:* During the monitoring system implementation period: $KPI_{\text{OC}} > 5\%$, after complete system implementation: 15% and above.

4.3. Agricultural Product Quality Certification Coefficient

$$KPI_{QC} = \frac{\text{Number of farms with quality-certified products}}{\text{Total number of farms}} \times 100\%, (13)$$

Measured in percentages (%), where the baseline value is 0.2%. *Target Value*: During the monitoring system implementation period: $KPI_{QC} > 2\%$, after complete system implementation: 5% and above.

5. Efficient Resource Utilization and Environmental Sustainability

5.1. Water Use Efficiency Coefficient

$$KPI_{WUE} = \frac{\text{Water consumption before innovation} - \text{Water consumption after innovation}}{\text{Water consumption before innovation}} \times 100\%, (14)$$

Measured in percentages (%), where the baseline value is 15%. *Target Value*: $KPI_{WUE} > 30\%$.

5.2. Organic Agriculture Expansion Coefficient

$$KPI_{OA} = \frac{\text{Number of farms practicing organic agriculture}}{\text{Total number of farms}} \times 100\%, (15)$$

Measured in percentages (%), where the baseline value is 10%. *Target Value*: During monitoring system implementation period: $KPI_{OA} > 15\%$, after complete system implementation: 30% and above.

6. Cooperative Collaboration

6.1. Cooperative Engagement Coefficient

$$KPI_{Coop} = \frac{\text{Number of farms engaged in cooperatives}}{\text{Total number of farms}} \times 100\%, (16)$$

Measured in percentages (%), where the baseline value is 5%. *Target Value*: During the monitoring system implementation period: $KPI_{Coop} > 15\%$, after complete system implementation: 30% and above.

6.2. Joint Innovation Initiatives Coefficient

$$KPI_{JI} = \frac{\text{Number of joint innovation initiators}}{\text{Total number of farms}} \times 100\%, (17)$$

Measured in percentages (%), where the baseline value is 0%. *Target Value*: During the monitoring system implementation period, $KPI_{JI} > 0.01$ coefficient, after complete system implementation, up to 0.5 coefficient.

6.3. Research Organization Collaboration Coefficient

$$KPI_{ROC} = \frac{\text{Number of farms collaborating with research organizations}}{\text{Total number of farms}} \times 100\%, (18)$$

Measured in percentages (%), where the baseline value is 2%. *Target Value*: During the monitoring system implementation period: $KPI_{ROC} > 10\%$, after complete system implementation: 30% and above.³

DISCUSSION

One of the important ways to ensure sustainable development and progress of Armenia's agriculture is the systematic implementation of innovative technologies. In the context of economic, social, and environmental challenges, it becomes necessary to form a stable, interactive, and coordinating structure in the form of clusters, which will be responsible for the introduction and dissemination of agro-innovations. The cluster's activities should be aimed at forming a multilateral cooperation platform, uniting state bodies, research centers, farms, supplier organizations, and other supporting structures. The inclusion of the "Agricultural Innovation Monitoring Center" as a link in the cluster will contribute to the continuous operation and increased effectiveness of the monitoring system. The main axis of the system is the application of the KPI (Key Performance Indicators) method, around which management structural approaches will be formed. KPIs can be tested

based on the purpose of the monitoring being implemented. The draft roadmap for the gradual implementation of the method and formation of the monitoring system will create a framework for evaluating the results of innovation policy, thereby contributing to both sectoral development and increased competitiveness of agricultural enterprises.

Scientific Innovation: This study advances an Armenia-tailored, KPI-driven monitoring architecture that links implementation, outcomes, and system-level effects of agro-innovations within a single, reproducible framework. Methodologically, it integrates a cluster governance model (state–industry–science–education) with multi-tier indicators—adoption rate, time-to-diffusion, productivity and input-efficiency gains, quality/compliance metrics, and market performance—plus feedback loops for continuous policy adjustment. A further innovation is the explicit incorporation of functional food production into the indicator set, enabling the evaluation of value-addition pathways (e.g., biomarker-supported quality metrics and export readiness) alongside conventional farm performance, thereby unifying technological, economic, and health-oriented innovation tracking.

Practical Implications: For policymakers, the framework provides actionable dashboards to target support (grants, tax incentives, extension services) toward innovations with demonstrated impact, reduce misallocation, and time interventions to stages where diffusion stalls. For enterprises, standardized KPIs enable benchmarking across farms and regions, de-risk investment decisions, and guide process upgrades that lift efficiency and competitiveness. For research and education partners, the cluster model clarifies roles, accelerates technology transfer, and aligns curricula and trials with measured needs. By embedding functional food production into the monitoring system,

stakeholders can prioritize high-value product lines, strengthen supply-chain coordination, and improve export competitiveness, creating a practical roadmap from pilot projects to scaled adoption in Armenia’s agricultural sector.

CONCLUSION

Continuity of management of innovation introduction, dissemination, and evaluation processes in Armenia, as well as the provision of institutional and practical mechanisms, directs the use of cluster approaches. The presence of a monitoring system will allow us to assess both the level of innovation application and ensure data-based policy formation. Through the additional roles of the agro-industrial cluster and the monitoring system, it will be possible to create an effective institutional environment that provides the continuity of innovations, sustainable dissemination, and increased farm competitiveness.

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